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Developing a national triage tool for use in NHS regional trauma networks: the MATTS mixed methods study

Gordon W Fuller, James Baird, Joshua Miller, Richard Pilbery, Esther Herbert, Samuel Keating, Tia Callaghan, Daniel Pollard, Abdullah Pandor, Munira Essat, Di Charles, Robin Chatters, Fiona Sampson, Jaqui Long, Michael Smyth, Jason E Smith, Gavin D Perkins, Fiona Lecky, Janette Turner and Cindy Cooper on behalf of the MATTS research group

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Extended Research Article

Developing a national triage tool for use in NHS regional trauma networks: the MATTS mixed methods study

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Abstract

Background: There is currently wide variation in prehospital major trauma triage across the National Health Service, with regional ambulance services using different triage tools, varying in format, structure and variables.

Objectives: To develop a national triage tool that is acceptable, usable, accurate, and optimises under- and over-triage.

Design: A three-phase research programme, comprising Phase 1: development of a new triage tool by expert consensus informed by existing evidence, a systematic review of elderly triage, document analysis of current tools, decision-analytic modelling, expert consensus definition of a major trauma reference standard, and a qualitative examination of current triage; Phase 2: case–cohort study validating triage tools identified and developed in Phase 1, with identification of an optimally performing candidate triage tool; Phase 3: evaluation of the candidate triage tool following implementation, including cohort study investigating accuracy of triage decisions, cost-effectiveness analysis, and examination of user experiences.

Setting: English regional trauma networks served by the South-Western, West Midlands, Yorkshire and London Ambulance Services. Phase 2 case–cohort study and Phase 3 cohort studies performed between 1 November 2019 and 28 February 2020, and 1 November 2021 and 15 May 2022, respectively.

Participants: Injured patients presenting to ambulance services in participating regional trauma networks.

Results: In Phase 1, document analysis identified 19 United Kingdom triage tools and 34 published international tools. The systematic review demonstrated limited diagnostic accuracy of triage tools in the elderly, with divergent real-life triage decisions. The reference standard included the need for critical trauma-related interventions, significant individual anatomical injuries, burden of multiple minor injuries and specific patient attributes. Decision-analytic modelling indicated that high-specificity triage tools were favoured. Triage tool simplicity and the option for clinical judgement were valued by stakeholders, but real-world triage was a multifaceted, nonlinear, dynamic and multiagency process. Following review of Phase 1 evidence, a three-step Major Trauma Triage Study candidate triage tool targeting relatively higher specificity was developed through expert consensus.

The Phase 2 case–cohort sample included 2757 patients, with a weighted prevalence of major trauma of 3.1% (95% confidence interval 2.3% to 4.0%). The Major Trauma Triage Study tool performed optimally compared to under- and over-triage targets (sensitivity 37.3%, specificity 95.1%).

In Phase 3, the newly implemented Major Trauma Triage Study triage tool was received favourably by stakeholders. Prehospital triage decisions using the new tool demonstrated a sensitivity of 55.3% (95% confidence interval 51.8% to 58.7%) and specificity of 94.3% (95% confidence interval 94.1% to 94.6%, n = 38,010, 2.2% prevalence of major trauma). Minimal differences were apparent between the costs (£149) and benefits (0.006 quality-adjusted life-years) of triage decisions, regardless of the triage tool used, reflecting similar real-life triage accuracy. However, the new Major Trauma Triage Study tool appeared cost-effective when theoretical triage tool performance was examined, demonstrating an incremental cost effectiveness ratio of £21,163.

Conclusions: The Major Trauma Triage Study triage tool performed optimally, targeted an appropriate under-/over-triage trade-off, and was perceived to perform well by stakeholders. National implementation could ensure evidence-based, standardised and cost-effective triage.

Limitations: Significant variation in National Health Service ambulance service and trauma network configurations could limit the generalisability of results.

Future work: Paediatric triage, pre-alerting and the benefit of remote clinical support could benefit from future research.

Trial registration: This trial is registered as Current Controlled Trials ISRCTN17968752.

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List of supplementary material

Report Supplementary Material 1 Protocol amendments

Supplementary material can be found on the NIHR Journals Library article page (https://doi.org/10.3310/ALPE8857).

Supplementary material has been provided by the authors to support the article and any files provided at submission will have been seen by peer reviewers, but not extensively reviewed. Any supplementary material provided at a later stage in the process may not have been peer reviewed.

The supplementary materials (which include but are not limited to related publications, patient information leaflets and questionnaires) are provided to support and contextualise the publication. Every effort has been made to obtain the necessary permissions for reproduction, to credit original sources appropriately, and to respect copyright requirements. However, despite our diligence, we acknowledge the possibility of unintentional omissions or errors and we welcome notifications of any concerns regarding copyright or permissions.

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List of abbreviations

ACS-COT	American College of Surgeons Committee on Trauma
AIS	Abbreviated Injury Scale
CCI	Charlson Comorbidity Index
CEAC	cost-effectiveness acceptability curve
CHEERS	Consolidated Health Economic Evaluation Reporting Standards
COVID-19	coronavirus disease 2019
CRAMS	Circulation, Respirations, Abdomen, Motor, Speech score
ED	emergency department
EMS	emergency medical services
EQ-5D	EuroQol-5 Dimensions
EQ-5D-3L	EuroQol-5 Dimensions, three-level version
EQ-5D-5L	EuroQol-5 Dimensions, five-level version
EVPI	expected value of perfect information
EVPPI	expected value of partial perfect information
EVSI	expected value sample information
FTDS	Field Triage Decision Scheme
GCS	Glasgow Coma Scale
GRADE	Grading of Recommendations, Assessment, Development, and Evaluation
HEMS	helicopter emergency medical services
HTA	Health Technology Assessment
ICER	incremental cost-effectiveness ratio
ISS	Injury Severity Score
JRCALC	Joint Royal Colleges Ambulance Liaison Committee
LAS	London Ambulance Service NHS Trust
LEH	local emergency hospital
LR	likelihood ratio
LR–	negative likelihood ratio
LR+	positive likelihood ratio
MAICER	maximum acceptable incremental cost-effectiveness ratio
MATTS	Major Trauma Triage Study
MGAP	Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score
MTC	major trauma centre
NICE	National Institute for Health and Care Excellence
NIHR	National Institute for Health and Care Research
PPI	public and patient involvement
PSA	probabilistic sensitivity analysis
QALY	quality-adjusted life-year
QUADAS-2	Quality Assessment of Diagnostic Accuracy Studies-2
ROC	receiver operating characteristic
SWAS	South Western Ambulance Service NHS Foundation Trust
TARN	Trauma Audit and Research Network
TBI	traumatic brain injury
TU	trauma unit
WI	working impression
WMAS	West Midlands Ambulance Service University NHS Foundation Trust
WTP	willingness to pay
YAS	Yorkshire Ambulance Service NHS Trust

Glossary

Emergency medical services Emergency services which treat illnesses and injuries that require an urgent medical response, providing out-of-hospital treatment and transport to definitive care. Also known as ambulance services or paramedic services.

Local Emergency Hospital The Local Emergency Hospital is a hospital in a Trauma Network that does not routinely receive acute trauma patients (excepting minor injuries that may be seen in a minor injury unit). It has processes in place to ensure that if this should occur, patients are appropriately transferred to a major trauma centre or trauma unit. It may have a role in the rehabilitation of trauma patients and the care of those with minor injuries.

Major trauma Major trauma describes serious and often multiple injuries where there is a strong possibility of death or disability. These might include serious head, chest, abdominal and skeletal injuries sustained as a result of accidents, sport or violence. Major trauma is a main cause of death for people under the age of 45 and is a major cause of debilitating long-term injuries.

Major trauma centre A specialist hospital responsible for the care of the most severely injured patients involved in major trauma. It provides 24/7 emergency access to consultant-delivered care for a wide range of specialist clinical services and expertise. A major trauma centre is part of a major trauma network.

Major trauma network Organised groups of health services and personnel, who serve a defined population and aim to reduce death and disability following injury. Integrates the organisations responsible for three overlapping phases (pre-hospital, in-hospital and rehabilitation) of a patient's journey. Incorporates defined patient pathways for different types of injuries, ensuring that patients are treated at the time and place that most benefits them. Each hospital in a major trauma network is formally designated by commissioners in terms of capacity to manage life-threatening multiple injuries from the scene as either a major trauma centre, trauma unit or local emergency hospital.

In 'exclusive' trauma networks, the underpinning philosophy is that all patients with possible major trauma within the area covered by the major trauma centre will be primarily transferred there from the scene, bypassing all other facilities. Exclusive systems are ideally suited for more densely populated urban areas with relatively short pre-hospital journey times and have a lower threshold for transport to the major trauma centre.

In 'inclusive' trauma networks, major trauma centres will receive patients injured within their catchment area, or selected cases requiring time-critical trauma-related interventions. However, non-major trauma centre hospitals must be able to receive, stabilise, and subsequently transfer if necessary, appropriate major trauma patients and those not initially requiring critical trauma interventions. Inclusive systems typically have higher thresholds for bypass, may define maximum travel times for transport to major trauma centres, and could stipulate diversion to the nearest non-major trauma centre trauma receiving hospital in the contingency of unmanageable airway, ventilation, or haemorrhage.

Over-triage Patients without major trauma injured closest to a non-specialist trauma unit, incorrectly bypass that hospital, and are transported directly to a specialist major trauma centre with an emergency department pre-alert call. For patients injured closest to a major trauma centre, patients without major trauma are incorrectly pre-alerted. Taking patients with minor injuries to the major trauma centre, and pre-alerting the major trauma centre emergency department, could waste time, money and resources; denying treatment to those who require it by overstretching the capacity of the major trauma centre. It could also inconvenience patients and their families by taking them further from home. Equivalent to 1 – sensitivity.

Real-life triage performance Triage tool outcomes can be considered at two levels: theoretical diagnostic accuracy and real-life performance. For real-life performance, the actual triage decisions in terms of final transport to a major trauma centre or non-major trauma centre hospital are considered, regardless of the theoretical triage tool result indicated by the observed data. This provides a global assessment of triage effectiveness regardless of whether triage tools are used, or if ancillary clinical judgement is applied to interpret objective triage tool results.

Sensitivity Sensitivity helps describe how well a test works. It reports how likely it is that the test will be positive if a person has a disease. A sensitive test will help rule out a disease if the result is negative. If the test is highly sensitive and the test result is negative, you can be confident that they do not have the disease.

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Specificity Specificity helps describe how well a test works. It reports how likely it is that the test will be negative if a person does not have a disease. A specific test will help rule in a disease if the result is positive. If the test is highly specific and the test result is positive, you can be confident that they do have the disease.

Theoretical triage tool accuracy Triage tool outcomes can be considered at two levels: theoretical diagnostic accuracy and real-life performance. When evaluating theoretical diagnostic accuracy, triage tools are assessed according to the test result that would arise if the constituent variables were scored exactly according to the objective prehospital findings, regardless of the final actual triage decision or hospital destination. Additional interpretation or clinical judgement would be ignored, for example a Glasgow Coma Scale score variable with a cut point of ≤ 14 would theoretically trigger for a reduced of value 13, despite this being the baseline level for an elderly patient secondary to underlying dementia and ignored by the attending ambulance clinician.

Trauma desk A location within the ambulance service emergency operations centre staffed by an experienced ambulance service clinician, for example a critical care paramedic. Roles include identification of potential major trauma cases from received emergency calls; provision of clinical and triage advice to ambulance clinicians attending injured patients; organising additional enhanced care team responses.

Trauma unit A major trauma unit is a hospital that is part of the major trauma network providing care for all except the most severely injured patients. When it is not possible to get to the major trauma centre within a safe time period (commonly 60 minutes), or where a patient needs immediate stabilisation (e.g. uncontrolled haemorrhage, obstructed airway), the patient is taken to the nearest trauma unit for immediate treatment and stabilisation before being transferred on to the major trauma centre. Once discharged from a major trauma centre, local trauma units also provide ongoing treatment and rehabilitation for patients.

Triage Prioritising of patients for treatment or transport according to their severity of injury.

Under-triage Patients with major trauma who are not recognised by ambulance services. For patients injured in the catchment area of a trauma unit, they are incorrectly transported to a non-specialist trauma unit, instead of being taken directly to a more distant specialist major trauma centre with an emergency department pre-alert. For patients injured in the catchment area of a major trauma centre, they are transported to that hospital, but without an emergency department pre-alert. Failing to recognise serious injury could result in less effective treatment or increased harm. Equivalent to 1 – sensitivity.

Plain language summary

Treatment in specialist hospitals, called major trauma centres, can improve survival after serious injury. Ambulance crews use a triage tool, a checklist of patient and injury features, to help them recognise whether a patient is seriously injured and indicate that early care in a major trauma centre care would be beneficial.

The presence of serious injury is not always obvious. Taking patients with minor injuries to the major trauma centre ('over-triage') wastes time, money and resources. In contrast, failing to recognise serious injury ('under-triage') could result in less effective treatment and a worse outcome. Each NHS ambulance service currently uses a different triage tool, and this project aimed to develop a new national tool to get the right patient to the right place at the right time.

The project had three phases. In Phase 1, background work was completed to help design the new triage tool. This work was carefully considered by a panel of experts who then designed a new triage tool (the 'Major Trauma Triage Study tool'). In Phase 2, the accuracy of the Major Trauma Triage Study tool was compared with other current triage tools in 2607 patients from four ambulance services. The Major Trauma Triage Study tool was shown to perform best, achieving the best balance of under- and over-triage.

In Phase 3, the Major Trauma Triage Study tool was introduced into practice in two ambulance services and information was collected on 38,010 patients. When ambulance crews using the tool thought early major trauma centre care was not needed, 99% of patients had injuries that could be safely managed initially in non-specialist hospitals. However, ambulance crews highlighted that they did not always use the tool, and often preferred using their own judgement. Wider implementation of the Major Trauma Triage Study tool might therefore have a limited impact on outcomes but could potentially improve the consistency of triage decisions.

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Scientific summary

Background

Major trauma is an important public health issue for the NHS. There are 20,000 cases annually in England, accounting for 5400 deaths, 8000 disabilities, £400M of healthcare costs and a £3.5B loss in economic output. Treatment in a major trauma centre (MTC) and the introduction of regional trauma systems have been associated with improved outcomes. Major trauma triage tools are used within English trauma networks to indicate which patients injured closest to a non-specialised hospital should be bypassed to a MTC, and to inform MTC emergency department (ED) pre-alert calls, facilitating patient reception into critical care areas for expedited assessment and resuscitation.

Only a small fraction of the 1.25 million patients attended by ambulance services following injury represent major trauma, and identification may not always be obvious at the scene of incident. Bypassing and pre-alerting patients to MTCs without the potential to benefit ('over-triage') will waste resources and inconvenience patients. Conversely, failing to recognise appropriate patients with serious injury ('under-triage') could result in transport to non-specialist hospitals, resulting in less effective treatment and worse outcomes. Triage tools must therefore optimise the balance between under- and over-triage.

There is currently wide variation in major trauma triage across the English NHS, with each regional ambulance service using a triage tool differing in format, structure, variables and cut points. This variability may contribute to inefficient care, unequal access to MTC treatment and suboptimal outcomes. Furthermore, as ambulance service and regional trauma network districts do not fully overlap, the use of multiple triage tools within a trauma network could present operational challenges. Consequently, the National Institute for Health and Care Excellence (NICE) recommended research to develop a national major trauma triage tool to improve patient outcomes and reduce costs.

Objectives

The Major Trauma Triage Tool Study (MATTS) project aimed to develop an accurate, acceptable and usable pre-hospital triage tool to identify patients with major trauma who could benefit from expedited MTC care in English trauma networks, optimising the trade-off between under- and over-triage. Specific objectives were to:

- Identify current major trauma triage tools and characterise their content.
- Review the evidence on performance of existing triage tools.
- Investigate user perspectives on major trauma triage tools and processes.
- Determine the optimal trade-offs between triage tool performance, costs and clinical outcomes.
- Define which patients benefit from expedited MTC care.
- Develop a new triage tool through expert consensus.
- Validate the diagnostic accuracy of expert derived and existing major trauma triage tools.
- Identify a candidate triage tool with optimal performance.
- Evaluate system-level performance of the implemented optimal triage tool, including identification of major trauma cases and compliance.
- Determine the usability and acceptability of the implemented triage tool.
- Evaluate the cost-effectiveness of triage using alternative triage tools.

Methods

The MATTS project was conducted in three phases. In Phase 1, preparatory background research was conducted to inform the development of a new major trauma triage tool, comprising: a document analysis of existing tools

to highlight possible designs and potential triage variables; a systematic review of triage tools in older people to supplement recently published reviews focusing on adults and children; decision-analytic modelling evaluating the cost-effectiveness of different triage tools and identifying the optimal target trade-off between under- and over-triage; a survey and focus groups to explore patient and clinician perspectives of current major trauma triage; and an expert consensus process to develop a relevant reference standard, defining the population of major trauma cases requiring expedited MTC care. Phase 1 culminated in the development of a candidate national triage tool through expert consensus (the 'MATTS tool').

In Phase 2, the theoretical diagnostic accuracy of existing triage tools identified in Phase 1 and the MATTS triage tool developed through expert consensus were examined. A diagnostic case–cohort study was performed between November 2019 and February 2020 in four English regional trauma networks. Consecutive injured patients presenting to participating ambulance services were included and matched to data from the Trauma Audit and Research Network (TARN) trauma registry. The theoretical accuracy of 22 adult major trauma triage tools, including the newly developed MATTS tool, was evaluated, against the MATTS reference standard for major trauma. Index tests were assessed according to objective ambulance service data, regardless of the final triage decision or hospital destination.

In Phase 3, the MATTS triage tool was implemented into practice by Yorkshire Ambulance Service NHS Trust (YAS) and West Midlands Ambulance Service University NHS Foundation Trust (WMAS) who collectively serve six English regional trauma networks. Consecutive injured patients between 1 November 2021 and 15 May 2022 were included in a multicentre, prospective cohort study, with nested case–cohort substudy. Electronic data from ambulance service patient report forms were linked to data from the TARN registry. The accuracy of prehospital triage decisions, in terms of conveyance to a MTC with an ED pre-alert, was calculated against the MATTS reference. Theoretical triage tool accuracy and triage tool use were also examined. Additional Phase 3 studies included an uncontrolled before-and-after study comparing triage accuracy pre and post implementation, a survey and focus groups to explore user experiences, and an economic evaluation investigating the cost-effectiveness, of the new triage tool.

Results

In Phase 1, the document analysis identified 53 major trauma tools using 173 distinct triage variables. Wide variation was apparent in format, number of triage variables, thresholds, scope for clinical judgement and relative diagnostic accuracy (high sensitivity vs. high specificity).

Fifteen studies were included in the systematic review of triage tools in older people. Estimates for sensitivity and specificity were highly variable, with sensitivity estimates ranging from 19.8% to 95.5% for theoretical accuracy, and 57.7% to 83.3%, for real-life triage performance. Specificity results were similarly diverse ranging from 17.0% to 93.1%, and 46.3% to 78.9%, respectively. Most studies had unclear or high risk of bias, and applicability concerns. Overall, sensitivity and specificity appeared to be lower than that reported in systematic reviews examining younger adults.

Decision-analytic modelling indicated that high-specificity triage tools were favoured. At a willingness-to-pay (WTP) threshold of £20,000 per quality-adjusted life-year (QALY) gained, the most cost-effective triage tool would have low sensitivity (28.0%), but high specificity (89.0%). However, results were sensitive to assumptions regarding MTC effectiveness and costs.

A total of 81 questionnaires, and 6 focus groups including 62 participants, were completed. Current major trauma triage was perceived as performing well overall, with simple, 'stepped' structure of triage tools and the option for clinical judgement valued, leaving limited areas for further optimisation. Real-world triage was more complex than application of a triage tool checklist, with a variable, multifaceted, non-linear, dynamic and multiagency process evident.

A reference standard for patients who would benefit from expedited MTC care was defined through expert consensus, comprising domains of need for critical interventions; presence of significant individual anatomical injuries; burden of multiple minor injuries; and important patient attributes.

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A three-step candidate MATTS triage tool was developed through expert consensus comprising physiology, anatomical injury and clinical judgement domains, with triage variables assessed in parallel. The triage tool targeted relatively higher specificity, defined inclusion criteria and variable definitions, and incorporated remote decision support.

In Phase 2, the case–cohort sample consisted of 2757 patients, including 928 primary reference standard positive patients {major trauma prevalence 3.1% [95% confidence interval (CI) 2.3% to 4.0%]}. The MATTS triage tool (sensitivity 37.3%, specificity 95.1%) performed optimally, with accuracy closest to previously established under- and over-triage targets.

The Phase 3 cohort study included 38,010 injured patients with a 2.2% prevalence of major trauma. Prehospital triage decisions using the new MATTS triage tool demonstrated a sensitivity of 55.3% (95% CI 51.8% to 58.7%) and specificity of 94.3% (95% CI 91.4 to 94.6%). There was evidence of triage tool use in a minority of patients (6.3%), with senior clinical advice sought in 9.3% of patients. Triage decisions were broadly unchanged before and after implementation of the MATTS tool (WMAS: Phase 2 sensitivity 48.3%/specificity 97.7% vs. Phase 3 : 59.0%/96.0%, $p < 0.01$ sensitivity/$p = 0.06$ specificity; YAS: 51.2%/94.3% vs. 51.3%/92.4% $p = 1.0/0.17$). However, actual triage decisions were more aligned with the indicated theoretical triage tool result post implementation (Gwets AC1 statistics for agreement between theoretical triage tool result and actual triage decision: WMAS = Phase 2 : 0.87 vs. Phase 3 : 0.89; YAS = 0.74 vs. 0.89; $p < 0.01$).

A total of 250 questionnaires and 4 focus groups including 26 participants were completed to explore user experiences. Although viewed positively, it was apparent that the MATTS tool was only used for selected cases where there was uncertainty, to validate heuristic decisions, or as a 'tick box' to justify pre-made triage decisions. When applied, it appeared that additional clinical judgement was often used either to over-rule positive criteria or to trigger the tool in the absence of other positive variables.

In the economic evaluation, minimal differences were apparent in the costs (£149) and benefits (0.006 QALYs) of triage across different ambulance services reflecting similar accuracy of real-life triage decisions regardless of the tool used. When theoretical triage tool performance was examined, the new MATTS triage tool appeared cost-effective with an incremental cost-effectiveness ratio (ICER) of £21,163.

Conclusions

The MATTS triage tool targets patients who can benefit from early MTC care, optimises the balance between under- and over-triage, was well received by users, and theoretical performance was cost-effective at NHS WTP thresholds. However, it is apparent that triage tools are used selectively, and clinical acumen often determines triage decisions. Consequently, the overall accuracy of triage decisions in trauma networks appears to be similar, regardless of the triage tool used. National implementation of the MATTS tool might therefore have a limited impact on triage accuracy, trauma network patient flows and subsequent patient outcomes. However, even if overall triage decisions are unaffected, national adoption could provide benefits of standardisation, and better alignment between theoretical triage tool results and actual triage outcomes.

Trial registration

This trial is registered as Current Controlled Trials ISRCTN17968752.

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Chapter 1 Background to major trauma, major trauma triage and the Major Trauma Triage Study project

Major trauma is a life-threatening condition caused by serious injury.[1] Correct prehospital identification of appropriate significant injuries with direct transportation to a specialist major trauma centre (MTC) may improve outcomes.[2] The Major Trauma Triage Study (MATTS) is a comprehensive research programme to develop an accurate, acceptable and usable prehospital triage tool for use in NHS trauma networks. The tool's purpose is to identify patients with major trauma that may benefit from MTC care, optimising the trade-off between under- and over-triage.

Defining major trauma

Physical trauma can range from inconsequential and isolated minor injuries to complex and significant insults involving multiple body regions and organ systems. The extent of injury is determined by the nature, magnitude and direction of energy applied from external mechanisms, together with the underlying susceptibility of the victim. Broadly, major trauma constitutes an injury, or a combination of injuries, that is potentially life-threatening or could result in long-term disability.

Injury and major trauma can be formally classified according to the mechanism of energy transfer, extent and anatomical location of injuries, severity, prognosis, or the requirement for specialist treatments. The type of force applied to the body may result in characteristic injury patterns, supporting categorisation of major trauma as low (e.g. ground-level falls) versus high energy transfer (e.g. high-speed road traffic collision); or blunt (e.g. high-level fall) versus penetrating (e.g. gunshot) trauma. Major trauma may also be defined according to extent, with isolated (single body region) injuries potentially having different management implications compared to polytrauma (multiple body region involvement) cases.

However, conventionally, major trauma is classified according to an assessment of anatomical injury location and severity, typically using the Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS). The AIS characterises individual injuries according to a reference definition and provides a rating on a 6-point scale, from minor severity (AIS 1) to un-survivable (AIS 6). The highest AIS scores in each of the three most severely injured body regions (defined as head, face, chest, abdomen, extremities and external) can be squared and summed to produce the ISS, an overall measure of trauma severity. If a patient has an AIS score of 6 in any body system, they are automatically assigned the maximum ISS of 75. An ISS ≥ 16 is customarily used to define major trauma, based on an increased risk of death at this threshold.

Resource-based criteria have also been proposed as an alternative, more relevant, measure to define major trauma. Several consensus-based definitions have been formulated focusing on identifying patients who need specialised trauma interventions that are only available in, or more effectively delivered, by MTCs.[3,4] Finally, prognostic reference standards can also be used to define severity of injury, using combinations of mechanistic, anatomical, physiological and demographic variables to predict mortality after injury.[5,6] A probability threshold can then be defined above which the risk of adverse outcome is judged to justify definition as major trauma.

Epidemiology of major trauma in the United Kingdom

Major trauma is an important public health issue for the NHS. There are 20,000 cases annually in England, accounting for 5400 deaths, 8000 disabilities, £400M of healthcare costs and a £3.5B loss in economic output.[1,7,8] Improvements in the management of major trauma, therefore, have the potential to improve greatly both health and individual and societal wealth. Despite its impact and relatively high absolute frequency, major trauma has a low prevalence among injured patients. In England, an estimated 20% of the annual 6.3 million 999 calls requiring an emergency medical services (EMS) response are due to injury, but < 1% of these patients will have major trauma.[8]

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Historically in the UK, the distribution of major trauma was unimodal, with the highest incidence in young male adults, typically following a high-energy mechanism of injury. Although major trauma remains a leading cause of death in adults aged under 40 years, the epidemiology has evolved over recent decades, with the emergence of an increasing burden of low energy transfer injuries in older patients, commonly and anecdotally termed the 'silver tsunami'.[1,9] This has resulted in a bimodal incidence distribution with 52% of cases submitted to the Trauma Audit and Research Network (TARN, the English national trauma registry) in 2018 arising from patients over 65 years.[10] Major trauma is currently more likely to represent elderly, frail, female patients injured following a ground-level fall. Conversely, the incidence of major trauma in children is very low, with an estimated prevalence of 0.04% among children attending UK emergency departments (EDs) following injury, constituting < 5% of all major trauma cases.[10] Children with serious injuries are also less likely to be transported by ambulance, with a third of children with ISS ≥ 16 taken to hospital by private car.[11]

The pattern of major trauma varies between these age groups.[12] The phenotype in low-energy elderly cases is predominantly chest wall injury, fractures and traumatic brain injury (TBI), contrasting to an increased risk of internal organ damage and vascular disruption with haemorrhage in younger, higher-energy transfer, adult cases.[9] Children are also predisposed to particular injury types, for example blunt abdominal visceral trauma from handlebar impacts. Other features of major trauma may also vary, including ease of detection, physiological response to injury, investigation and focus of treatment.[13] Evaluation of young children can be more difficult due to limited available history or deliberate concealment in non-accidental injury.[14] Imaging protocols differ, aiming for focused scanning to minimise radiation exposure. Specific injury management can also diverge from that in adults, for example, favouring non-invasive management of splenic injuries.[15] Assessment of elderly adults is challenged by the influence of concomitant acute medical conditions, chronic comorbidities, polypharmacy and altered natural history of injury, for example TBI with relatively high Glasgow Coma Scale (GCS) secondary to the extenuating effects of cerebral atrophy on raised intracranial pressure.[16] More liberal use of whole-body CT scanning may therefore be indicated to detect significant occult injuries. Management of 'silver' trauma is more likely to be conservative, defining appropriate ceilings of treatment, and focusing on supportive care from multidisciplinary geriatric and rehabilitation services.[16] In contrast, younger adults with high-energy blunt or penetrating trauma usually have more obvious injuries, although sometimes confounded by alcohol or drug intoxication. This patient group will often require time-sensitive advanced resuscitation and urgent specialist surgical interventions.[17] Major trauma is therefore increasingly recognised as constituting three separate disease entities in children, adults and the elderly.

National Health Service organisation of major trauma services

The care of seriously injured patients in England was noted to be suboptimal in a 2007 report by the National Confidential Enquiry into Patient Outcome and Death, where 60% of cases demonstrated deficiencies in organisational or clinical aspects of care.[18] A subsequent 2010 National Audit Office enquiry confirmed these findings, highlighting the ad hoc organisation of trauma care, with unacceptable variations in mortality rates, depending on where and when a patient received treatment.[7]

In response, trauma care in England was reconfigured with the introduction of regional trauma networks in 2011, based on the established model of care for injured patients in North America.[19] Such networks aim to ensure transport of patients injured within a defined geographical area to a hospital matched to their clinical need. These systems of care consist of a central MTC hospital providing specialist resuscitation, definitive care and rehabilitation to the highest acuity and most seriously injured patients. Non-specialist general hospitals, termed trauma units (TUs), manage lower acuity and less seriously injured patients, and can provide stabilisation and transfer of the more seriously injured to MTCs when needed. Other acute hospitals, which would not routinely manage significantly injured patients, are designated local emergency hospitals (LEHs). Management, training and governance structures are incorporated to co-ordinate patient management and ensure high-quality care is delivered. Trauma networks have subsequently been similarly introduced in Northern Ireland (2017), Scotland (2018) and Wales (2021).

Trauma systems follow one of two broad conceptual models, often referred to as 'inclusive' and 'exclusive'.[20] The models differ in the extent to which available hospitals can provide major trauma care. In 'exclusive' systems, the underpinning philosophy is that all patients with possible major trauma within the area covered by the MTC will be

primarily transferred there from the scene, bypassing all other facilities. Exclusive systems are ideally suited for more densely populated urban areas with relatively short prehospital journey times and have a lower threshold for transport to the MTC. Conversely, the principle in 'inclusive' systems is that, by virtue of geography, longer prehospital journey times, MTC capacity constraints and system efficiency, TUs must be able to receive, stabilise and subsequently transfer, if necessary, appropriate major trauma patients and those not initially requiring critical trauma interventions. Inclusive systems typically have higher thresholds for bypass, may define maximum travel times for transport to MTCs, and could stipulate diversion to the nearest trauma receiving hospital in the contingency of unmanageable airway, ventilation or haemorrhage. The National Institute for Health and Care Excellence (NICE) major trauma service delivery guidelines recommended implementation of inclusive trauma networks.[21]

Prehospital care for injured patients is complex, varies between regions, and potentially involves overlapping ambulance services, major trauma networks and specialist services catchment areas (e.g. burns, ortho-plastics). Multiple prehospital resources may be available to respond to suspected major trauma cases, including ambulance clinicians, helicopter emergency medical services (HEMS), prehospital physician–paramedic teams, or specialist critical care paramedics.[22,23] Major trauma specialist services may also be spread across different hospitals, within or across NHS trusts and local healthcare organisations. Moreover, hospital TU and MTC designations may differ depending on paediatric or adult presentations. Remote ambulance service 'trauma/critical care desks', offering telephonic advice from senior clinicians, are available in some regions to co-ordinate the care of patients in the field.

Mann et al.[24]collated the evidence from several systematic reviews examining the effectiveness of trauma network implementation in a well-conducted US Centres for Disease Control and Prevention funded umbrella review. They included 28 observational studies from 3 systematic reviews and performed a narrative synthesis. They concluded that overall, there was a clinically and statistically significant reduction in hospital mortality among the seriously injured with implementation of regional trauma networks and MTCs. Generalisability of these findings to the contemporary UK context is limited by the relative historicity of the included studies, restriction to North American settings, and predominantly urban study populations. Moreover, more relevant longer-term mortality and disability outcomes were not available. Included studies were also noted to be at risk of bias from confounding and possible selection and information biases, providing only Class III evidence overall. More recently, Moran *et al.*[2] conducted an interrupted time series analysis to evaluate the introduction of trauma networks in England. Although subject to similar limitations as preceding studies, increased numbers of patients were noted to receive treatment in MTCs, more consultant led care and more rapid imaging was delivered, and a small positive change in mortality was noted with an increase of 0.08 survivors per 100 patients every quarter year.

Importantly, although trauma networks and MTCs appear to provide benefit overall, there may be heterogeneity in outcomes across age groups and care settings. A recent meta-analysis of 34 observational studies compared the effectiveness of sub-specialist paediatric MTCs compared to combined age MTCs.[25] They suggested that paediatric MTCs may confer a survival benefit, demonstrating lower odds of mortality of 0.59 [95% confidence interval (CI), 0.46 to 0.76]. However, constituent studies were at high risk of bias and the certainty of evidence was consequently very low. Although specialist care in MTCs has been associated with improved outcomes at younger ages, the benefit in older patients is much less certain.[2,26] The US National Study on Costs and Outcomes of Trauma (2007) demonstrated that improved outcomes associated with MTC care in younger adults were not apparent in older cases, where no significant difference in case-mix adjusted odds of mortality was observed over 55 years of age.[26] These findings were recently confirmed in the English setting, where Tonkins *et al.*[27] demonstrated that MTC care was not associated with improved survival compared with TU/LEH care in elderly, low-energy transfer, major trauma cases.

Major trauma triage

Only a small fraction of the large number of patients attended by ambulance services following injury represent major trauma, and identification may not always obvious at the scene of incident. It is not feasible to transport all injured patients to MTCs due to limited capacity; many less-severely injured patients can be manged appropriately in TUs and LEHs, and not all patients with major trauma may benefit from MTC care. Ambulance service clinicians therefore require assistance to accurately identify patients that can benefit from expedited MTC care.

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In accordance with NICE major trauma service delivery guidelines, NHS ambulance services therefore use prehospital triage tools within regional trauma networks.[28] Their primary purpose is to identify which patients injured within the catchment areas of TUs and LEHs might benefit from prolonged transportation to distant MTCs, bypassing the closer non-specialist hospital. Furthermore, relevant to patients injured in both MTC and non-MTC catchment areas, triage tools have an important secondary role to inform ED pre-alert calls, facilitating patient reception into critical care areas and activation of multidisciplinary hospital trauma teams to provide rapid, specialised, and co-ordinated assessment and resuscitation.

A wide range of triage tools are available, varying in structure and content.[29] Traditionally, and most commonly, these are paper-based, and expert-opinion derived. The US Field Triage Decision Scheme (FTDS) was initially introduced by the American College of Surgeons Committee on Trauma (ACS-COT) in 1986, with multiple modifications published at regular intervals up to the current iteration in 2021.[30–32] Its structure of multiple domains (or 'steps') comprising physiology, injury, mechanistic and patient characteristic variables has been influential, and is followed by the majority of UK and international tools. More rarely statistical scores, prediction models and machine learning algorithms have been developed for use in major trauma triage.[5] These use combinations of incident, injury and patient variables to estimate the probability of major trauma. A probability threshold is then defined to dichotomise injured patients according to the predicted presence of major trauma.

There are seven important issues to consider when deliberating major trauma triage tools. Firstly, it is very important to carefully define the reference standard for major trauma triage. The fundamental property of triage tools is to identify injured patients with major trauma who would benefit from bypassing and pre-alerting to MTCs. Notably, this may not correlate with injury severity per se, for example defined by ISS. Some subgroups of seriously injured patients, such as those with advanced frailty, may not accrue benefit from MTC care but could contribute to delays in ED access, consume ambulance service capacity, waste MTC resources, increase health care costs, reduce TU experience of injured patients and separate patients from families for no benefit.[33]

Once the target population of major trauma cases has been defined, a second essential consideration is maximising triage tool accuracy, selecting variables that provide the best ability to predict cases with and without major trauma. Variable selection may be performed through expert opinion, statistical prediction modelling, or by training machine learning algorithms.[34] Expert derived clinical decision rules have been shown to perform well across many disease areas and are usually relatively simple and easy to interpret, increasing acceptability and usability.[35] Statistical or machine learning-derived triage models require large, high-quality data sets, but could potentially achieve higher accuracy.[36]

There are many possible measures of diagnostic accuracy, and a third facet of triage tools is how best to summarise performance in identifying, or ruling out, major trauma. Typically, triage tool accuracy is reported in terms of sensitivity and specificity,[37] with 'under-triage' defined as 1 – sensitivity, and 'over-triage' as 1 – specificity. However, these metrics may be counterintuitive as they are defined retrospectively by disease status, rather than the clinically relevant probability of a condition being present when the test result is known.[38] Graphical representations, predictive values, natural frequencies, or using likelihood ratios (LRs) with pre- and post-test probabilities may promote better understanding.[38–40] The relative importance of a false-negative versus a false-positive diagnosis of major trauma is unlikely to be equally important, and incorporation of clinical costs is necessary to fully assess tool performance. Decision curve analysis and cost–utility modelling are possible net-benefit methods that overcome the limitations of traditional statistical metrics, and capture the value of different triage outcomes.[41]

Fourthly, triage tools must balance under-triage and over-triage.[33,37] Bypassing of patients without the potential to benefit from MTC care ('over-triage') may waste the time, money and resources of ambulance services and MTCs; and may inconvenience patients and their families. Conversely, failing to recognise appropriate patients with serious injury ('under-triage') could result in transport to non-specialist hospitals, resulting in less effective treatment, increased harm including higher rates of mortality, and poorer recovery. The diagnostic accuracy of triage tools can be manipulated by changing the number, type and thresholds of included variables, or altering the classification threshold of prediction models or machine learning algorithms. As the number of triage tool variables is increased, the cut points for quantitative variables are more easily triggered, or probability thresholds of prediction models/machine learning algorithms are lowered, sensitivity will increase with fewer false negatives, but with a corresponding fall in specificity,

and more false positives. The converse will occur if the number of variables is reduced, variable thresholds are tightened, or the probability threshold increased.[37]

The optimal compromise depends on the prevalence of major trauma in injured patients presenting to ambulance services, and the relative importance given to false-positive and false-negative cases.[42] The ACS-COT has recommended minimising under-triage and accepting a higher level of over-triage to avoid increased mortality, with targets set at ≤ 5% and ≤ 35%, respectively.[32] However, it is important to consider the benefits, harms and costs of prioritisation; and economic evaluations have consistently demonstrated that a high-sensitivity triage approach consistent with such benchmarks is not cost-effective, and, in contrast, specificity should be emphasised.[43–46] Moreover, in very low disease prevalence scenarios, such as that present for major trauma cases among injured patients, relatively higher specificity would be favoured ex ante to maximise positive predictive value, limit the number of false-positive cases, and avoid MTC capacity becoming overwhelmed. In the contingency of low prevalence, negative predictive value will remain relatively high for a given specificity despite commensurately lower sensitivity.[37]

Fifthly, the intended population for triage tool application has important implications due to spectrum effects.[47] These are variations in the performance of tests when used in different settings or population subgroups, where the prevalence and distribution of disease vary. If triage tools are used in higher prevalence settings, such as following high-energy transfer mechanisms, then sensitivity will tend to be higher, and specificity lower.[48] 'Stealth trauma' is an increasingly recognised phenomenon, with a significant proportion of severe injuries occurring with low-energy mechanisms or presenting atypically, resulting in increased numbers of major trauma cases that will be missed if the threshold for using tools is higher.[14] Conversely, applying trauma tools to all patients following injury, regardless of apparent severity, will result in a very low prevalence of major trauma, with spectrum effects leading to relatively higher specificity and lower sensitivity. However, applying triage tools more comprehensively to all injured patients will increase the chance of detecting 'stealth' trauma.

Sixthly, triage tools must be acceptable and usable in the pressured, complex and austere prehospital environment. Despite an explosion of published clinical decision rules, statistical prediction models and machine learning algorithms for emergency conditions, it has been demonstrated that there is very poor uptake and implementation into clinical practice.[49,50] Commonly cited barriers include time pressures, complexity, additional cognitive load, poor integration into workflows, lack of transparency and preference for experienced clinical judgement.[51] Previous qualitative research has reported that prehospital clinicians assessing injured patients '*place significant emphasis on speed of decisions*' and '*complex decision tools are not routinely conducted before a triage decision is made*'.[52]

Finally, ancillary clinical judgement may be applied. Triage tool outcomes can be considered at two levels: theoretical diagnostic accuracy and real-life performance. When evaluating theoretical diagnostic accuracy, triage tools are assessed according to the test result that would arise if the constituent variables were scored exactly according to the objective prehospital findings, regardless of the final actual triage decision or hospital destination. Additional interpretation or clinical judgement would be ignored, for example a GCS score variable with a cut point of ≤ 14 would theoretically trigger for a reduced value of 13, despite this being the baseline level for an elderly patient secondary to underlying dementia and ignored by the attending ambulance clinician. For real-life performance, the actual triage decisions in terms of final transport to a MTC or non-MTC hospital are considered, regardless of the theoretical triage tool result indicated by the observed data. This would provide a global assessment of triage effectiveness regardless of whether triage tools are used, or if ancillary clinical judgement is applied to interpret objective triage tool results.

Effectiveness of major trauma triage

Several systematic reviews have examined the theoretical diagnostic accuracy of adult major trauma triage tools.[29,53–56] The most recent, valid and comprehensive review by van Rein *et al.*[55] identified 21 predominantly North American studies, investigating 16 different triage tools. In general, included studies were noted to be at high risk of bias, most often due to assessing accuracy in skewed trauma registry study populations, rather than undifferentiated injured patients in the prehospital setting. Sensitivity and specificity estimates were extremely heterogeneous, ranging from 9% to 100%, with poorer quality retrospective studies reporting more optimistic results. The performance of the ACS-COT

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triage tool,[57] on which many current UK instruments are based, was variable, with sensitivity and specificity ranging between 56% and 66% and 75% and 88%, respectively. The largest and most robust included studies were conducted by Newgard (2016) and Voskens (2017). Newgard *et al.*[44] evaluated the 2011 ACS-COT FTDS in a sample of 53,487 patients presenting to EMS against an ISS ≥ 16 reference standard, reporting a prevalence of 3.1%, sensitivity of 66.2%, and specificity of 87.8%. Voskens *et al.*[29] studied 4950 injured adults judged by ambulance providers to be high priority (conveyed with flashing lights and siren). They evaluated the Dutch field triage protocol, demonstrating a prevalence of 8.8%, sensitivity of 36.2%, and specificity of 92.6%. A diagnostic prediction model for major trauma was also derived in this Dutch population. External validation in the Brabant region of the Netherlands revealed reasonable discrimination with a *c*-statistic of 0.83, but some miscalibration, with underestimation of major trauma at higher predicted risks. The model cut-off point with a minimum specificity of 50.0% led to a sensitivity of 88.8%.

Two systematic reviews have examined the real-life performance of major trauma triage decisions in adults. Van Rein *et al.*[56] examined studies using transport to MTCs as the index test, and serious injury as the reference standard. From the 40 included studies, three were at relatively low risk of bias, and investigating unselected injured patients presenting to EMS. Meisler *et al.* (2010) observed a prevalence of 12.6% for ISS ≥ 16, sensitivity of 32%, and specificity of 76% when using the Triage protocol of Denmark.[58] Newgard *et al.* (2017) reported a prevalence of 3.3% for ISS ≥ 16, sensitivity of 64% and specificity of 70% for inclusive US trauma systems using the 2006 FTDS.[59] Voskens (2017) reported a prevalence of 8.8% for ISS ≥ 16, sensitivity of 78% and specificity of 69% in the central Netherlands. More recently, Lokerman *et al.* (2023) evaluated triage decisions based on hospital destination against a reference standard of ISS ≥ 16, before and after introduction of an app-based major trauma prediction model in the Netherlands.[60] Prevalence was 2.5%/2.9% before and after app introduction, sensitivities were 68%/73% and specificities 68%/73%.

A further systematic review by van Rein *et al.*[56] examined the 'compliance' of real-life triage decisions with the corresponding theoretical triage tool result. Overall compliance rates ranged from 21% to 94%, with higher rates for penetrating injury, and lower rates for vital signs, triage variables and elderly patients. However, similar limitations of heterogeneity and high risk of bias challenge interpretation. Examining the most internally valid studies by Newgard (2017, compliance rate of 72%) and Voskens (2017, compliance rate of 73%) suggests that additional clinical judgement applied to theoretical triage tool outcomes resulted in increased sensitivity, with a fall in specificity.[29,61]

The evidence base for the major trauma triage tools in children is less developed,[62–65] but a recent well-conducted systematic review suggests likely suboptimal real-life performance.[65] Five studies published between 1996 and 2017 were included, all of which were conducted in the USA, analysing a total of 1222 children, and examined real-life triage decisions. Most included studies were judged to be at high risk of bias from non-representative samples, missing data, or reference standard misclassification. The most internally valid study from Newgard *et al.*[66] examined hospital destination decisions using the 2006 version of the FTDS in 4197 children aged under 14 years (major trauma prevalence of 2.6%), demonstrating sensitivity of 87% and specificity of 80%. No systematic reviews were available examining theoretical diagnostic accuracy of triage tools in children. Prior to commencement of the MATTS project, there were no dedicated systematic reviews investigating triage accuracy in elderly patients.

Need for the Major Trauma Triage Study project

Systematic reviews examining the diagnostic accuracy of international major trauma triage tools have suggested that existing tools can be inaccurate.[29,55,65] Despite the importance of treating the '*right person in the right place at the right time*', there has been no consensus on the best triage tool structure, most appropriate combination of triage variables, or the ideal trade-off between under- and over-triage. The NICE major trauma service delivery guidelines acknowledged these issues, noting that each UK ambulance service uses a different tool, with wide variation in the intended population, individual variables and cut points, and recommending further studies as a research priority. The National Institute for Health and Care Research (NIHR) Health Technology Assessment (HTA) Programme consequently commissioned the MATTS project to develop a national major trauma triage tool for use in NHS trauma networks (Grant: 17/16/04). A study protocol was pre-specified (ISRCTN17968752). Protocol modifications and amendments are detailed in *Report Supplementary Material 1*. Ethical approval was provided by Yorkshire and The Humber Bradford Leeds Research Ethics Committee (Reference: 19/YH/0197).

Major Trauma Triage Study project aims and objectives

The MATTS project aimed to develop an accurate, acceptable and usable prehospital triage tool to identify patients with major trauma who could benefit from expedited MTC care in UK trauma networks, optimising the trade-off between under- and over-triage. Specific objectives were to:

- Define which patients benefit from expedited MTC care.
- Identify current major trauma triage tools and characterise their content.
- Review the evidence on performance of existing triage tools.
- Investigate user perspectives on major trauma triage tools and processes.
- Determine the optimal trade-offs between triage tool performance, costs and clinical outcomes.
- Develop a new triage tool through expert consensus.
- Validate the diagnostic accuracy of expert derived and existing major trauma triage tools.
- Identify a candidate triage tool with optimal performance.
- Evaluate system-level performance of the implemented optimal triage tool, including identification of major trauma cases and compliance.
- Determine the usability and acceptability of the implemented triage tool.
- Evaluate the cost-effectiveness of alternative triage tools.

Major Trauma Triage Study project structure

The MATTS project was conducted in three phases. In Phase 1, preparatory background research was conducted to inform the development of a new major trauma triage tool. A document analysis of existing tools was performed to highlight possible designs and potential triage variables (see *Chapter 2*). A systematic review of geriatric triage tools was completed to supplement recently published reviews examining adult and children, and address an evidence gap for the elderly subgroup of patients (see *Chapter 3*). Decision-analytic modelling then evaluated the cost-effectiveness of different triage strategies and identified the optimal target trade-off between under- and over-triage (see *Chapter 4*). A survey and focus groups explored patient and clinician perspectives of current major trauma triage and identified areas for improvement (see *Chapter 5*). An expert consensus process developed a reference standard, defining the population of major trauma cases requiring expedited MTC for use in evaluating triage performance, and as a focus for the new triage tool (see *Chapter 6*). Finally, Phase 1 culminated in the development of a candidate national MATTS triage tool through expert consensus (see *Chapter 7*).

In Phase 2, the theoretical diagnostic accuracy of existing triage tools identified in Phase 1 and the MATTS triage tool developed through expert consensus were examined in a case–cohort study using data from four English regional trauma networks (see *Chapter 8*). Real-life triage performance, using the existing triage tools in each ambulance service, was also examined in this study population. An optimally performing triage tool was then selected for implementation.

In Phase 3, a candidate triage tool was implemented into practice in six English regional trauma networks. Theoretical diagnostic accuracy and real-life triage performance of the new triage tool were prospectively evaluated in a diagnostic cohort study (see *Chapter 9*) and compared to that observed prior to implementation (see *Chapter 10*). Surveys and focus groups were conducted with clinician stakeholders to explore user experiences following implementation of the new triage tool (see *Chapter 11*). An economic evaluation investigated the cost-effectiveness of triage using the new triage tool (see *Chapter 12*). Finally, the findings of the MATTS project were reviewed, implications for clinical practice considered, and priorities for further research identified (see *Chapter 13*).

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Chapter 2 'Endless variation on a theme': a document analysis of recent international and UK major trauma triage tools

Introduction

The US FTDS is the prototype major trauma triage tool, initially introduced by the ACS-COT in 1986, with multiple subsequent iterations, culminating in the current 2021 version.[30–32] Systematic reviews suggest that its variables and thresholds have been extensively modified to develop other alternative triage tools.[29,55,56,65,67] However, triage tool structure and content have not been comprehensively examined previously.

Reviewing the structure, included criteria, and variable cut points in existing triage tools is a helpful early step in development of a new triage tool. It highlights possible designs, identifies potential candidate variables for consideration, and may provide insights into how best to format and integrate tools into practice. The aim of this study was therefore to identify, collate, review and interpret established major trauma triage tools to help inform the development of a new national triage tool for the NHS. Specific objectives were to identify all recent UK and published international triage tools, summarise structure and content, and recognise patterns across triage tools.

Methods

A qualitative document analysis was undertaken according to best practice recommendations.[68] Firstly, major trauma triage tools were identified by a comprehensive strategy encompassing MEDLINE® searches for systematic reviews of major trauma triage tools, direct e-mail correspondence with UK trauma networks, ambulance services, the English National Clinical Director for Major Trauma and the Joint Royal Colleges Ambulance Liaison Committee (JRCALC); and ad hoc web searches for publicly available triage tools. This strategy aimed to identify all UK triage tools used between 2012 and 2021, corresponding to the time when trauma networks were implemented in the NHS, and published international major trauma triage tools from the same period. Prehospital scales and scores, not implemented clinically, or used primarily for research or prognosis were not eligible. Generic prehospital triage tools, tools specific to individual injuries, or tools primarily for burns were also excluded from consideration.

Document analysis then proceeded in three stages, with skimming (superficial examination), reading (thorough examination) and interpretation of identified tools. A conceptual content analysis was undertaken using an inductive codebook developed after initial skimming of identified triage tools. This comprised concepts of triage tool structure, intended population and setting, inclusion and exclusion criteria, and included variables and thresholds. Triage tools were coded by a single researcher and checked independently by a second investigator. Analogous concepts were grouped together under a single code, for example 'inhalational injury' and 'respiratory tract burns'. Variables with differing thresholds/cut-points, or representing meaningfully different concepts, were coded separately, for example '> 20%' versus '> 30% body surface area burns', 'spinal injury with neurological deficit' versus 'spinal injury with paralysis'. Composite triage tool criteria, consisting of multiple separate concepts grouped together, were split into their constituent terms if they represented distinctly different conceptions, for example crushed, mangled or de-gloved extremity. Coding units were summarised using tabulation, descriptive statistics and visualisation using hierarchical scaled tree-maps.[69]

Thematic analysis was also performed to identify additional higher-level patterns within the data, with emerging themes becoming categories for analysis.[70] Coding framework and category construction was determined inductively based on the data's characteristics by a single researcher and checked by a second investigator. A narrative synthesis of findings was then undertaken.

Results

All UK ambulance services and major trauma networks provided information on their major trauma triage tools between 2012 and 2021. Five systematic reviews examining major trauma triage tools were identified during the same study period.[53,55,56,65,71] In total, 53 major trauma tools were subsequently included for analysis, comprising 19 UK tools and 34 published international tools. Of these, 34 were adult only tools, 11 were adult-focused (primarily designed for adults, with minor modifications for use in children), 6 were paediatric only, and 2 were for elderly patients only. Age thresholds for non-adult tools ranged from < 16 to < 12 years for paediatric, and > 65 to > 70 years, for geriatric tools.

The structure and format of the identified tools are summarised in *Table 1*. Most triage tools were developed by expert opinion and were paper based (*n* = 42/53, 80%). A common structure of multiple domains (or 'steps') was evident for these tools, with constituent triage predictors assessed in parallel as a 'checklist'. Physiology and anatomical injury steps were present in all such tools (*n* = 42/42, 100%), representing mandatory bypass/pre-alert criteria. Mechanism of injury (*n* = 31/42, 74%) and special circumstance (*n* = 18/42, 43%) steps were less commonly implemented, and when present usually included as discretionary variables. A minority of tools were statistically derived prediction models, operationalised either as simple scores (*n* = 10/53, 19%) or as an electronic application (*n* = 1/53, 1%), providing a probability or total number for the likelihood of major trauma. All models included physiology variables, but anatomical (*n* = 6/11, 55%), mechanistic (*n* = 2/11, 18%) and special circumstance (*n* = 2/11, 18%) predictors were less commonly included. Triage tools otherwise differed widely, with variation in the intended population, individual variables and cut-points, formal incorporation of clinical judgement, and the option to obtain senior clinical advice (e.g. consultation with a remote ambulance service 'trauma desk', or specialist paramedic).

TABLE 1 Triage tool structure and format

Triage tool structure			*n/N*	%
Derivation/format	-	Expert opinion/paper/multiple steps	42/54	80
	-	Statistical prediction model (score)	10/54	19
	-	Statistical prediction model (electronic application)	1/54	1
Target age group	-	Adult only (≥ 16 years)	35/54	66
	-	Adult-focused	11/54	21
	-	Paediatric (< 16 years)	5/54	9
	-	Elderly (≥ 65 years)	2/54	4
Intended population defined	-	Serious injuries	3/54	6
	-	Suspected major trauma	8/54	15
	-	Significant mechanism	1/54	2
	-	Serious injuries or significant mechanism	1/54	2
	-	Suspected major trauma, except nursing home residents or clinical frailty score > 4 excluded	1/54	2
	-	Injury	4/54	7
	-	Not defined	36/54	66
Variable domains present	-	Physiology	54/54	100
	-	Anatomical injury	48/53	91
	-	Mechanism of injury	33/53	62
	-	Special circumstances	20/53	38
Unstructured clinical judgement	-	Formally incorporated	18/53	34
Decision support	-	Option for senior clinical advice	15/53	28

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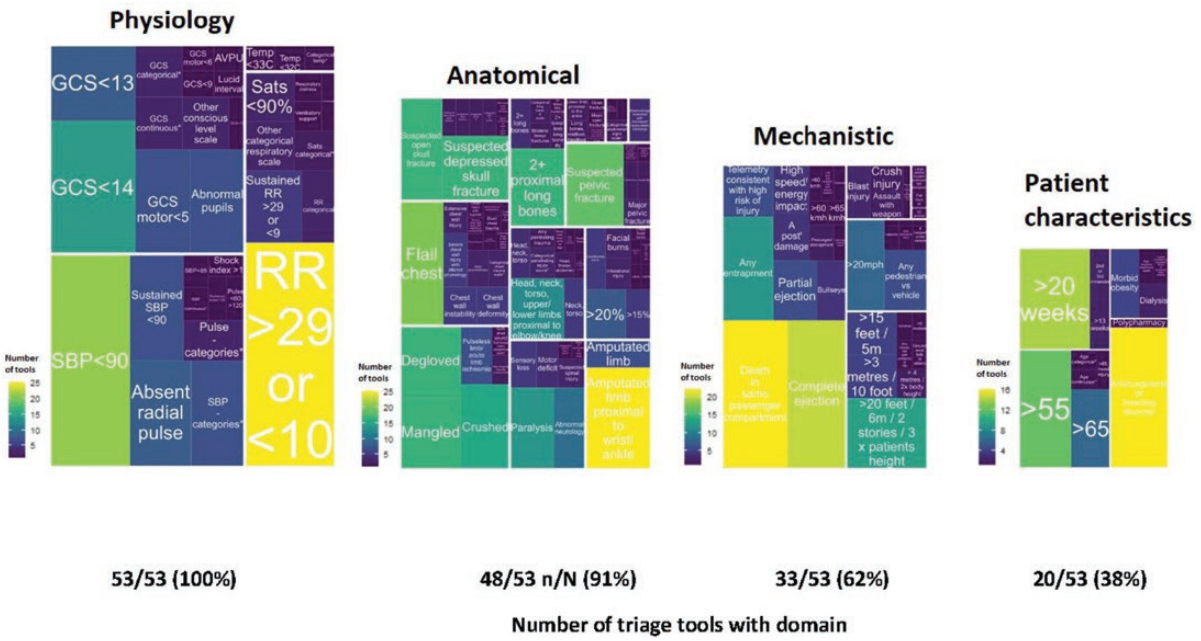


FIGURE 1 Scaled tree-maps demonstrating how commonly domains and individual variables are used across UK and international triage tools.

Individual triage variables from identified adult triage tools (*n* = 45) are summarised in *Figure 1*. In total, 173 distinct variables were used, and the median number of constituent triage variables in each triage tool was 19 (range 3–31). Variable descriptions ranged from precise to vague terms, within and across triage tools [e.g. *'Suspected pelvic fracture'*, compared with *'Suspected major pelvic fracture, where mechanism of injury is suggestive of a pelvic fracture AND is accompanied by any one or more of the following: Haemodynamic instability/signs of shock; Deformity on examination; Suspected open pelvic fracture due to bleeding PU, PV or PR (or scrotal haematoma)'*].

Cardiovascular, respiratory and level of consciousness physiological variables were included in all tools, with moderate variation evident in the exact definitions and cut points used. Anatomical injury variables were less common (*n* = 41/46 tools, 89%), and more diverse, with chest injury (89%), penetrating trauma (76%), spinal injury (72%), pelvic injury and limb amputation (72%) being the commonest categories; however, the exact number and definitions differed greatly across tools. When present, there was very wide variation in the number and definitions of mechanism and special circumstances variables. Paediatric and elderly triage tools demonstrated similar findings.

Four distinct patterns of triage tools were identified during thematic analysis: 'specific and prescriptive', 'sensitive and permissive', 'intermediate' and 'prediction models'. These four groups differed in terms of format, number of triage variables, thresholds, scope for clinical judgement and relative diagnostic accuracy, as summarised in *Table 2*. Exemplar triage tools for each thematic group are presented in *Figure 2*. Triage tools used in inclusive trauma networks were distinctive in containing additional bypass exclusion criteria, for example travelling time limits; and diversion to closer hospitals for patients with uncontrollable airway, breathing or circulation deficits. This group of tools were often formatted as flow charts, more commonly included the option for senior clinical support, and frequently included triage variables for open fractures and burns. More recent, post 2020 tools tended to have fewer mechanism of injury or special circumstance criteria. No other major themes were identified in the data, and UK tools appeared to be broadly comparable to international tools, except for increased provision of senior clinical decision support.

The size of each individual tree-map is proportional to how often that domain of variables was included in triage tools. Within each tree-map, the size and colour of each block indicate how commonly an individual variable was observed; for example a physiology domain was included in all triage tools, with respiratory rate < 10 and > 29, systolic blood pressure < 90 and GCS < 14 being the commonest individual variables.

TABLE 2 Subgroups of triage tools

	Specific and prescriptive	Sensitive and permissive	Intermediate	Statistical prediction models
UK tools (*n*)	5	10	4	0
International tools (*n*)	4	14	5	11
Derivation	Expert opinion	Expert opinion	Expert opinion	Statistical modelling
Format	Paper	Paper	Paper	Paper scoring system or electronic application
Inclusion	High-energy mechanism of injury or suspected major trauma	Not defined	Inconsistently defined as suspected major trauma	Inconsistently defined as suspected major trauma
Domains (or 'steps')	2 – Mandatory physiology and anatomical	4 – Mandatory physiology and anatomical – Discretionary mechanism and patient characteristics	3 – Mandatory physiology and anatomical – Unstructured clinical judgement	N/A – Variables given weights and added together to provide score of probability.
Relative number of variables	Fewer	Higher	Intermediate	Fewer
Variable descriptions/ thresholds	Stricter	Liberal	Intermediate	Categorical or continuous scoring of variable
Relative accuracy	Specific	Sensitive	Intermediate	Intermediate
Formal clinical judgement	No	Yes	Yes	Rarely
Senior clinical support	Rarely	Yes	Yes	No
Other	Rural trauma networks	Includes all elderly and paediatric tools		

N/A, not applicable.

Discussion

Summary

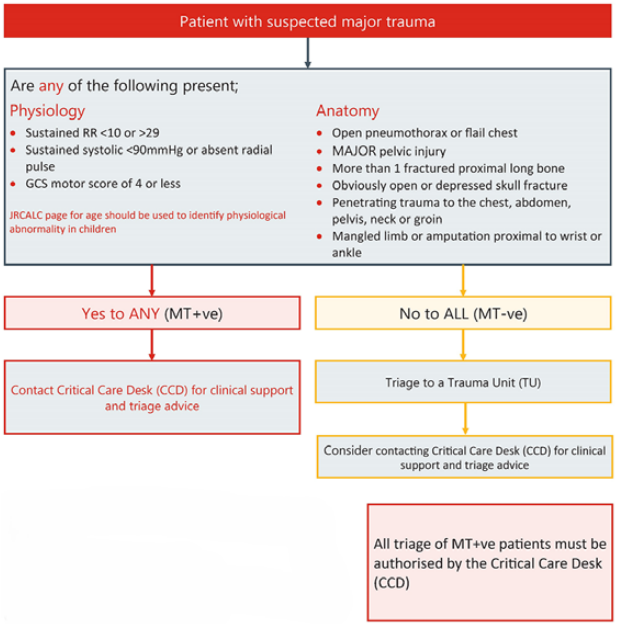
In summary, a wide range of UK and international major trauma triage tools were identified, with marked variation in structure and included variables. Four broad groups were identified, comprising expert-derived specific and prescriptive, sensitive and non-prescriptive, and intermediate tools; and statistically derived prediction models. Triage tools used in inclusive trauma networks were notable for additional bypass exclusion criteria and increased use of senior clinical decision support. More recently introduced tools tended to de-emphasise mechanism of injury and patient characteristic variables.

Interpretation

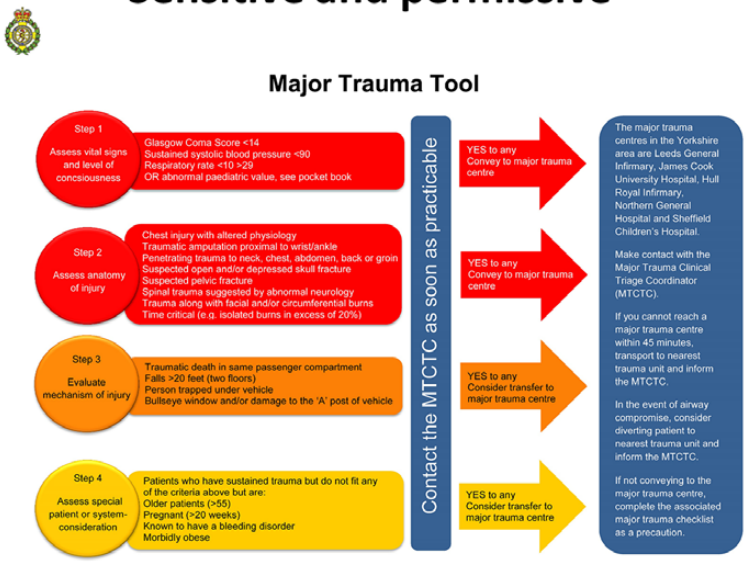
Clinical judgement may be used at various levels within prehospital triage, including the decision to use a tool, interpretation of variable definitions, use of discretionary variables, or planned application of unstructured clinical judgement. Clinical acumen has been repeatedly demonstrated to outperform strict adherence to clinical decision rules across many medical conditions.[35,72] It is therefore not surprising that gestalt was formally incorporated into many triage

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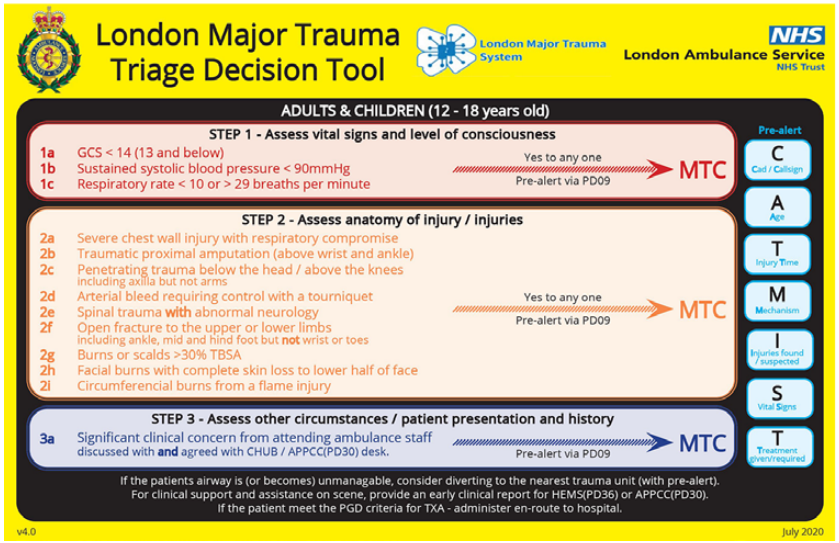
Specific and prescriptive



Sensitive and permissive



Intermediate



Statistical prediction model



Variables	β Coefficient (SD)
Patient characteristics	
Age, y	
Spline basis function 1	0.011 (0.004)
Spline basis function 2	0.001 (0.005)
Physiologic characteristics	
Systolic blood pressure	
Spline basis function 1	−0.011 (0.002)
Spline basis function 2	0.020 (0.003)
GCS score	−0.337 (0.001)
Mechanism of injury	
Mechanism criteria[b]	1.314 (0.056)
Injury characteristics	
Penetrating injury to head, thorax, or abdomen	1.196 (0.131)
Signs and/or symptoms of head or neck injury	0.571 (0.056)
Expected injury in AIS region of thorax	0.405 (0.071)
Expected injury in ≥2 AIS regions	0.713 (0.129)
Intercept[c]	2.069 (0.315)

FIGURE 2 Exemplar triage tools for each thematic category.

tools, particularly given the heterogeneity of major trauma and often confounding prehospital circumstances. Decision support, provided by senior clinicians, for example from a dedicated ambulance service 'trauma desk', was used in many UK tools and could further finesse the benefit of clinical judgement.

It is well established that major trauma encompasses different disease entities in children, adults and the elderly,[9] with contrasting incidence, mechanisms, patterns of injury and treatment considerations. The finding of predominantly adult triage tools, with uncommon minor modifications for children and elderly, might reflect the need to avoid complexity from multiple different tools, or age-variable interactions, in the challenging prehospital environment.

Most identified tools were created through expert consensus; however, advances in health data science, with access to large robust linked data sets, may facilitate increased use of statistical prediction modelling and machine learning.[73,74] This study provides a comprehensive source of candidate variables for use in any of these approaches. Strikingly, existing triage tools did not state their target definition of major trauma or desired sensitivity/specificity trade-off. Where defined, the intended patient population for application was high-energy trauma or suspicion of major trauma.

No triage tool consistently provided definitions, and there were often subtle differences between variable labels, for example *'thorax and abdomen' versus 'trunk'*; or *'obviously' versus 'suspected'* depressed skull fracture. Not all anatomical domains were routinely included, with blunt abdominal injuries, for example, rarely included, and no point-of-care tests were used. The observation that newer triage tools tended to exclude mechanism of injury or special circumstance variables may reflect an emerging perception that these factors have less accuracy in predicting major trauma.[75]

Comparison to existing literature

A single scoping review examining prehospital triage tools has been published previously but did not focus on major trauma.[76] No other previous studies were found that have qualitatively investigated major trauma triage tool structure and content.

Limitations

This study has several strengths, including a comprehensive search strategy, concordance with document analysis recommendations, and detailed coding of triage tools. However, limitations could include a non-exhaustive search for international triage tools; and checking of triage tool coding, rather than independent re-coding. The inclusion of all recent NHS tools ensures the findings are directly applicable to UK major trauma triage.

Conclusions

Many diverse major trauma triage tools were identified, with no consensus in format, structure, or content. Quantification of constituent variables will provide a comprehensive source of candidate predictors for future triage tool development. Other important considerations include providing variable definitions, addition of supporting operational information, and defining the entry threshold for tool use.

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Chapter 3 Diagnostic accuracy of prehospital triage tools for identifying major trauma in elderly injured patients: a systematic review

Introduction

Recent systematic reviews have investigated the accuracy of major trauma triage tools and resulting triage decisions in adults. Prior to the commissioning of the MATTS project, there were no systematic reviews available investigating major trauma triage in the elderly subgroup. In developed countries, recent demographic changes have had a profound effect on the epidemiology of major trauma, with a 'silver tsunami' of serious injury in the elderly.[1,9] Major trauma in the elderly can be considered a separate disease entity, and older adults are a particularly vulnerable population. The aim of this systematic review was therefore to examine the theoretical diagnostic accuracy of prehospital triage tools, and performance of real-life triage decisions, for identification of major trauma in elderly patients presenting to ambulance services following injury.

Methods

Study design

The study was undertaken in accordance with the general principles recommended by expert consensus guidelines for the conduct of diagnostic accuracy systematic reviews[77,78] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[79] A pre-specified review protocol was also registered with the PROSPERO international prospective register of systematic reviews (CRD42020150342).

Inclusion criteria

All studies (prospective or retrospective) reporting diagnostic accuracy metrics were eligible if they examined any multivariable prehospital major trauma triage tool (either evaluated according to actual paramedic decision or scored using observed patient variables) compared with any reference standard for major trauma such as ISS. The study population was elderly adults evaluated in a prehospital setting who required transport by land ambulance following injury. The review question and inclusion criteria are detailed in *Table 3*.

Although a standard consensus definition of elderly has not been established, a cut-off of over 60 years is commonly used.[80] Studies that enrolled participants < 60 years of age were included if it was possible to identify the ratio of

TABLE 3 Systematic review question and inclusion criteria

Review question	
What is the diagnostic performance of prehospital triage tools for identification of major trauma in elderly patients presenting to EMS following injury?	
Inclusion criteria	
Population	Elderly adults aged > 60 years attended by land EMS following injury with the potential for major trauma.
Index tests	Multivariable prehospital major trauma triage tools (either scored using observed patient variables or evaluated according to actual paramedic decision).
Reference standard	Any definition of major trauma, such as ISS.
Outcomes	Diagnostic accuracy metrics including sensitivity, specificity, under-triage (1 – sensitivity), over-triage (1 – specificify), predictive values.
Study design	Diagnostic accuracy studies (prospective or retrospective).

participants who were more than 60 years of age; if the ratio was more than 75%, such studies were included. In case of studies with mixed populations, for example data for adults above and below 60 years of age which could not be separated, the study authors were contacted to provide the data separately for the group of interest, where possible. Studies including people presenting to the ED via non-EMS, that is private transportation or helicopter transport, were excluded.

Data sources and searches

Potentially relevant studies were identified through searches of 10 electronic databases comprising: MEDLINE, EMBASE, CINAHL, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Database of Abstracts of Review of Effects, Health Technology Assessment Database, Science Citation Index Expanded, ClinicalTrials.gov and the International Clinical Trials Registry Platform. The search strategy used free text and thesaurus terms and combined synonyms relating to the condition (e.g. prehospital trauma triage) with risk assessment model terms (used in the searches of MEDLINE, Cochrane Library and EMBASE only). Searches were supplemented by examination of the reference lists of all relevant studies (including existing systematic reviews), performing a citation search of relevant articles, contacting key experts in the field, and undertaking systematic keyword searches of the World Wide Web using the Google search engine. No language or date restrictions were used on any database. Further details on the search strategy can be found in *Appendix 1*, *Tables 24–26*.

Study selection

All titles were examined for inclusion by one reviewer and any citations that clearly did not meet the inclusion criteria (e.g. non-human, unrelated to prehospital major trauma triage) were excluded. All abstracts and full-text articles were then examined independently by two reviewers. Any disagreements in the selection process were resolved through discussion with a third reviewer and included by consensus.

Data extraction and risk-of-bias assessment

Data relating to study design, methodological quality, diagnostic accuracy and outcomes were extracted by one reviewer into a standardised data extraction form and independently checked for accuracy by a second. Any discrepancies were resolved through discussion to achieve agreement. Where differences were unresolved, a third reviewer's opinion was sought. Where multiple publications of the same study were identified, data were extracted and reported as a single study. In papers focusing primarily on adult triage, subgroup results relating to elders were extracted. If multiple triage tools were evaluated in elderly patients within a single study, results were extracted separately as distinct index test assessments. Where results were reported for various thresholds of a single triage tool, the version giving results closest to ACS-COT triage guidance for sensitivity (95%) and specificity (65–75%) targets were included. In the event of multiple elderly subgroup or sensitivity analyses, the primary results for each individual triage tool were included.

The methodological quality of each included study was assessed using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool.[81] This instrument evaluates four key domains: patient selection, index test, reference standard, flow and timing. Each domain is assessed in terms of risk of bias and the concern regarding applicability to the review (first three domains only). The subdomains for each domain include a number of signalling questions to guide the overall judgement about whether a study is at high, low or an unclear (in the event of insufficient data in the publication to answer the corresponding question) risk of bias. Since there are two types of prehospital triage-based studies, the original QUADAS-2 tool was modified to include an index test assessment of both real-life triage tool performance (i.e. evaluated according to actual paramedic decision) and diagnostic accuracy (i.e. theoretical results if triage tools were scored using observed patient variables), where reported.

Data synthesis and analysis

Estimates of sensitivity and specificity are presented as point estimates and 95% CIs for individual prehospital major trauma triage tools. Results were recalculated if alternative metrics of diagnostic accuracy were originally reported, for example under-triage (1 – sensitivity) or over-triage (1 – specificity). Estimates of sensitivity and specificity for individual triage tools were compared using Forest plots. Results were grouped according to the type of triage evaluation (theoretical diagnostic accuracy vs. real-life performance) and study population (undifferentiated injuries vs. head injured). Performance was then compared to the ACS-COT benchmark for the triage of trauma patients. Heterogeneity

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was assessed subjectively by visual inspection, Cochrane Q test and the I^2 statistic. It was not possible to perform a meta-analysis due to significant levels of heterogeneity between studies, variable reporting of items and the high risk of participant selection bias. As a result, a pre-specified narrative synthesis approach was undertaken.[77,82] Analyses were conducted using Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA) and Stata 13.1 (StataCorp, College Station, TX, USA).

The overall quality of evidence across studies was evaluated using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach for diagnostic tests and strategies.[83,84] The quality of evidence was assessed by evaluating the evidence on each outcome for the following domains: study design and conduct (risk of bias); imprecision of diagnostic accuracy estimates (wide CIs); variability in results; indirectness of evidence; or publication bias. The overall quality of evidence was assessed as high, moderate, low and very low. These levels imply a gradient of confidence in estimates of a diagnostic test strategy on patient outcomes.[83]

Results

Study flow

Figure 3 summarises the process of identifying and selecting relevant literature. Of the 1843 citations identified, 15 studies investigating 21 index tests (19 unique triage tools) met the inclusion criteria.[85–99] The majority of the articles were excluded primarily on the basis of an inappropriate target population (not elderly adults with suspected major trauma and evaluated in a prehospital setting and transported by land EMS), where the intervention was not a prehospital major trauma triage tool, or an unsuitable publication type (i.e. reviews, commentaries or editorials). More specifically, four potentially relevant papers were excluded as they included potential publication overlap from a single large study.[66,100–102]

Study and patient characteristics

The design and patient characteristics of the 15 included studies[85–99] are summarised in *Table 4*. All studies were observational cohort studies (2 prospective[88,99] and 13 retrospective),[85–87,89–98] undertaken in Australia,[86] Canada,[89] the Netherlands[99] and the USA,[85,87,88,90–98] and were published between 1996 and 2019. Eleven studies[85–93,95,98] investigated the diagnostic accuracy of triage tools, three studies[96,97,99] evaluated real-life triage performance and one study[94] assessed both. The majority of included studies examined non-selected injured patients (11 studies),[85–93,95,99] with the remainder investigating narrower populations of motor vehicle accident (3 studies)[96–98] or head injury victims (1 study).[94]

While all studies included adult elderly trauma patients, the definition of elderly or older persons ranged between 55+ and 70+. The proportion of male patients ranged from 31%[87] to 60%.[94] In studies that reported the cause of suspected major trauma in the elderly, the most common were blunt injuries, caused by motor vehicle accidents and falls. Comorbidities and medication use (e.g. anticoagulants and or antiplatelet therapy) were poorly reported. The percentage of patients with major trauma ranged widely from 3%[98] to 32%[85] depending on definition, study design and type of participating hospitals.

Risk of bias and applicability assessment

The methodological quality of the included studies was variable, with most studies having unclear or high risk of bias and applicability concerns in at least one item of the QUADAS-2 tool. The main risk-of-bias limitations were related to patient selection (arising from patient exclusions[85,87,94,96,97,99] and incomplete patient enrolment),[88,92,95] missing index test or outcome data[85–95,98] and suboptimal matching of prehospital and hospital data.[87,89–93]Moreover, for studies examining real-life transport decisions,[94,96,97,99] inclusion of patients injured closest to a MTC could overestimate sensitivity results, and underestimate specificity results, as these patients would always be transported to the MTC regardless of triage tool results or EMS provider judgement. Other systematic errors included possible information bias from index test misclassification secondary to retrospective chart review and overfitting of non-externally validated statistical models. Applicability concerns for the majority of studies were generally related to patient selection (highly selected study populations, e.g. triage of patients involved in motor vehicle accidents[96–98] or after head injury[94] only; definitions of elderly not fully matching the review question)[86,88,93,94,97] and unconventional reference standards (major trauma was

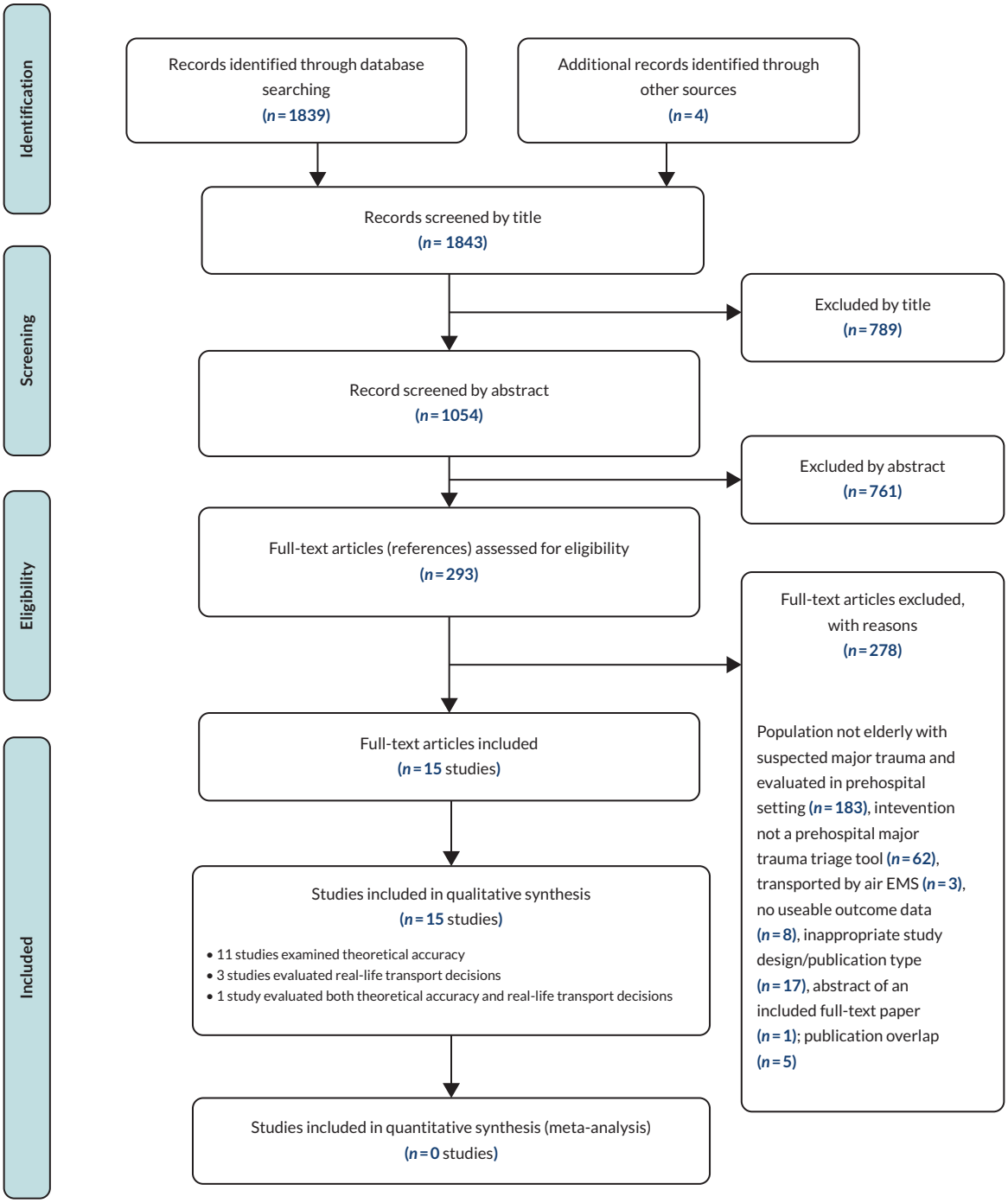


FIGURE 3 Systematic review study flow chart.

defined in some studies as intracerebral haemorrhage,[88,94] ISS > 12,[86] or any AIS score ≥ 3).[97] The overall methodological quality of the 15 included studies[85–99] is summarised in *Appendix 1*, *Table 27*.

Diagnostic performance of prehospital trauma triage protocols

The theoretical diagnostic accuracy of major trauma triage tools is summarised in *Figure 4*. All triage tools included an assessment of vital signs, suspicion of certain anatomical injuries and specific mechanisms of injury. The performance of real-life triage decisions using different triage tools is presented in *Figure 5*.

Triage accuracy fell below ACS-COT suggested triage targets for sensitivity (95%) and specificity (65–75%) in the large majority of included studies. Sensitivity estimates varied from 19.8%[94] to 95.5%[86] for theoretical accuracy, and 57.7%[97]

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TABLE 4 Characteristics of studies included in the systematic review

Author, year	Design	Country	Sample size	Elderly definition	Population	Triage tool	Triage system	Definition of major trauma	Mean/ median age	Male	Mechanism of injury	Blunt trauma	Major trauma prevalence
Phillips, 1996[95]	R,CS	USA	3116	> 65	Unselected injuries	Florida Trauma Scorecard	Theoretical accuracy	MacKenzie definition	NR	NR	NR	NR	NR
Scheetz, 2003[96]	R,CS	USA	463	≥ 65	MVA victims	New Jersey Trauma Guideline	Real-life decisions	ISS > 15	75	49%	RTA: 100%	NR	22%
Scheetz, 2007[98]	R,CS	USA	7883	≥ 65	MVA victims	Novel tool	Theoretical accuracy	ISS > 15	74	50%	RTA: 100%	NR	3%
Lavoie, 2010[89]	R,CS	Canada	4072	≥ 65	Unselected injuries	Montréal prehospital system	Theoretical accuracy	ISS > 15, resource use, death	NR	NR	NR	NR	NR
Scheetz, 2011[97]	R,CS	USA	166,685	≥ 55	MVA victims	1. FTDS 1999 2. FTDS 2006	Real-life decisions	AIS ≥ 3	68	NR	RTA: 100%	NR	12%
Newgard, 2013[91]	R,CS	USA	31,055	> 60	Unselected injuries	Novel tool	Theoretical accuracy	ISS > 15	81	34.6	Falls: 80%; RTA: 9%; other: 11%	99%	30%
Cox, 2014[86]	R,CS	Australia	NR	> 55	Unselected injuries	Victoria triage tool	Theoretical accuracy	ISS > 12, resource use, death	NR	40%	Falls: 6%; RTA: 30%; other/ missing: NR	NR	NR
Newgard, 2014[93]	R,CS	USA	17,804	≥ 55	Unselected injuries	FTDS 2011 (GCS ≤ 14)	Theoretical accuracy	ISS > 15	NR	NR	NR	NR	NR
Brown, 2015[85]	R,CS	USA	438,828	> 65	Unselected injuries	1. FTDS 2011 (SBP < 110) 2. FTDS 2011 (SBP < 90)	Theoretical accuracy	ISS > 15, resource use, death	80	39%	NR	99%	32%
Ichwan, 2015[87]	R,CS	USA	33,379	≥ 70	Unselected injuries	1. Ohio adult trauma criteria 2. Ohio geriatric trauma criteria	Theoretical accuracy	ISS > 15	82	31%	NR	99%	13%
Newgard, 2016[90]	R,CS	USA	13,401	≥ 65	Unselected injuries	1. FTDS 2011 2. FTDS 2011 (modified)	Theoretical accuracy	ISS > 15	NR	32%	Falls: 80%; RTA: 10%; other: 10%	NR	5%
Jones, 2017[88]	P,CS	USA	4295	≥ 55	Unselected injuries	1.Novel tool 2. FTDS 2011	Theoretical accuracy	ICH	NR	41%	Falls: 75%; other/missing: NR	NR	4%
Nishijima, 2017[94]	R,CS	USA	2110	≥ 55	Head injured	1. FTDS 2011 2. FTDS 2011 (+ anticoags)	1. Theoretical accuracy 2. Real-life decisions	ICH	73	60%	Falls: 72%; RTA: 17%; other: 11%	100%	6%
Voskens, 2018[99]	P,CS	The Netherlands	1085	> 65	Unselected injuries	Dutch Field Triage Protocol	Real-life decisions	ISS > 15	NR	NR	NR	NR	12%
Newgard, 2019[92]	R,CS	USA	5021	≥ 65	Unselected injuries	1. Novel tool 2. FTDS 2011	Theoretical accuracy	ISS > 15, resource use	82	33%	Falls: 83%; RTA: 8%; other 9%	NR	6%

Anticoags, anticoagulants; CS, cohort study; ICH, intracranial haemorrhage; MVA, motor vehicle accident; NR, not reported; P, prospective; R, retrospective; RTA, road traffic accidents; SBP, systolic blood pressure.

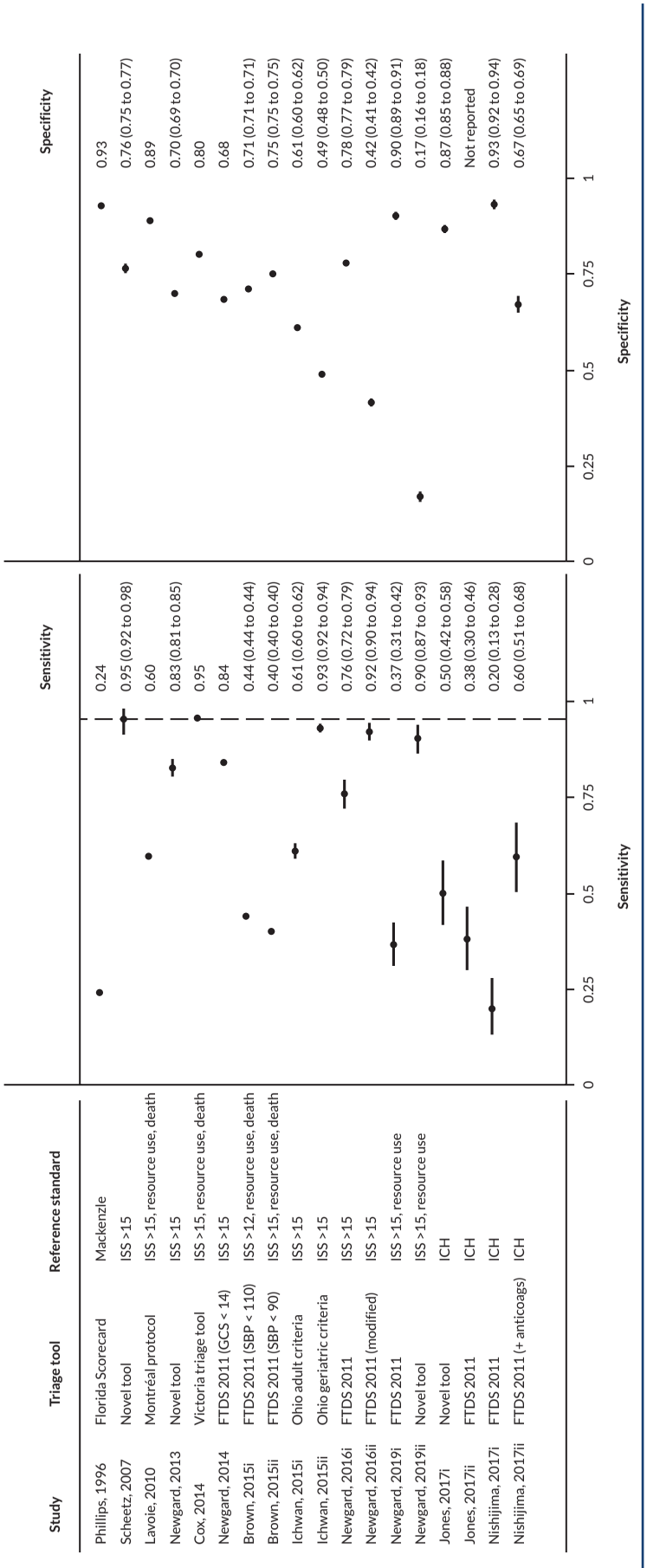


FIGURE 4 Forest plot presenting the theoretical diagnostic accuracy of triage tools.

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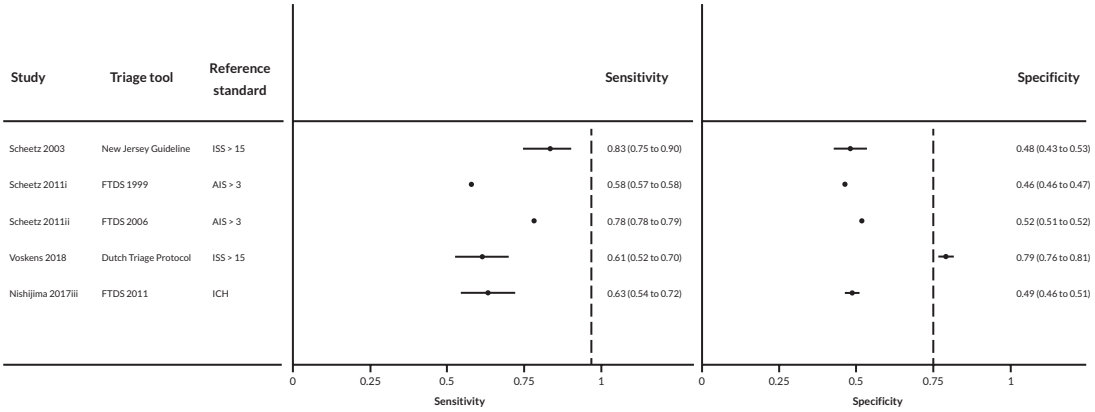


FIGURE 5 Forest plot presenting real-life triage performance when using major trauma triage tools.

to 83.3%[96] for real-life triage performance. Specificity results were similarly diverse, ranging from 17.0%[92] to 93.1%,[94] and 46.3%[97] to 78.9%.[99] There were no clear patterns evident for sensitivity between studies investigating theoretical diagnostic accuracy and real-life transport decisions. However, specificity generally appeared relatively lower for real-life transport decisions.

The studies at lowest risk of bias, with the best applicability, were Newgard *et al.*[92] (theoretical accuracy) and Voskens *et al.*[99] (real-life transport decisions). Sensitivity and specificity estimates from these studies were 37% and 90% (prevalence 6%, FTDS 2011)[92] and 61% and 79% (prevalence 12.2%, Dutch Field Triage Protocol),[99] respectively. Risk of bias and applicability concerns appeared to influence specificity estimates, with higher results evident in studies with increased risk of bias, particularly those conducted using trauma registry data. No clear relationship was apparent between QUADAS-2 assessment and sensitivity estimates. In studies evaluating multiple triage tools, sensitivity increased, with a commensurate fall in specificity, as additional variables were added and less conservative variable thresholds were used. There were no obvious differences between individual triage tool accuracy, or the findings of studies with varying major trauma prevalence, age ranges, reference standards, study designs, or settings.

Overall quality of evidence

The GRADE quality of evidence was considered low quality based on methodology (high or unclear risk of bias); heterogeneity (disparate and contradictory study results); and indirectness of evidence (study populations' not fully reflecting undifferentiated elderly prehospital patients). The quality rating was not affected by publication bias (no registered, but unpublished studies) or precision (relatively narrow 95% CIs for included studies).

Discussion

Summary of results

In a systematic review of 15 observational studies evaluating prehospital major trauma triage tools to identify suspected elderly trauma patients in need of specialised MTC care, it was apparent that various triage tools were being used but most lacked a rigorous evaluation. Both the theoretical diagnostic accuracy and real-life triage performance of the triage tools were highly variable, and differences in study design, study populations and reference standard make a comparison of the evidence difficult. Overall, sensitivity and specificity appeared to be lower than in younger adults.

Interpretation of results

With the current demographic trend of an ageing population, transport of injured elders to the most suitable hospital is increasingly important. However, elderly patients have been previously highlighted as a subgroup of trauma patients who may be at risk of under-triage to MTCs.[103,104] The findings of this review could support this viewpoint, with most studies indicating very substantial under-triage, together with considerable over-triage. The included studies with the lowest risk of bias and best applicability indicated sensitivity and specificity estimates of 37% and 90% (Newgard *et al.*,

theoretical accuracy, FTDS 2011),[92] and 61% and 79% (Voskens *et al.*, real-life transport decisions, Dutch Field Triage Protocol).[99] These contrast with higher sensitivity and slightly lower specificity observed in adults under 65 years from the same studies.

However, it is important to consider which elderly patients could benefit from transportation and pre-alerting to MTCs, whether accurate geriatric prehospital triage is in fact achievable, and if high-sensitivity triage is cost-effective. Firstly, chronological age, and arbitrary age cut-offs, may not be appropriate to gauge the potential to benefit from MTC care.[105] Ageing is *'heterogeneous, variable and malleable'*, with some elderly patients demonstrating better fitness, cognition, and functional status than younger people.[106] Frailty, a multisystem ageing syndrome, with *'increased vulnerability resulting from aging-associated decline in reserve and function across multiple physiologic systems'* is likely to be a better measure of prognosis and response to treatment.[107]

Secondly, not all severely injured patients may benefit from advanced MTC care, and the traditional anatomical reference standard of ISS threshold of > 15 might not be appropriate for elderly or frail patients. The premise that elders will have the same benefit from MTC care as younger adults in unproven, with the US Costs and Outcomes of Trauma study for example failing to identify a significant improvement in mortality for the elderly population.[26] Rehabilitation and supportive management, available in TUs, could be more important than urgent resuscitative and surgical interventions delivered in MTCs. For patients with un-survivable injuries, or very severe comorbidities, outcomes may be fixed regardless of specialist care, making bypass futile. For other injured elders, particularly in the context of advanced frailty, the probability of improved outcome may be low compared to the burden of treatment, and advanced MTC care might not be in a patient's best interests. Patients and families may also prefer care closer to home in a local hospital and be willing to 'trade' better overall outcome to achieve this. Reference standards, including resource use and frailty scores, might therefore provide a better evaluation of triage performance in the elderly.

Thirdly, accurate geriatric prehospital triage may ultimately not be achievable. The signal-to-noise ratio is reduced by the confounding effects of frailty, ageing, comorbidities, polypharmacy, and differing responses to injury, potentially reducing sensitivity and specificity. Physical and cognitive disability may limit the available history and challenge assessment of GCS. Normal physiological ranges change during ageing and may also be affected by comorbidities.[108] Elders frequently take medications that influence physiology (e.g. beta-blockers), or the sequelae of injury, for example delayed bleeding secondary to anticoagulants. Furthermore, the response to injury may also be altered because of the ageing process, for example initially higher GCS following expanding ICH due to brain involution and increased intracranial volume.[109]

Traditionally, triage tools have generally included a common set of variables, with universal vital sign thresholds for all adults. Different cut points for elderly patients have been considered, including thresholds of GCS ≤ 14 and systolic blood pressure < 110, used instead of the common adult thresholds of ≤ 13 and < 90, respectively.[110] However, studies examining these vital signs have demonstrated that the area under the receiver operating characteristic (ROC) curve is much less favourable in older age.[93] Moreover, the familiar trade-off between sensitivity and specificity indicates that more liberal thresholds increasing sensitivity could result in unacceptable over-triage. Novel triage variables including anticoagulation, comorbidities and road traffic accident characteristics have also been shown to have little utility in the elderly.[111] This is well illustrated by Newgard *et al.*[92] who developed a geriatric-specific triage tool, adding comorbidity information and geriatric-specific physiological measures to current US field triage guidelines. This demonstrated improved triage sensitivity for elders (37% to 90%), but with a substantial, and unworkable, decrement in specificity (90% to 13%).

Fourthly, it appears very unlikely that high sensitivity triage is cost-effective in elderly patients. A recent economic evaluation demonstrated that high-sensitivity triage, meeting ACS-COT benchmarks, would result in an extraordinary incremental cost-effectiveness ratio (ICER) of $1.32M per quality-adjusted life-year (QALY) gained. Conversely, favouring specificity, with the consequent trade-off of reduced sensitivity, would be cost-effective at generous willingness-to-pay (WTP) thresholds under $88,000.[45] Taken together, these considerations suggest that aiming for high sensitivity triage of ISS ≥ 16 major trauma in the elderly might not be needed, as TU management may often be appropriate; might not be possible due to background noise from confounders associated with ageing; and might not be desirable due to the limited impact of MTC care and associated lack of cost-effectiveness.

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Given these challenges, how might triage of injured elders be improved? Firstly, the reference standard for triage decisions in elderly patients should reflect the need for direct MTC care rather than injury severity per se. This would help prehospital clinicians balance benefit and burden and identify the subset of elderly patients with major trauma who would benefit from bypass to MTCs and hospital trauma team activation. Secondly, it should be acknowledged that it is likely not possible to achieve ACS-COT suggested triage targets for sensitivity (95%) and specificity (65–75%) for this revised reference standard. An optimal and achievable trade-off of under- and over-triage could be formulated based on clinical costs, benefits and patient preferences rather than arbitrary thresholds. Thirdly, focusing on prehospital clinician training could improve real-life triage performance through better application of triage tools after low energy trauma or medical presentations, and honing clinical interpretation of triage variables. Finally, trauma systems should ensure efficient processes for secondary transfer of any initially under-triaged patients.

This review included studies from a range established trauma systems in Western countries, and the findings should be largely generalisable to other similar health services in the developed world, including the English NHS. However, it is important to note that the quality assessment overview highlights the limitations of the current literature. As such, further high-quality prospective observational cohort studies are needed. Some of the primary studies included highly selected populations (e.g. high-risk road traffic accident patients or head injured patients) that may limit the ability to apply the findings to undifferentiated populations. Triage performance between countries could also vary due to geographical distance, compliance to protocols, and EMS training. External validity to triage by prehospital physicians or HEMS is less certain.

Strengths and limitations

This systematic review has a number of strengths. It is the first study to evaluate the performance of major trauma triage tools in the elderly, and it was conducted with robust methodology in accordance with established guidelines for undertaking diagnostic accuracy systematic reviews.[77,78] However, there are a number of potential weaknesses. A single experienced reviewer screened titles for inclusion, rather than conventional double screening. Hand-searching (i.e. manual page-by-page examination of the entire contents) of journals or conference proceedings were not performed, and regional bibliographic databases were not included, although the yield of such searches is generally low. Inadequate reporting of non-randomised studies and poor indexing in databases may have impaired the detection of all published information. Decisions on study relevance, information gathering and validity were un-blinded and could potentially have been influenced by pre-formed opinions. However, masking is resource intensive with uncertain benefits.

Conclusions

Studies of prehospital triage tools in the elderly are at high risk of bias and report heterogeneous estimates for sensitivity and specificity. Future work to improve prehospital trauma triage in elders could focus on: a more relevant reference standard reflecting the need for MTC care rather than injury severity; establishing the best trade-off between under- and over-triage; optimising the role prehospital clinician judgement; and ensuring efficient processes for secondary transfer of any initially under-triaged patients.

Chapter 4 An economic evaluation of prehospital triage strategies for patients with suspected major trauma in England

Introduction

Sensitivity and specificity of triage tools for the correct diagnosis of major trauma are dependent on which variables are included and the variable cut-off levels chosen for continuous or ordinal variables. Any triage tool will trade-off the number of true positive cases correctly transported to MTCs (sensitivity), with the number of true negative cases correctly conveyed to local hospitals (specificity). However, it is uncertain where the optimal balance of sensitivity and specificity lies, as the use of MTCs is associated with improved outcomes for severely injured patients, but also costs more.[26] Low-specificity triage could also overwhelm the capacity of MTCs with detrimental effects on other patients.

The aim of this study was to conduct a cost–utility analysis of several plausible major trauma triage tools from the perspective of an English decision-maker. Specific objectives were to characterise the costs and consequences of different triage strategies; to identify the optimal trade-off between achievable sensitivities and specificities; and model flows of patients within a trauma network, as this will influence which tools are feasible. The results from this modelling would be used to inform the target sensitivity/specificity trade-off the new, expert-derived, MATTS candidate triage tool.

Methods

Modelling approach

A lifetime patient-level decision tree, followed by a discrete event simulation, was developed to model patient flows through an English MTC system. The model estimated patient's outcomes, costs incurred and QALYs accrued for patients with suspected severe injuries. Conceptual modelling, informed by a previously published model by Newgard *et al.* and consultation with subject experts, informed the final model design.[44] A patient-level approach was undertaken for two reasons. Firstly, it is possible to accurately predict the risk of death using a validated 30-day probability of survival equation, developed by the TARN, in an English population.[112] Secondly, when actual tools are assessed in English populations, the model could easily be adapted to include any correlations that exist between triage tool outcomes and the patient's probability of survival predicted by the TARN survival equation. The economic evaluation was conducted according to the NICE Guide to the methods of technology appraisal and reported in accordance with recommendations from the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) 2022.[113,114]

Patient population

The model considered patients who were injured outside of the MTC's local catchment area for two reasons. Firstly, patients who live closest to a MTC will usually go to the MTC regardless of the severity of their injury. However, if a patient is thought to be severely injured, the MTC will be pre-alerted. Secondly, the available effectiveness evidence appears to treat all patients who live closest to a MTC as having been treated at a MTC regardless of pre-alert status. Consequently, there is no trade-off between cost and effectiveness that could be assessed in our analyses.

The model was populated with simulated patients' representative of injured patients presenting to an English trauma system. To generate these characteristics, baseline demographic and clinical data were used from a recent prehospital MATTS by van Rein *et al.*, using the data collected in the Central Netherlands region.[115] This provided a high-quality data set, which should be representative of developed world patients. These data are summarised in *Appendix 2*, *Table 28*. Means, standard deviations and covariances between all parameters were obtained from the van Rein *et al.* data for patients with complete data for age, gender, ISS, GCS and trauma type. Simulated patients were sampled using correlated draws from these distributions.

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Interventions

Nine triage tools were examined, based on Newgard *et al.* in which triage tools were derived by statistically analysing a retrospective cohort study conducted at six sites in the Western USA between January 2006 and December 2008.[91] This study was selected as it fitted nine triage tools to one data set, so represented feasible trade-offs between sensitivity and specificity for any new triage tool. These analyses produced nine triage tools, for which the reported sensitivities and specificities were:

- sensitivity 99.8%, specificity 2.5%
- sensitivity 94.8%, specificity 18.7%
- sensitivity 90.4%, specificity 58.4%
- sensitivity 87.5%, specificity 62.8%
- sensitivity 74.6%, specificity 65.7%
- sensitivity 69.8%, specificity 70.1%
- sensitivity 64.2%, specificity 76.1%
- sensitivity 57.0%, specificity 80.0%
- sensitivity 28.4%, specificity 88.6%

It was assumed that the sensitivity and specificity values for each triage tool represented the final triage decision, combining the diagnostic accuracy of the triage tool and the application of judgement by the on-scene ambulance service clinicians. A recent analysis of a Dutch triage tool in an English data set produced a receiver operator characteristic curve that would result in similar triage tool sensitivity and specificity as observed by Newgard *et al.*[116]

Perspective

In line with guidance from NICE, the English and Welsh decision-maker, a cost–utility analysis was undertaken; analyses had a lifetime horizon; an NHS and personal social services perspective was taken; and future costs and QALYs were discounted at 3.5%.[113]

Outcome measures

The primary outcome measure of the model was the ICER. Key secondary outcomes of the model included: life expectancy; discounted costs; discounted QALYs; the number of patients who died prior to discharge; the number of patients who died between discharge and 1 year post injury; and the number of patients sent to a MTC.

The ICERs between the strategies were calculated as difference in cost/difference in QALYs. As the decision problem comprised multiple strategies, a full incremental analysis was undertaken in line with the NICE methods guide.[113] In this approach, strategies are ordered by their effectiveness (measured in QALYs). Any tools that were dominated (they produce less QALYs at a higher cost than another tool) or extendedly dominated (a combination of two other tools can produce the same QALYs at a lower cost) were removed from consideration. ICERs were then calculated comparing each remaining tool, except the least effective tool, to the next least effective remaining tool.

The maximum acceptable ICER (MAICER) is the amount of money that a decision-maker is willing to pay to gain one additional QALY. NICE's MAICER is usually considered to be £20,000 per QALY, but may increase to £30,000, as detailed in the NICE methods guide.[113] In a full incremental analysis, the most effective tool with an ICER below the decision-maker's MAICER is the cost-effective tool.

Model structure and logic

The decision-analytic model was developed over five face-to-face meetings, including health economists, major trauma triage clinical experts and modellers. Disease logic and service pathway conceptual models were initially used to ensure that all events and outcomes relevant to the decision problem were considered. A design-orientated conceptual model then build on these theoretical views of disease and treatment pathways to develop a prototype mathematical model design, which was developed through expert consensus. A diagram of the final model is presented in *Figure 6*. Patients enter the model and the sensitivity and specificity of the triage tool determine whether they go to the MTC or local hospital. For patients who go to a local hospital, there is a probability that they will undergo secondary transfer to the MTC. For patients who the triage tool indicates transport directly to the MTC, there is a chance that they will initially go

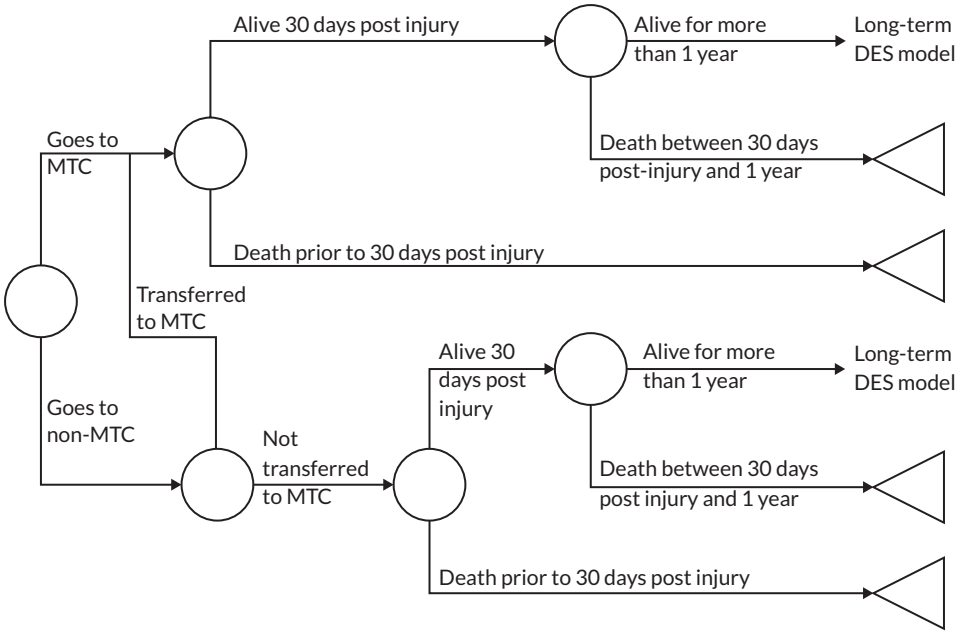


FIGURE 6 The economic model structure. DES, discrete event simulation.

to a local hospital for stabilisation in the event of unmanageable airway, breathing or circulation, after which they will undergo a secondary transfer to the MTC. Any patient who goes to the MTC gains the full benefit from MTC care, but all patients who undergo a secondary transfer will incur costs for an additional ambulance callout. Post admission, each patient's probability of survival within 30 days is estimated. Patients with an ISS of 16 or more and who did not go to a MTC have a relative risk of death applied to their 30-day survival probability to reflect the poorer outcomes expected for these patients. Patients who survive up until 30 days post injury have their probability of survival up to 1 year post-injury estimated. Again, a relative risk of death was applied to increase the probability of death for patients with an ISS of 16 or more who did not receive MTC care. Patients who survive up to 1 year post injury enter a long-term discrete event simulation in which their life expectancy is estimated using general population mortality data, increased by a hazard ratio dependent on their ISS, to estimate their expected remaining life expectancy. The model was developed in R v4.0.2 (R Core Team 2023, The R Foundation for Statistical Computing, Vienna, Austria). Model validation was performed by comparing model outputs with published estimates from the major trauma literature, including the mortality rates and costs predicted from the short-term model and longer-term discrete event simulation.

Probability of events and effectiveness of major trauma centres

The same evidence as the previously published Newgard *et al.* economic model was used to provide the effectiveness of MTCs on patient outcomes, as presented in *Appendix 2*, *Table 29*.[44] These studies are analyses of large cohort studies in a North American setting.[118,119,122] The data on the probability of death were updated to include UK data, where this was known to exist. The 2006 TARN survival prediction model was selected for use in the base-case economic model, as the patient cohort did not have information on comorbidities which is required in the 2015 TARN survival equation.[117,131]

Utilities

The utilities are from Ahmed *et al.*, which is a survey in which 154 patients whose ISS was 9 or more completed the EuroQol-5 Dimensions, five-level version (EQ-5D-5L) questionnaire at an English MTC 1 year post injury.[123] There was no evidence in this study that utility varied by ISS score. For patients with an ISS of 9 or more, utilities were applied multiplicatively to age–gender-matched utilities for the UK general population.[124] For patients with an ISS of < 9 it was assumed that their injury did not have long-term effects on their utility. The utility parameters used in the model are detailed in *Appendix 2*, *Table 29*.

Costs

The costs in the model reflect English practice and were recorded in 2017–8 prices. Costs from previous years were inflated to 2017–8 prices using the Hospital and Community Health Services Pay and Prices inflation index.[132] Other

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costs incurred within the first 6 months post injury were obtained from UK-based studies and sources.[125–127] (John Nicholl, personal communication) After 6 months, the data reported in Delgado *et al.* were adopted, which was a cost-effectiveness analysis of helicopter versus ground transport in the USA.[129] These parameters, based on data from one Canadian study, are an increase in costs for patients with a history of trauma compared to the general population.[128] English healthcare costs incurred by the general population were used, according to their age and gender, and the data from Delgado *et al.* to calculate the increased long-term healthcare costs incurred by each patient in the model.[129,130] Details of all costs are provided in *Appendix 2*, *Table 29*.

Scenario analyses

A base-case deterministic analysis was performed, where all parameters were set to mean values. To account for the uncertainty in model inputs, a probabilistic sensitivity analysis (PSA) was conducted using Monte Carlo simulation to randomly sample from a distribution assigned to each model parameter.[133] Multiple model runs were performed, each with independent random draws from every parameter's distribution. ICERs were calculated from the mean expected costs and effects over all model runs. The stability of our model results was assessed with respect to the number of patients (assessed visually) and number of PSA runs (assessed using the Hatswell *et al.* method).[134] A total of 25,000 simulated patients and 2000 PSA runs produced stable results.

Three scenario analyses were performed to explore the robustness of model assumptions. In the first scenario analysis, the 2015 TARN survival equation was used and assumed that the simulated patients were in the same risk category as people with missing Charlson Comorbidity Index (CCI).[131] In the second scenario analysis, the benefit of MTC care to patients with an ISS between 9 and 15 inclusive was explored, as these patients incur costs for going to a MTC in England, implying there may be a belief by payers that these patients would benefit from MTC care. In the final set of scenario analyses, the cost of MTC care was varied, as the cost of MTC care in England is reviewed regularly.

Results

Base-case analysis

The results of the deterministic base-case analysis are given in *Table 5*. All ICERs were in excess of £30,000 per QALY gained, consequently they are above the upper limit of the ICER that NICE would consider acceptable, meaning that the cost-effective strategy is the least sensitive, and most specific, triage tool. The PSA results are given in *Table 5*. The PSA results are very different to the deterministic results in terms of the ICERs and the tools which are dominated or extendedly dominated. Consequently, all conclusions and scenario analyses are based on the PSA results, as the difference between the deterministic and PSA results for the base case indicates that conducting deterministic analysis introduces bias into the estimated ICER due to model non-linearity.

In the PSA results, a low-sensitivity and high-specificity tool results in the least number of cases going to a MTC, the lowest cost, and the worst outcomes (probability of death, life expectancy and QALYs). Conversely, a highly sensitive and low-specificity tool results in the most cases going to a MTC, the highest cost and the best outcomes. Low sensitivity (28.4%) high specificity (88.6%) would be cost-effective at MAICERS below £25,039. Three other strategies have ICERs above £20,000 per QALY gained, but below £30,000 per QALY gained (sensitivities and specificities of: 57%/80.0%, 64.2%/76.1%, 87.5%/62.8%). The two remaining strategies, that were not dominated or extendedly dominated, had ICERs that were above the usual upper limit of NICE's MAICER of £30,000 per QALY gained.

The model results indicate that out of a population of 100,000 patients to whom a major trauma triage tool was applied, 18,448 out of the 100,000 assessed patients would go to a MTC using the most specific tool, whereas 97,860 of the 100,000 assessed patients would go to the MTC using the most sensitive tool. Even when using a very specific triage tool, the majority patients with an ISS ≥ 16 would ultimately go to a MTC due to transfers from the local hospitals.

Scenario analyses

When the TARN 2015 survival equation is used and all patients in the simulation are treated as having a missing CCI, the results are remarkably similar to the base-case analysis, as the strategies which are cost-effective at £20,000 and £30,000 per QALY gained are the same. In the scenario analyses in which patients with an ISS between 9 and

TABLE 5 The results of the base-case analyses

Triage tool	Number of cases sent to the MTC per 100,000 patients	Number of cases sent to the MTC per 8916 patients (ISS ≥ 16)	Number of cases sent to the MTC per 91,084 patients (ISS < 16)	Proportion of patients who died before discharge	Proportion of patients who die between discharge and 1 year post injury	Mean years lived	Mean discounted QALYs	Mean discounted costs	ICER
Deterministic									
28.4% Sens, 88.6% Spec	18,912	4600	14,312	4.17%	1.80%	32.07	13.620	£32,574	–
57.0% Sens, 80.0% Spec	28,120	6220	21,900	4.14%	1.78%	32.08	13.624	£32,698	ED
64.2% Sens, 76.1% Spec	31,892	6724	25,168	4.12%	1.78%	32.08	13.625	£32,743	ED
69.8% Sens, 70.1% Spec	37,536	7092	30,444	4.11%	1.77%	32.08	13.626	£32,774	ED
74.6% Sens, 65.7% Spec	41,672	7392	34,280	4.10%	1.78%	32.08	13.626	£32,793	ED
87.5% Sens, 62.8% Spec	44,976	8156	36,820	4.09%	1.76%	32.09	13.629	£32,854	£33,026
90.4% Sens, 58.4% Spec	49,100	8364	40,736	4.08%	1.75%	32.09	13.630	£32,889	£39,584
94.8% Sens, 18.7% Spec	83,116	8612	74,504	4.08%	1.75%	32.09	13.630	£32,979	ED
99.8% Sens, 2.5% Spec	97,860	8912	88,948	4.06%	1.74%	32.10	13.633	£33,064	£54,515
Probabilistic (all values are mean values)									
28.4% Sens, 88.6% Spec	18,448	4607	13,841	4.78%	1.78%	32.05	13.580	£33,024	–
57.0% Sens, 80.0% Spec	27,670	6331	21,339	4.72%	1.76%	32.07	13.586	£33,181	£25,039
64.2% Sens, 76.1% Spec	31,505	6763	24,741	4.70%	1.75%	32.07	13.588	£33,223	£27,311
69.8% Sens, 70.1% Spec	37,069	7100	29,969	4.69%	1.75%	32.07	13.589	£33,262	ED
74.6% Sens, 65.7% Spec	41,192	7388	33,804	4.68%	1.74%	32.08	13.590	£33,294	ED
87.5% Sens, 62.8% Spec	44,499	8165	36,334	4.65%	1.73%	32.08	13.593	£33,363	£27,624
90.4% Sens, 58.4% Spec	48,516	8339	40,177	4.65%	1.73%	32.08	13.594	£33,386	£35,791
94.8% Sens, 18.7% Spec	83,383	8603	74,779	4.64%	1.72%	32.09	13.594	£33,486	ED
99.8% Sens, 2.5% Spec	97,810	8904	88,906	4.62%	1.72%	32.09	13.596	£33,542	£77,477

ED, extendedly dominated; Sens, sensitivity; Spec, specificity.

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15 inclusive receive a benefit from MTC care, the conclusions of the base case are changed. If the benefit that these patients receive is 25% or 50% of the benefit accrued from MTC care by patients with an ISS of 16 or more, then the most cost-effective tool at a MAICER of £20,000 per QALY gained remains the most specific triage tool; however, at a MAICER of £30,000 per QALY gained the most sensitive triage tool is cost-effective. However, when these patients receive 50% of the benefit of MTC care, the ICER for the most sensitive strategy is only £20,306 per QALY gained. This indicates that only a very small margin over the lower end of NICE's usual range of MAICERs would be required to consider the most sensitive rule to be cost-effective in this scenario. In the scenario where these patients receive 75% of the benefit of MTC care that is accrued by patients with an ISS over 16, the most sensitive triage tool would be cost-effective at MAICERs of both £20,000 and £30,000 per QALY gained. Changing the cost of MTC care in England did not significantly affect results. At a MAICER of £20,000, the optimal tool is again the highly specific tool, unless MTC costs are considerably reduced. At MAICERs of £30,000 per QALY gained, either the tool with a sensitivity of 88% or a sensitivity of 90% is cost-effective. The results of the scenario analyses are detailed in *Appendix 2*, *Tables 30–31*.

Discussion

Summary of findings

Overall, high-specificity triage tools were favoured in the base case and most scenario analyses. If the MAICER in the UK for this problem is £20,000 per QALY gained, then the base case indicates that the most cost-effective triage tool will be a low-sensitivity (28%), but highly specific tool (89%). However, as the MAICER for this problem rises to £30,000 per QALY gained, the most cost-effective triage tool would have increasingly greater sensitivity (57% to 88%) with correspondingly reducing specificity (80% to 63%). The sensitivity of all these tools is lower than the ACS-COT recommended sensitivity of 95%.[28] The key uncertainties in the ICERs relate to the benefit that MTCs offer to patients with an ISS of between 9 and 15. If this subgroup of patients gains a substantial benefit from MTC care, then the cost-effective tool may be a highly sensitive tool. Furthermore, the results are sensitive to the current cost of MTC care in England, which is determined by best practice tariffs payments made to hospitals.

Interpretation of results

Due to the fixed NHS budget, introduction of a more expensive major trauma triage strategy would require disinvestment elsewhere. Cost-effectiveness grounds are a major deciding factor in whether NICE accepts or rejects healthcare technologies currently using a threshold in the range of £20,000 to £30,000 per QALY. However, NICE have stated that *'in general, interventions with an ICER of less than £20,000 per QALY gained are considered to be cost effective'*.[135] A review of the NICE Diagnostics Assessment Programme has confirmed that the large majority of technology adoption decisions were consistent with a £20 000/QALY ICER threshold.[136] Moreover, an empirical estimate of the true cost-effectiveness threshold used by NICE suggested that there was an 89% probability that the threshold is < £20,000 per QALY, with a best estimate of £12,936 per QALY.[137] From this viewpoint a highly specific, lower sensitivity, triage strategy appears to be optimal, a finding that was robust in most scenarios.

However, when deciding upon the exact MAICER between £20,000 and £30,000/QALY used for a decision problem in England, NICE committees consider: how certain the ICERs are; whether health-related quality of life has been adequately captured in utilities; and whether they believe the technology is innovative.[135] As the MAICERs increase from £20,000 to £30,000 per QALY gained, the committee make explicit references to these criteria in their judgement as to whether a new technology is cost-effective. Therefore, if a more sensitive tool was to be judged cost-effective in the base-case analysis, it would have to meet one or more of these additional criteria by a NICE guidelines committee on major trauma. Although there was some uncertainty in the results in across scenario analyses, it is not obvious that any other decision-modifying factors are present. The EQ-5D-5L survey used to calculate utility values is acknowledged as a useful measure for health-related quality of life of injured adults and triage tools do not appear to represent a cutting-edge technology that adds benefits beyond the measured health gains.[138]

Major trauma triage represents a relative trade-off between true positives (benefits) and false positives (costs). The choice of variables included in different triage tools or major trauma prediction model will determine a ROC

curve, comparing the true-positive rate against the false-positive rate across different variable cut points. The cost-effectiveness of a given triage tool will be determined by maximising specificity for any given sensitivity (thus increasing the area under the ROC curve) and choosing a point along the ROC curve that best balances the costs and outcomes of under- and over-triage. The nine triage tools evaluated in the current study appear to provide a plausible range of under- and over-triage trade-offs, consistent with those observed across a range of studies. However, as spectrum effects in sensitivity and specificity will be evident depending on the underlying prevalence of major trauma, it is possible that the cost-effectiveness results could be different if the ROC curve for best achievable triage tool or prediction model differs.[47] However, it seems unlikely that the findings favouring relatively higher specificity would qualitatively alter.

Comparison to previous literature

Despite large-scale investment in major trauma networks, the cost-effectiveness of major trauma triage is not well studied. A single, well-conducted, economic evaluation by Newgard *et al.*[44] was identified that examined the cost-effectiveness of adult major trauma triage in a US setting. They examined three competing triage strategies with sensitivities of 98.6%, 87.2%, 71.2%, and corresponding specificities of 17.1%, 64.0%, 66.5%. Implementing the highest sensitivity tool was shown not to be cost-effective (ICER $1,317,333 per QALY), with higher specificity triage being most cost-effective at an ICER threshold of less than $88,000 per QALY gained. A further robust cost-effectiveness evaluation was conducted by Maughan *et al.*[45] examining elderly patients in a US setting. High-sensitivity trauma field triage (sensitivity 91.2%, specificity 16.5%) for older adults was shown to have an extraordinarily high ICER of $1,236,295 per QALY, compared to a high-specificity strategy (sensitivity 40.2%, specificity 91.2%) representing current US practice. These results are very similar to the current findings, showing that developing high-sensitivity tools for major trauma is unlikely to be a cost-effective use of resources in either the UK or the USA, based on our current understanding of major trauma systems. As observed by Newgard *et al.* '*the optimal triage strategy for cost effectiveness appears closely tied to specificity and over-triage*'.[46]

Strength and limitations

This study is the first model of adult major trauma set in the UK, follows recommendations for health economic evaluations, and brings together the best available evidence to inform decision-making on MTCs in the England. The TARN prediction model was derived and validated in English patients, population lifetables for the UK were used for long-term survival, costs were supplied by NHS reference values, and secondary transfer rates were informed by UK data. However, it was not possible to parameterise the model entirely with UK data. The simulated population was based on a Dutch cohort of injured patients. The Netherlands has comparable patient demographics, trauma system configuration and culture to the UK. Although open to debate, cases are likely to be broadly comparable to injured English patients presenting to ambulance services. MTC effectiveness estimates were based on evidence from the USA, but these estimates are consistent with English case-mix adjusted odds of death reported in an evaluation of trauma network implementation.[2] Overall, findings could be confidently applied to trauma networks in Great Britain and Northern Ireland.

However, there are several other limitations in the underlying evidence base that must be taken into account when considering the results and when designing future research projects designed to make well-informed decisions regarding major trauma care in an English or UK wide context. Firstly, all the clinical evidence underpinning the model related to a definition of major trauma based solely on patient's ISS. However, as previously discussed, ISS may not be the gold standard definition of major trauma with other criteria for patients who benefit from major trauma existing.[3,4,139] Secondly, it is thought that patients who go directly to MTCs have better outcomes than patients who receive secondary transfers to the MTC; however, quantitative evidence on this effect is lacking, meaning that this cannot be accurately quantified in our analyses. Thirdly, the data on the healthcare costs incurred by major trauma patients in the UK are old, as they use TARN data from 2000 to 2005. Therefore, an update of this evidence would be a useful addition to this model. There is a partial update to this evidence, which uses TARN data from 2009 to 2011.[140] However, the population of this study was limited to patients with major trauma who also had severe bleeding. Fourthly, we did not examine compliance, with no separate examination of theoretical triage performance based on the objective triage tool results, and real-life triage performance based on ultimate clinical decisions. Finally, due to an absence of available data, it was not possible to include children in the model.

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Conclusions

In conclusion, cost-effective prehospital trauma triage involves high specificity and lower sensitivity, unless it can be proved that patients with an ISS between 9 and 15 receive a significant benefit from MTC care. Cost-effective trauma triage will unavoidably result in a proportion of severely injured patients being transported to local hospitals. These findings are important in setting a target sensitivity and specificity when developing new major trauma triage tools.

Chapter 5 'A heavy mix of ambiguity and pointless specificity?': a qualitative analysis of clinician views on major trauma triage

Introduction

Existing evidence suggests that the accuracy of triage tools in identifying major trauma cases is suboptimal.[55] There is often an underlying assumption in quantitative analyses of triage tool diagnostic accuracy that these will be applied as intended in the field. However, there is evidence that the decision-making process is more complex than simple application of binary criteria. Cognitive reasoning may be more heuristic than algorithmic, with individual clinical judgement used more than specific triage criteria. Speed, triage tool usability, and emergency care system-level factors may also influence triage decisions.[52,141]

Given the possible complexity of on-scene decision-making, and emerging evidence about the implications of human factors on triage decision, this study aimed to elicit the experiences and views of clinicians who use, or interact with, major trauma triage tools in their practice. These may provide important insights into why tools do not always work as intended and how they might be optimised, informing development of a new candidate national triage tool. Specific objectives were to describe important themes that influence major trauma triage, establish which aspects of triage tools are preforming effectively, determine how triage tools are used in the field, and identify any areas for triage tool improvement.

Methods

A qualitative approach comprising a survey and focus groups was undertaken to explore clinician views on UK prehospital major trauma triage tools. Study procedures followed best practice recommendations for conduct and reporting of qualitative research.[70]

Firstly, a questionnaire was developed to examine opinions on current UK prehospital major trauma triage tools. The questionnaire was paper-based, pre-piloted, contained background information and consisted of six questions focused on: identification of patient subgroups that benefit or do not benefit from MTC care; triage criteria that contribute to over- and under-triage; potential changes to current physiological triage criteria; and any other issues considered important to the development of a new triage tool. Text-only answers were collected, with more than one answer possible per respondent. Basic demographic data about role, specialty and work setting (e.g. ambulance, MTC, TU) were also collected. No names or identifiable staff details were recorded. Completion of the survey was taken as implied consent.

The survey was administered at the UK National Trauma Networks Meeting, 2018, Birmingham, following a brief introductory presentation to delegates. This conference is intended for stakeholders involved in regional trauma networks including prehospital, MTC and TU clinicians, managers and commissioners. Survey responses were collated using Excel, with the overall number of responses forming the denominator for each question. Data were then coded by a single researcher with independent checking by a second investigator. Answers which clearly and directly related to other survey questions were re-coded according to the that question's response categories. Common themes were identified and summarised using tabulation, descriptive statistics and graphical visualisation using stacked bar charts. Sample size was determined by available respondents but aimed for > 50 respondents in line with previous recommendations to achieve data saturation.[142]

Secondly, focus groups were held to explore experiences and thoughts on current triage tools, and major trauma triage processes more generally. Purposive sampling was performed to include ambulance service clinicians, prehospital

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physicians, and hospital nursing and medical staff, aiming to obtain a comprehensive system-wide view encompassing prehospital, MTC and non-MTC perspectives. Five separate face-to-face focus groups were undertaken between March 2019 and May 2019 in the following settings: Trauma Care Conference 2019, 999 EMS conference 2019, South Yorkshire Trauma network, Barnsley TU, West Midlands Ambulance Service University NHS Foundation Trust (WMAS). A further focus group with the Paediatric Emergency Research in the United Kingdom and Ireland network was conducted online in August 2020 due to coronavirus disease discovered in 2019 (COVID-19) restrictions. Participants were provided with a participant information sheet and provided written consent prior to commencement. Each focus group was conducted using a topic guide that initially focused on eliciting views on the trauma triage tool(s) in use and then broadened to include wider issues that may need to be considered in the design of a new tool. Focus groups lasted about 1 hour, were facilitated by one or two members of the research team, and were recorded using encrypted digital recorders supplemented by handwritten notes. Facilitators were senior researchers, trained in qualitative methods, with extensive experience of qualitative studies. Recordings were then transcribed by an independent researcher. Empirical research has demonstrated that > 4 focus groups will usually achieve thematic saturation ('heard it all').[142]

A framework analysis approach was then undertaken by two researchers.[143] This comprised examination of focus group transcripts, followed by independent identification and tabulation of key patterns using the topic guide categories. Emerging patterns were cross-checked with each other, the notes from each focus group, and triangulated with the survey findings to identify common features. Themes and related subthemes were then identified, synthesised and developed into a conceptual diagram to inform further interpretation. Representative statements made by participants were used to illustrate each theme. Lastly, a theoretical schematic model was created based on the sample's responses to delineate the processes used by ambulance service clinicians during prehospital major trauma triage.

Results

A total of 81 questionnaires (from 274 registered attendees, 30%) were completed at the 2018 National Trauma Networks Meeting. Non-response for one or more questions was present in 23/81 surveys (28%). As summarised in *Table 6*, a diverse range of professional groups and clinical settings relevant to major trauma triage responded, with MTC consultants in emergency medicine representing the largest group.

Responses to each survey question are summarised in *Figure 7*, with illustrative examples of text responses for each question detailed in *Appendix 3*, *Table 32*. Mechanism of injury and older age were the most identified contributors to

TABLE 6 Characteristics of survey respondents

Role/level	*N* (%)	Location	*N* (%)	Specialty/service	*N* (%)
Consultant paramedic	1 (1.2)	Air ambulance	1 (1.2)	Plastics	1 (1.2)
Physiotherapist	2 (2.4)	General hospital	1 (1.2)	Paediatrics	1 (1.2)
Advanced paramedic	5 (6.2)	Major trauma network	3 (3.7)	Anaesthesia	3 (3.7)
Consultant nurse	5 (6.2)	Ambulance	14 (17.3)	Orthopaedics	3 (3.7)
Manager	7 (8.6)	MTC	34 (42.0)	Major trauma	9 (11.1)
Paramedic	7 (8.6)	TU	21 (26.0)	Ambulance	14 (17.3)
ED – other[a]	9 (11.1)			Emergency medicine	34 (42.0)
Nurse	10 (12.3)				
Consultant doctor	35 (43.2)	Missing	10 (12.3)	Missing	16 (19.8)
Total	**81**	**Total**	**84**[b]	**Total**	**81**

a Other included major trauma fellow, sister, admin, allied health professional , advanced practitioner.
b Some respondents indicated more than one location.

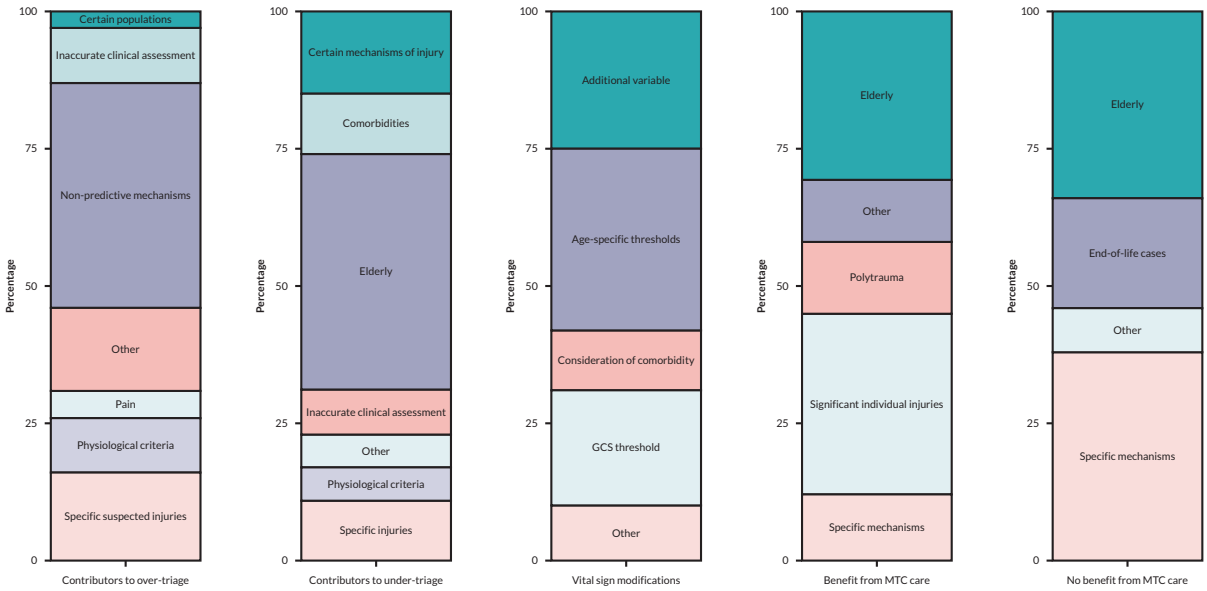


FIGURE 7 Stacked bar charts summarising responses to National Major Trauma Network Meeting survey.

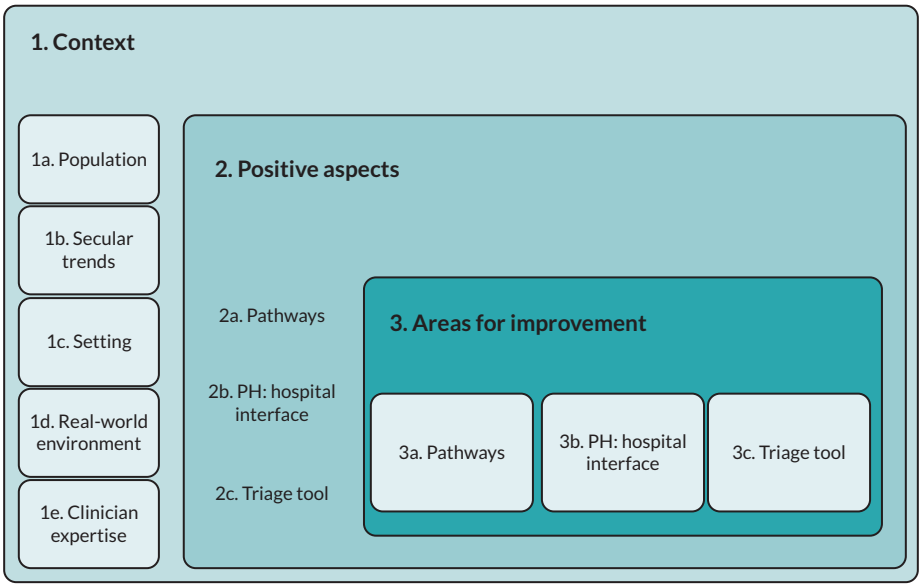


FIGURE 8 Conceptual diagram of system or higher-level major trauma triage themes and subthemes emerging from focus group data. PH, prehospital.

over- (32/79, 41%) and under-triage (36/87, 43%), respectively. Most respondents indicated no changes were required to physiological triage criteria (26/81, 32%), although a significant minority indicated that age-specific thresholds (20/81, 25%) or additional vital signs (20/81, 25%) should be used. Significant individual injuries requiring specialist management (27/84, 32%), elderly (25/84, 30%) and multisystem polytrauma (11/84, 13%) were identified as having the most potential to benefit from MTC care. Hypoxic injuries (23/60, 38%), elderly (20/60, 34%) and palliative patients (12/60, 20%) were the commonest subgroups thought not to benefit from MTC care. There was divergent opinion on whether elderly patients per se require MTC care, with text responses indicating a more nuanced position of certain, non-frail, cases possibly benefiting. General comments covered wider systemic issues including the influence on triage of distance to MTCs, MTC–TU–ambulance service co-ordination, staffing and training. Responses did not appear to differ across different stakeholder groups.

The 6 focus groups comprised a total of 62 participants (range 5–19 participants per focus group) and lasted between 58 and 108 minutes. A conceptual diagram of identified themes and subthemes is presented in *Figure 8*. Focus group

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participants felt that the setting and circumstances in which major trauma networks operated were of paramount importance (Theme 1 'context'); with strong influences arising from trends in injury epidemiology, local trauma network geography and organisation, real-world human factors, available resources and staff expertise (Subthemes i–v: Population, secular trends, setting, human factors, expertise). They agreed that current major trauma triage was performing well overall (Theme 2 'positive aspects') including network pathways, the prehospital–hospital interface, and current triage tools (subthemes a and c: pathways, prehospital: hospital interface, triage tools), leaving a smaller area for further optimisation (Theme 3 'areas for improvement'). Theme and subtheme hierarchy and size, as presented schematically in *Figure 8*, are reflective of their strength, relationship and relative importance. Focus groups findings mirrored the survey results, with no clear areas of discordance. Findings within each theme and subtheme are detailed in *Appendix 3*, *Table 33*.

There was concordance on all theme and subthemes except triage tools (subthemes 2c and 3c). Consensus was present that triage tools were generally effective in accurately triaging patients, with a simple, 'stepped' structure valued. There was also agreement on possible areas for improvement, with elderly patients widely recognised as being at risk of under-triage, albeit with the recognition that frailty and patient/family wishes often influenced whether MTC care could be appropriate. Consensus was also evident that supporting information or definitions of triage variables would help reduce ambiguity, some mechanisms of injury traditional perceived as high risk were now less important, and flexibility and the ability to apply clinical judgement would add value to triage decisions. However, discordance was apparent in this subtheme, with conflicting opinions apparent around several aspects of triage tools as detailed in *Appendix 3*, *Table 34*.

Participants described a variable, dynamic, multifaceted, non-linear and multiagency process for major trauma triage, as modelled conceptually in *Figure 9*. Following arrival at the scene of injury, assessment, treatment and consideration of injury severity occur concurrently. Formal application of a triage tool is variable and is more likely for 'grey area' cases. Clinical judgement is often used to interpret imprecisely defined variables, or to over-ride objective triage tool results based on intuition, prior to decision-making on destination and pre-alert. Contextual factors such as distance to MTCs and base ambulance station, local service configuration, and perceived quality of local hospitals could also contribute to the final triage outcome. The choice to seek senior decision support was influenced by service expectations, training, experience, clinical uncertainty and perceived expertise. Experienced clinicians often follow a different process, relying primarily on unstructured clinical judgement, with the triage tool fulfilling a protective role to retrospectively justify triage decisions. Some subjective triage variables, while not necessarily being accurate triage variables, could be dubiously triggered to achieve this purpose, for example 'boggy scalp swelling', 'suspected pelvic binder' (through application of a pelvic binder).

Discussion

Summary

A variable, multifaceted, non-linear and multiagency process for major trauma triage was evident. Stakeholders indicated that triage tools were a central intervention determining the effectiveness of trauma networks and were generally perceived as performing well with the simple, 'stepped' structure valued. Possible areas for improvement were under-triage of elderly patients, reducing ambiguity in variable descriptions, removal of less accurate mechanistic criteria, and increasing the role for clinical judgement. However, there were multiple areas lacking consensus, including when to use tools, accuracy of individual variables, need for separate tools for paediatric and elderly subgroups, paper versus electronic format, and the role of remote decision support. National- and system-level issues were recognised as influential modifying factors, including secular trends in injury epidemiology, local trauma network geography and organisation, real-world human factors, available resources and staff expertise.

Interpretation

Very few, if any, stakeholders will have prehospital experience of triage tool use, a TU and MTC perspective on trauma pre-alerts, and knowledge of true-positive and false-negative case outcomes. Given the unfeasibility of an all-encompassing view, and relatively low prevalence of major trauma, a definitive personal assessment is unlikely. The diversity of opinion on triage tools in general, and the utility of individual triage tool variables and cut points, may

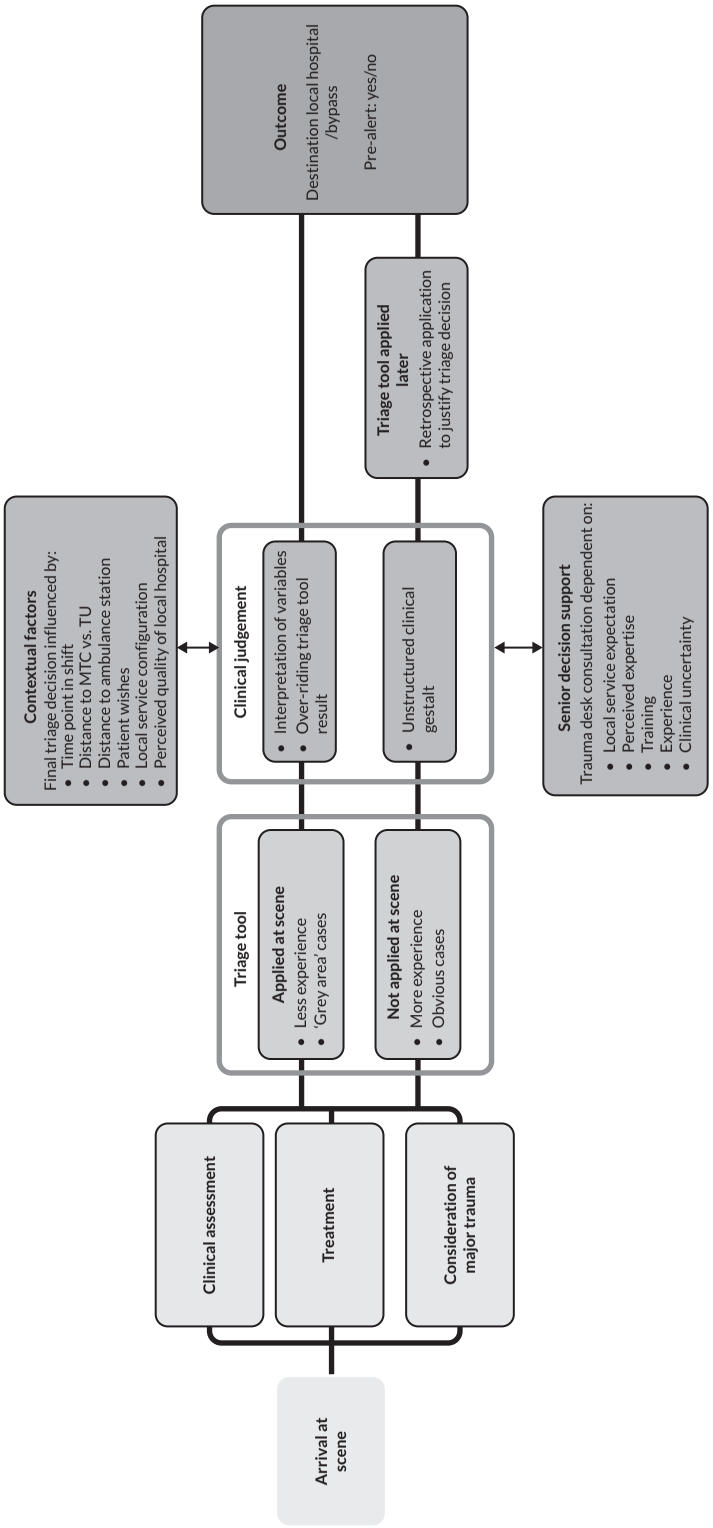


FIGURE 9 Conceptual diagram describing a variable, multifaceted, non-linear and multiagency process for major trauma triage.

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therefore be unsurprising. Triangulation of viewpoints from multiple prehospital and hospital perspectives are likely to be important to fully characterise the triage process, and both qualitative and quantitative data analysis may be necessary for complete evaluation.

The absolute and proportional projected growth in older persons in the UK has important implications for major trauma triage, which has historically focused on high energy or penetrating trauma in younger adults. The prevalence of major trauma in elders presenting after injury is lower, leading to a 'needles in haystacks' scenario where high specificity is required to achieve a satisfactory positive predictive value of triage tools. However, specificity is challenged by polypharmacy, comorbidities and altered physiological response to injury, significantly reducing the signal-to-noise ratio. Even with accurate identification, seriously injured older adults, particularly with frailty, may have fixed outcomes, and receive no benefit from MTC care.[26] This refined position was reflected in participants' responses, with an articulated desire for improved triage of elders, but with a recognition that this is a challenging area.

Clinical judgement, either individually applied or from remote decision support, featured prominently in discussions, and may be an important addition to triage tools. A systematic review by van Rein *et al.* reported that 'compliance' with indicated triage tool result ranged from 21% to 94% and suggested EMS provider judgement could lower the under-triage rate.[56] The MATTS document analysis of UK triage tools reported that remote ambulance service decision support was available for 13/16 identified tools, consisting of either a dedicated 'trauma desk' or critical care paramedic. However, there appears to be variability in how well developed this role is across services, and quantitative evaluations of effectiveness are lacking. Less experienced prehospital participants appeared to welcome the additional support available, contrasting with more experienced ambulance service clinicians who questioned its added value. Taken together, particularly considering the clear importance of contextual factors, remote decision response may have a role in supporting junior clinicians and navigating local trauma network idiosyncrasies.

Comparison to previous literature

There is a paucity of research on qualitative aspects of prehospital major trauma triage. Newgard *et al.*, using EMS records and ethnography, reported that triage decisions were primarily driven by 'gut feeling' with provider experience, injury mechanism and early visual cues playing an important role.[141] Jones *et al.* used focus groups to explore prehospital assessment, application of triage criteria and selection of hospital in EMS providers.[52] They identified four overarching themes that influenced on-scene decision-making: initial assessment; the importance of speed versus accuracy; usability of criteria; and patient and emergency care system-level factors. The findings suggested EMS providers consider speed of decision as important, and they make significant use of easily observable information rather than precise measurement of vital signs and systematic application of triage criteria. More widely, qualitative research examining how clinical decision rules are used in emergency medicine practice has similarly found they are not uniformly used, are heavily influenced by contextual factors, and seldom factor prominently into the final clinical decision. These previous findings largely concord with the conceptual model for triage reported here. However, speed of decision-making was not identified as a significant issue in the current study, less importance was attached to mechanism of injury and a more subtle position of clinical judgement depending on provider training and experience was observed.

Limitations

This study has several strengths, including a sample covering all relevant professional groups (clinicians, managers, commissioners), specialties (prehospital, emergency medicine, inpatient specialties) and settings (ambulance services, TUs, MTCs, trauma networks), recruitment of participants from diverse geographical areas across England, and concordance with qualitative research standards. However, there are important limitations. Although consistent with other research surveys, the response rate for the survey was only 30% with consequent risk of response bias.[144] Available resources restricted the methodological approach to focus groups, but other approaches such as ethnography, observation, case studies, or conversational analysis could potentially provide richer insights. Full demographic information, such as qualifications and year of qualification, was not available for participants, preventing granular evaluation of the effect of experience level or education of decision-making processes. Mixed focus groups offered the possibility of cross-specialty discussions but may have been affected by social desirability bias due to peer-pressure or perceived hierarchy, although this may have been mitigated by meeting moderation by non-clinicians. Finally, although generalisable throughout the NHS, external validity to other settings is uncertain given the observed importance of contextual factors in major trauma triage.

These findings have important implications for major trauma triage. The clear support for a simple 'checklist' with clear variable descriptions argues against development of a 'black box' machine learning algorithm or more complex statistical prediction model. The deprecation of mechanistic criteria and support for flexibility to apply clinical judgement could inform the steps included in any future tool. Elderly patients and individual variables were highlighted as potential sources of under- and over-triage, requiring consideration. The importance of contextual factors highlights that the checklist of triage variables does not operate in isolation and additional instructions and guidance might be required.

Conclusions

Triage tools were recognised as a central intervention for improving outcomes in major trauma, but prehospital decision-making is complex, may be more heuristic than algorithmic, and is potentially influenced by systemic issues, including training and local trauma network organisation. Although perceived as working well, triage could be improved through increased scope for clinical judgement, refinements in senior decision support, and consideration of contextual factors, rather than minor modifications of triage tool variables in isolation.

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Chapter 6 Injured patients who would benefit from expedited major trauma centre care: a consensus-based definition for the English National Health Service

Introduction

Major trauma triage tools are a critical intervention within regional trauma networks to ensure the 'right patient is treated at the right time in the right place'. Therefore, the first step in development of a new triage tool is to define which subgroup of injured patients should be identified for bypass and/or pre-alerting to MTCs. A valid, reproducible and credible reference standard will inform the optimal selection of triage tool variables and facilitate research, allowing evaluation of the accuracy and effectiveness of major trauma triage.

This study therefore aimed to identify a reference standard applicable to UK NHS major trauma networks for defining which patients should receive expedited MTC care. Such a definition would inform the development and validation of major trauma triage tools, help assess the performance of trauma networks and guide resource allocation.

Methods

A 1-day facilitated round-table expert consensus meeting was conducted at the University of Sheffield, UK, on 4 September 2019.[145,146] Seventeen clinicians were purposively sampled to form an expert clinical panel, ensuring that both MTC and non-MTCs, and all specialties relevant to injury and major trauma management, were represented. Participants are detailed in *Appendix 4*, *Table 35*. The meeting was co-chaired by an independent University of Sheffield researcher, and an established major trauma expert. Study procedures, including sample size determination, followed recommended principles for best practice in developing consensus.[146]

Prior to the consensus meeting literature searches were conducted to identify existing major trauma reference standards. The findings were summarised in preparatory materials and initial presentations to participants. The study's aim of developing a 'gold standard' definition for injury that would benefit from expedited MTC care was emphasised, that is defining which patients should be transported from the scene of injury with pre-alerting of the receiving MTC ED, and bypassing of a closer non-MTC if necessary, rather than severe injury per se. The meeting then proceeded in a structured format, covering the scope, perspective, structure and components of the reference standard in repeated rounds of iterative discussions. Discussions were facilitated to ensure all issues were thoughtfully deliberated, incorporated diverse experience and views, and produced the best possible decision.[145,146] Consensus was defined a priori as 'finding a decision together that all members can feel comfortable with'.[146] Consensus was developed through group negotiation mediated by the meeting chairpersons.

Following the consensus meeting, separate focus groups were conducted with the Sheffield Emergency Care Forum and Birmingham Injuries Public and Patient Involvement (PPI) groups.[147] Focus groups began with a short presentation of the proposed reference standard and following a series of familiarisation questions designed to build rapport between the interviewer and interviewees, participants were asked to discuss their perspectives. A single moderator led all interviews, and a second researcher was present to take field notes. Sessions continued until code saturation was reached ('heard it all'). Discussions were audio-recorded and later transcribed verbatim by a professional transcriptionist. Analysis followed the Framework Method, with familiarisation, thematic framework development, indexing, charting and mapping with interpretation.[148]

Public and patient involvement feedback was then circulated remotely to expert panel members via e-mail, with any changes to the reference standard discussed remotely, before agreement was confirmed. Finally, to allow

operationalisation of the reference standard in UK research a coding algorithm was developed with the English national trauma registry, the TARN, facilitating classification of any case submitted to their database.

Results

Iterative rounds of facilitated discussions achieved consensus on four aspects of the reference standard for identifying patients who would benefit from expedited major trauma care: scope, perspective, structure and content.

In terms of scope, expert consensus was achieved that the reference standard should apply to patients presenting to NHS ambulance services, excluding major incidents and those involved in military action where treatment priorities may differ. Isolated burns were excluded due to the existence of separate NHS major burns networks, which may not overlap with major trauma networks. Cases with isolated hypoxic brain injury (e.g. drowning, non-judicial hangings) were judged ineligible as they usually lack concomitant physical injuries.

The reference standard perspective was agreed to characterise patients who would benefit from expedited MTC care, rather than injury severity singularly. There was also unison to develop a theoretical criterion standard initially, with later operationalisation for retrospective application and classification of cases to facilitate future research evaluating triage accuracy. A composite reference standard structure was confirmed comprising four domains of critical interventions, individual anatomical injuries, multiple minor injuries and patient attributes (see *Appendix 4*, *Figure 28*). This was designed to capture all injured patients with the potential to benefit from expedited MTC care, allow operationalisation in trauma registry data, and to minimise the disadvantages of existing single domain reference standards, for example ISS.

Individual criteria were defined by consensus within each domain, as detailed in *Table 7*. The AIS was chosen as the most comprehensive and validated system available to describe anatomical injuries.[149] Each injury in the AIS 2005 (Update 2008) dictionary was examined individually for qualification as a condition benefiting from expedited MTC care in the NHS setting, rather than categorisation using an arbitrary AIS injury severity scoring rule, for example inclusion of all AIS 4+ injuries.[150] Additional qualifiers were added to specific chest (presence of acute respiratory failure) and head (GCS thresholds) injuries to better capture clinical acuity. Qualifying AIS codes are available on request. Finally, circumstances where expedited MTC care could not be beneficial (prolonged out-of-hospital traumatic cardiac arrest and catastrophic injuries) or would not be in a patient's best interests (applicable advanced directive, advanced frailty) were confirmed.

Theoretical reference standard criteria were then operationalised by defining time intervals, identifying specific interventions, specifying clinical parameters and listing qualifying operations. These were then formulated according to data fields available in the TARN database, together with the categorised AIS codes. A TARN coding algorithm was subsequently developed to allow retrospective application in research (available from TARN on request).

Focus groups with the Sheffield Emergency Care Forum and Birmingham Injury PPI groups included 12 and 15 participants, and lasted 63 and 94 minutes, respectively. Three important themes emerged, comprising reference standard structure, futility and patient choice. Participants were universally supportive of the four-domain reference standard structure. There was overwhelming agreement that *'elderly frail patients should* not *be managed "aggressively"'*. However, there were divergent opinions on whether age alone should be used as a criterion to determine whether a patient would benefit from expedited MTC care. Examples representing these conflicting viewpoints included *'the Equity Act of 2012 makes it illegal to discriminate by age, and in any case 65 years old is too low!'* and *'my parents are far too old to be going to [MTC name]'*. In contrast, there was broad support, and no dissenters, that expedited MTC care would not be in the best interests of patients with advanced frailty. Finally, a minority of participants voiced strong opinions about patient choice in determining their desired location of care following injury, specifically referencing travelling distances and perceived quality of care in individual hospitals. Representative comments included

> *'Please remember that many older trauma patients will have carers who are also older and can't travel far'*, *'an MTC probably provides better care for all levels of injury'*, *'for me it depends which hospital they're trying to take me to . . . I would never let them take me to [non-MTC name]'*.

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TABLE 7 United Kingdom consensus definition of injury benefiting from MTC care

Domain	Critical interventions	Individual anatomical injuries	Multiple minor injuries	Patient attributes
Rationale	Injury requiring a time-critical trauma-related intervention only available, or more effectively delivered, in a MTC.	Presence of significant individual anatomical injuries that would benefit from expedited MTC care.	Presence of multiple injuries, non-significant in isolation, but cumulatively resulting in significant injury that would benefit from expedited MTC care.	Exclusion of patients who do not want, or would not benefit from, expedited MTC care.

Criteria	• Resuscitation requiring any of:
	  • Emergency intubation
	  • Ventilation
	  • Blood product transfusion.
	• Indication for an emergency trauma-related surgical procedure (including ICP monitoring)
	• Indication for emergency trauma-related interventional radiology
	• Requirement for multidisciplinary critical care admission
		• Most AIS 4+ injuries, for example spinal injury with neurological deficit, (unless can be satisfactorily managed in a non-MTC)
		• Specific AIS < 4 injuries:
		  • Significant de-gloving injury
		  • Open long bone fractures
		  • Amputations proximal to the fingers/toes.
		  • Pelvic ring fractures (excluding osteoporotic fractures).
		  • Chest injuries with respiratory failure.
		• TBI causing GCS < 9 if clinical frailty score < 6 (residential home-level care).
		• TBI causing GCS 9–13 if clinical frailty score < 6 and focal neurology or pupillary abnormalities.
		• Complex skull fractures: large, depressed areas, open with exposed brain, CSF leak.
			• AIS injuries in 2+ body regions combining to ISS ≥ 16; total ISS ≥ 16 calculated by either:
			• In presence of an AIS 4+ injury excluded from significant isolated injuries, then requires AIS 2+ injury in second body region.
			• If no AIS 4+ injury excluded from significant injuries, then include all AIS codes, except:
			  • Exclude all AIS = 1
			  • Exclude all non-skeletal face AIS codes
			  • Exclude head region AIS codes in patients with clinical frailty score > 4
			  • Exclude all 'external and thermal' and 'other' region codes.
			  • Exclude ingestions and hypoxic brain injuries
				• Applicable advanced directives
				• Clinical frailty score ≥ 7 (nursing home-level care)
				• Un-survivable injuries, for example torso transection, massive brain destruction, decapitation
				• Traumatic cardiac arrest > 15 minutes transport from MTC

CSF, cerebrospinal fluid; ICP, intracranial pressure.

Discussion

Summary

A reference standard to define which injured patients will benefit from expedited MTC care in the UK setting was developed through expert consensus and PPI consultation. Four domains were identified, comprising: need for critical interventions, presence of significant individual anatomical injuries, burden of multiple minor injuries and specific patient attributes. A coding algorithm to allow operationalisation in TARN data for future research was also created.

Interpretation

A fundamental principle in developing and choosing a valid reference standard for injured patients is specifying the required perspective and purpose. The most appropriate reference standard may vary according to the specific circumstance, and it is therefore important to differentiate between foci of measurement of injury severity (often termed major trauma or polytrauma), the potential to benefit from expedited MTC care, and risk of poor outcome. For the development of prehospital triage tools and assessing the performance of trauma networks, it is the need for expedited MTC care that is relevant, rather than the severity of injury or prognosis per se. For example, a patient with a fatal injury such as decapitation manifestly has major trauma but could not benefit from prehospital triage to a MTC.

Traditionally, injured patients have been classified according to an assessment of anatomical injuries using the AIS and ISS, with an ISS threshold ≥ 16 defining major trauma.[151] While the ISS provides an overall estimate of injury severity,

it has a number of potential limitations as a marker for benefit from expedited specialist MTC management.[4,139,152] The total number of contributing injuries to the ISS is limited to three, with equal importance to each body region, and an inability to account for multiple injuries to the same body region. Its calculation is confounded by the extent of radiological investigation performed. ISS has a non-linear relationship with mortality. Many different injury patterns, often with varying acuity and prognosis, can yield the same ISS. Furthermore, the ISS ≥ 16 threshold does not account for heterogeneity in intensity, urgency and complexity of treatments required for different injuries. Certain patients with high ISS, but not requiring urgent resuscitation or specialist interventions, may be satisfactorily managed entirely in a non-MTC, or with a later planned secondary transfer if necessary. Other anatomical reference standards, including the new ISS, have similar limitations.[153]

Consequently, resource-based criteria have been proposed as an alternative to anatomical measures to define major trauma. A number of consensus-based definitions have been formulated focusing on identifying patients who need specialised trauma interventions that are unavailable, or less effectively delivered, in non-MTCs.[4,154] However, purely resource-based definitions of major trauma also have limitations for reflecting benefit from expedited MTC care. Retrospective classification is subject to variability in medical decision-making and hospital expertise and may not reflect the clinical indication for an intervention. For example, it has been demonstrated that splenic injuries, which would usually be managed conservatively in most MTCs, may undergo inappropriate emergency splenectomy if managed in non-MTCs.[155,156] There may also be large inherent resource needs despite mild anatomical injury in those suffering a concomitant acute medical event. Improved outcomes secondary to early MTC management over and above emergency interventions, such as improved resuscitation, supportive care, or investigations, are additionally not accounted for.

Prognostic reference standards can also be used to define severity, using combinations of mechanistic, anatomical, physiological and demographic variables to predict mortality after injury.[5,6] While numerous prediction models have been developed, they have largely demonstrated suboptimal performance.[5,6] Further issues with this approach include justifying an arbitrary cut-off point to represent the need for MTC care, a focus on mortality rather than morbidity, and not accounting for whether MTC care would change outcome. The advantages and disadvantages of existing reference standards for injured patients are detailed in *Appendix 4*, *Table 36*.

The inclusion of UK major trauma experts should ensure this reference standard is valid throughout the NHS. The proposed composite structure aims to maximise the advantages, and minimise the drawbacks, of single domain anatomical, resource-based or prognostic reference standards. There is consequently substantial overlap with the US consensus definition of major trauma and ISS,[151,154] but with the important differences of inclusion of significant individual injuries, finessing of the traditional ISS ≥ 16 threshold, more nuanced chest and TBI criteria, and consideration of clinical frailty scores. Specific individual injuries that could benefit from bypass to MTCs are captured, such as chest injuries with respiratory failure, or open fractures. The TBI criteria will include any patient where emergency neurosurgery or intracranial pressure monitoring is indicated but allows for the fact that head injury has a poor prognosis with advanced age, increasing frailty and multimorbidity.[157]

Limitations

This study has several strengths including a comprehensive sample of MTC and non-MTC experts, PPI input and conformity with consensus study guidelines.[145,146] The consensus approach allowed fuller deliberation of the decision problem compared to other decision-making approaches such as executive decisions or majority rule. Round table methodology is better suited to complex, multi-dimension constructs than other consensus methodology such as Delphi process or nominal group technique, which are designed to answer narrow, single issue, questions.[145,146] However, there are some limitations. The geographical spread of included experts was relatively restricted, and although generalisable to the UK, external validity of the proposed reference standard to other settings is less likely, due to differences in trauma system configuration, health service organisation, patient values and accepted clinical standards of care. Moreover, it is possible that individual views within the expert panel may not be fully consistent with evidence-based practice or could be unrepresentative of general opinion within each clinical specialty. Lastly, while the final reference standard was agreed by the whole expert panel, when highly specialist topics were discussed, the specific clinical expert may have a dominant input.

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Conclusions

Expert consensus criteria are presented to identify injured patients who would benefit from expedited major trauma care. This reference standard could be used as the target for future prehospital injury triage tools, setting best practice tariffs for trauma care reimbursement, and to evaluate trauma network performance. Future research is recommended to compare patient characteristics, management and outcomes between the proposed definition and existing reference standards.

Chapter 7 Major Trauma Triage Tool Study expert consensus-derived injury assessment tool

Introduction

The MATTS project document analysis (see *Chapter 2*) identified 53 English, other UK and international major trauma triage tools, raising the question of why another triage tool is required. However, the use of a different tool in each English ambulance service, and observed wide variation of structure and content, combined with unsatisfactory performance reported in systematic reviews examining diagnostic accuracy suggests there is a need for a standardised major trauma triage tool for the NHS. This would reduce variations in care, help streamline processes at interfaces between different ambulance services and trauma networks, and optimise the trade-off between under- and over-triage to ensure cost-effective management of major trauma in the NHS.

The aim of this study was therefore to develop a candidate national major trauma triage tool for use in English trauma networks through expert consensus. This was intended to build on previous work, rather than develop a radically new triage tool, offering the opportunity to address deficiencies in previous triage tools and directly address the English context. This tool would undergo external validation in the MATTS Phase 2 cohort study, where its diagnostic accuracy would be compared to other existing triage tools. If identified as the optimally performing tool, the candidate MATTS tool would then be implemented and prospectively evaluated in Phase 3 of the MATTS project. Specific objectives were to define the candidate tool's purpose, scope, intended population, structure and constituent variables and thresholds.

Methods

This study involved four consecutive phases, as summarised in *Figure 10*. Firstly, a web-based Delphi survey was conducted to determine candidate variables for the candidate MATTS triage tool. Secondly, a roundtable consensus meeting was conducted to determine the proposed triage tool's purpose, target diagnostic threshold, scope, intended population and structure; and to confirm the individual triage tool variables and cut points. Thirdly, emerging results from the MATTS Phase 2 cohort study, where the diagnostic accuracy of the candidate tool was compared to other existing triage tools, were reviewed by the expert panel to inform triage tool modifications in a further consensus meeting. Fourthly, PPI focus groups were held to ensure triage tool acceptability to service users. Study procedures, including sample size determination, followed recommended principles for best practice in developing consensus.[146]

Delphi survey

The Delphi survey was conducted from January 2016 to January 2017. Purposive sampling was used to recruit a heterogeneous group of experts, representative of clinicians involved across the major trauma clinical pathway, based on their roles as directors or leads of major trauma networks, MTCs, NHS ambulance service trusts or air ambulance services, or their membership of the NHS Major Trauma Clinical Reference Group or Royal College of Emergency Medicine Major Trauma Committee (see *Appendix 5*, *Table 37* for full details).

The open first round of the classical Delphi approach was modified, with a review of existing English triage tools used to identify possible major trauma predictors.[158] All unique adult triage variables (with or without different cut points or descriptions) were grouped into categories, under domains (Physiology, Anatomy, Mechanism and Special Circumstances). For example, 'GCS < 14' and 'GCS motor score 4 or less' were different cut points for the 'GCS' variable, aggregated under the 'level of consciousness' category, within the 'Physiology' domain. Participants were also invited to propose additional novel variables for consideration.

In the second Delphi round, participants were asked whether each domain and category should be included in a national tool, and to rate the appropriateness of each variable. In subsequent rounds, participants revisited domains and categories with moderate agreement and selected the most appropriate variables (including cut point or descriptor)

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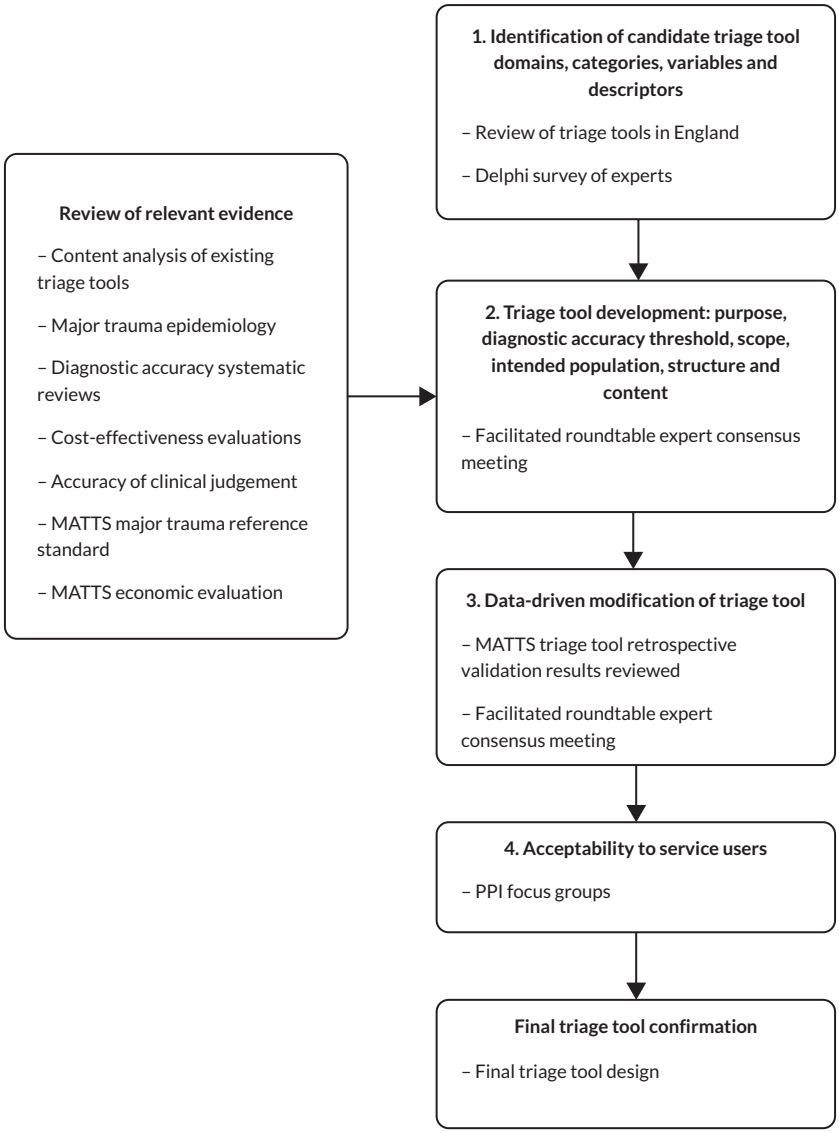


FIGURE 10 Schematic representation of candidate triage tool development.

for each selected category. In each Delphi iteration, participants were provided with the results of the previous round. Consensus for inclusion of each domain and category was defined a priori as ≥ 80%, with exclusion of those with < 50% agreement. The number of Delphi rounds was dependent on when group agreement or stability of opinion was achieved on each domain and category.

Following confirmation of included variables and descriptors, further survey rounds were planned to inform the implementation of the triage tool. Participants were asked whether there should be consideration of including the following implementation categories: enhanced care team support, management of immediate clinical risk, for example uncontrollable haemorrhage, definition of a time threshold for bypass journeys and/or inclusion of unstructured clinical judgement. Within each category, possible variables were ranked on a 1 (highly favoured) to 5 (not favoured) Likert scale.[159]

Each Delphi round allowed up to 4 weeks for responses, with e-mail reminders sent after 1 week. The study would terminate when it was obvious that no further consensus was possible with further iterations. Surveys were designed, pre-piloted and implemented using the SurveyMonkey web application (Momentive Inc., San Mateo, CA, USA). Data analysis was performed in Microsoft Excel. No financial incentives were offered, and participants remained anonymous throughout the study.

Consensus meetings

Secondly, a 1-day facilitated roundtable expert consensus meeting was conducted to finalise triage tool structure and content.[145,146] Eleven clinicians were purposively sampled to form an expert clinical panel, ensuring that all clinicians relevant to prehospital major trauma triage were represented (see *Appendix 5* for full details). The meeting was co-chaired by an experienced health service researcher, and a senior emergency medicine academic, and was conducted at the University of Sheffield, in September 2019.

Introductory sessions were provided to cover the findings of the preceding Delphi survey; major trauma triage concepts;[33,160] major trauma reference standards;[161] existing triage tools;[55] systematic reviews examining the diagnostic accuracy of existing triage tools;[29,55,56,65] cost-effectiveness evaluations;[43,44] and the role of clinical judgement.[56,162] This evidence included all relevant systematic reviews available at the time of the consensus meeting, supplemented by the most valid studies identified from ad hoc MEDLINE searches for topics where a pre-existing research synthesis was not available. Participating experts also had the opportunity individually to highlight important supporting evidence.

The meeting then proceeded in a structured format covering the purpose, target reference standard, optimal diagnostic threshold, scope, intended population and structure of the triage tool in repeated rounds of iterative discussions. The findings of the Delphi survey were then re-reviewed, individual triage tool criteria discussed, and final variables and thresholds confirmed. Discussions were facilitated to ensure all issues were thoughtfully deliberated, incorporated diverse experience and views, and produced the best possible decision.[145,146] Consensus was defined a priori as 'finding a decision together that all members can feel comfortable with'.[146] Consensus was developed through group negotiation mediated by the meeting chairpersons.

Thirdly, a further facilitated expert consensus roundtable meeting was conducted to confirm a final triage tool, informed by results of the MATTS retrospective validation study. This validation study, described in detail in this chapter, assessed the diagnostic accuracy of the expert derived MATTS triage tools and individual triage variables. This meeting was held online due to COVID-19 restrictions in July 2021 and was chaired by a single independent clinician, but otherwise followed the same methodology as described above, including the same participants. The meeting focused on any changes to included triage tool variables and cut points. At this meeting, detailed definitions were also developed for included variables.

Public and patient involvement focus groups

Following the consensus meetings, separate focus groups were conducted with the Sheffield Emergency Care Forum and Birmingham Injuries PPI groups.[147,163] Focus groups began with a short presentation of the proposed triage tool, and following a series of familiarisation questions designed to build rapport between the interviewer and interviewees, participants were asked to discuss their perspectives. A single moderator led all interviews, and a second researcher was present to take field notes. Sessions continued until code saturation was reached ('heard it all'). Discussions were audio-recorded and later transcribed verbatim by a professional transcriptionist. Analysis followed the Framework Method with familiarisation, thematic development, indexing, charting and mapping with interpretation.[148]

Results

Delphi survey

The review of existing NHS ambulance service major trauma triage tools in England identified 97 unique variables, grouped into 25 categories across 4 domains (see *Appendix 5*, *Table 39* for full details). A further 12 novel variables and 2 novel categories were suggested by participants in the first round of the Delphi survey (see *Appendix 5*, *Table 40*). In round two, these 109 variables were grouped under 27 categories, across 4 domains: physiology (3 categories), anatomical injury (9 categories), mechanism of injury (9 categories), special circumstances (6 categories). Consensus was achieved on inclusion of two domains and nine categories, and exclusion of seven categories. In round three, a further six categories were excluded. At this stage, it was apparent that agreement on the remaining categories was declining. It was considered that further sampling would lead to declining response rates rather than more relevant findings, and selection of categories and variables was therefore terminated after round three. The variable (and cut point or descriptor) with the greatest agreement was confirmed for each selected category in each domain at this stage. *Table 8* summarises the responses across Delphi rounds 1–3 confirming triage tool domains and categories. Final selected triage tool domains and variables are detailed in *Table 9*.

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TABLE 8 Results for Delphi rounds 1–3 selecting triage tool domains and categories

	Round 2 results			Round 3 results		
Domain/variable category	Agree	Disagree	Result	Agree	Disagree	Result
Physiology domain	100%	0%	Included	–	–	Included
Level of consciousness	100%	0%	Included	–	–	Included
Circulation	93%	7%	Included	–	–	Included
Ventilation	89%	11%	Included	–	–	Included
Anatomy domain	100%	0%	Included	–	–	Included
Chest injury	100%	0%	Included	–	–	Included
Spinal injury	100%	0%	Included	–	–	Included
Pelvic injury	98%	2%	Included	–	–	Included
Long bone injury	98%	2%	Included	–	–	Included
Penetrating injury	96%	4%	Included	–	–	Included
Limb/extremity injury	93%	7%	Included	–	–	Included
Skull fracture	67%	33%	No consensus	37%	63%	Excluded
Burns	67%	33%	No consensus	56%	44%	No consensus
Haemorrhage control	56%	44%	No consensus	37%	63%	Excluded
Mechanism of injury domain	73%	27%	No consensus	61%	39%	No consensus
Vehicle ejection	76%	24%	No consensus	61%	39%	No consensus
Falls	73%	27%	No consensus	61%	39%	No consensus
Vehicle entrapment	53%	47%	No consensus	26%	74%	Excluded
Motor vehicle collision	53%	47%	No consensus	32%	68%	Excluded
Blast injury	51%	49%	No consensus	24%	76%	Excluded
Occupant fatality	44%	56%	Excluded	–	–	Excluded
Crush injury	40%	60%	Excluded	–	–	Excluded
Vehicle deformation	29%	71%	Excluded	–	–	Excluded
Assault	11%	79%	Excluded	–	–	Excluded
Special circumstances domain	67%	33%	No consensus	58%	42%	No consensus
Pregnancy	67%	33%	No consensus	58%	42%	No consensus
Bleeding risk	60%	40%	No consensus	58%	42%	No consensus
Age	53%	47%	No consensus	45%	55%	Excluded
Comorbidity	31%	69%	Excluded	–	–	Excluded
Intoxication	22%	78%	Excluded	–	–	Excluded
Patient preference	9%	91%	Excluded	–	–	Excluded

An additional Delphi round examining triage tool implementation reached consensus on the following categories: inclusion of immediate clinical risk, and a 60-minute journey time threshold for bypass. The Delphi survey was terminated due to declining response rates at this point. Consideration of enhanced care team support and inclusion of clinical judgement fell just short of consensus. The group opinions on additional implementation categories and

TABLE 9 Evolution of the MATTS triage tool content

Domain	Delphi survey	First consensus meeting: MATTS tool validated in Phase 2	Second consensus meeting: final 'MATTS triage tool' implemented in Phase 3	Comment
Physiology	• Sustained respiratory rate < 10 or > 29 • Sustained systolic BP < 90 or absent radial pulses • GCS motor score 4 or less	• Sustained respiratory rate < 10 or > 29[a] • Sustained systolic BP < 90 or absent radial pulses[a] • GCS motor score 4 or less	• Sustained respiratory rate < 10 or > 29[a] • Sustained systolic BP < 90[a] • GCS motor score 4 or less[a]	Absent radial pulses omitted to simplify tool at second consensus meeting.
Anatomy	• Chest injury with altered physiology • Suspected major pelvic fracture • Two or more long bone fractures • Penetrating injury to neck, chest, abdomen, back or groin • Neck or back injury with paralysis • Amputation or mangled extremity proximal to ankle or wrist	• Chest injury with altered physiology • Suspected major pelvic fracture • Two or more long bone fractures • Penetrating injury to neck, chest, abdomen, back or groin • Neck or back injury with paralysis • Amputation or mangled extremity proximal to ankle or wrist • Open fracture proximal to forefoot/wrist[b] • Open or depressed skull fracture	• Chest injury with new oxygen requirement • Major pelvic fracture • Two or more proximal long bone fractures • Penetrating injury to neck, chest, abdomen, back or groin • Neck or back injury with paralysis • Amputation or mangled extremity proximal to ankle or wrist • Open fracture proximal to forefoot/wrist[b] • Open or depressed skull fracture	Open fractures and skull fractures added to meet MATTS reference standard definition at first consensus meeting. Chest injury with new oxygen requirement and proximal long bone fractures detailed to increase specificity at second consensus meeting. Suspected pelvis fracture changed to major pelvis fracture at second consensus meeting to improve specificity.
Clinical judgement		• Significant clinical concern for major trauma requiring MTC care.	• Significant clinical concern for major trauma requiring MTC care.	Clinical judgement domain added to provide established benefit of clinical acumen at first consensus meeting.

BP, blood pressure.

a Use JRCALC abnormal paediatric values if < 16 year.
b Optionally could be transported to a TU with ortho-plastic capabilities dependent on local network configuration.

descriptors are detailed in *Appendix 5*, *Table 41*. Of the 91 experts invited to participate in the survey, 54 completed the first round (59%), with response rate of 45 (49%), 38 (42%) and 32 (35%) achieved in each subsequent round.

Expert consensus meeting

Following review of relevant evidence during the facilitated roundtable expert consensus meeting, iterative rounds of discussion achieved consensus on six aspects of the triage tool: purpose, target reference standard, scope, intended population, structure and optimal diagnostic threshold. In terms of purpose and reference standard, agreement was achieved that the triage tool should be used to identify patients who would benefit from bypassing and pre-alerting to MTCs, rather than injury severity per se, as defined by the MATTS major trauma reference standard (see *Chapter 6*). This reference standard included the need for a time-critical trauma intervention, significant individual injuries requiring expedited specialist management, or polytrauma benefiting from early MTC care, and excluded patients where MTC care would not be beneficial (e.g. advanced frailty).

Expert consensus established that the triage tool was intended for use by ambulance service clinicians. HEMS and prehospital physician services were considered out of scope, as their additional training and experience would allow accurate use of unstructured expert clinical judgement. Detailed inclusion and exclusion criteria were also agreed. It was recognised that major trauma can occur from low-energy mechanisms of injury, for example ground-level falls, and the intended population was, therefore confirmed as any patients presenting following a non-trivial injury event. For

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simplicity, ease of use in the challenging prehospital environment, and consistent with the NIHR MATTS commissioning brief, all age groups were included in a single triage tool. It was accepted that the triage tool should not be applied in cases where bypass would obviously not be beneficial, or could be harmful, including prolonged journey (> 60 minutes travel time) to a MTC, unmanageable airway, breathing, or uncontrollable external bleeding, traumatic cardiac arrest with > 15 minutes travel time to a MTC, advanced frailty, end-of-life care, or advanced directives. Isolated burns were also excluded due to the existence of separate NHS major burns networks, which may not overlap with major trauma networks. Cases with isolated hypoxic brain injury (e.g. drowning, non-judicial hangings) were also judged ineligible as it was recognised these usually lack concomitant physical injuries.

Complete agreement was evident that the triage tool should be structured as a checklist of individual variables assessed in parallel, with variables grouped into physiology and anatomical injury domains to maximise familiarity and concordance with currently used tools. A target trade-off between under- and over-triage was confirmed, as informed by the preceding MATTS economic and operational modelling which indicated prioritisation of specificity for cost-effective major trauma triage (see *Chapter 4*).[43] The importance of clinical acumen, over and above stated triage variables, was agreed with an additional domain for unstructured clinical judgement unanimously agreed. Decision support provided by senior clinical staff, operationalised through a trauma/critical care desk, was felt to be important in optimising this clinical gestalt. It was also felt that deployment of enhanced care team support (e.g. HEMS, critical care paramedics, prehospital physicians) would be best facilitated via this senior clinical support.

Individual triage variables were defined by consensus as detailed in *Table 9*. All variables reaching consensus in the Delphi survey were included in the triage tool, with open fractures and significant skull fractures variables added to ensure conformity with the target MATTS reference standard definition. It was recognised that services may vary regionally, and the option for isolated open fractures to be transported to a TU with ortho-plastic capabilities was allowed dependent on local trauma network configuration. Two further exploratory triage tools with differing triage variables were also developed for future evaluation, targeting relatively more sensitivity and balanced sensitivity/specificity (see *Appendix 5*, *Table 42*).

In the second facilitated roundtable meeting, the expert consensus group drew on information from the MATTS retrospective validation study (see *Chapter 8*) to make minor modifications to the triage tool. Examination of individual triage predictors revealed that absent radial pulses did not provide additional benefit over systolic blood pressure< 90 mmHg and this variable was therefore dropped to simplify the tool. Modification of > 2 long bone fractures to > 2 proximal long bone fractures, and chest injury with altered physiology to chest injury with new oxygen requirement, both appeared to slightly improve triage tool specificity with no loss in sensitivity. No other variables appeared to offer the possibility of improvement in performance. Detailed variable definitions were also confirmed, including a minor change in terminology from 'suspected major pelvis fracture' to 'major pelvis fracture' to improve specificity. The final triage tool variables are presented in *Table 9*, with detailed variable definitions presented in *Appendix 5*, *Table 43*.

Public and patient involvement focus groups

Focus groups with the Sheffield Emergency Care Forum and Birmingham Injury PPI groups included 12 and 15 participants, and lasted 63 and 94 minutes, respectively. The triage tool was received favourably with no negative feedback specific to the triage tool structure, format or variables. Exclusion of bypass in advanced frailty were accepted. A minority of participants voiced strong opinions about patient choice in determining their desired location of care following injury, specifically referencing travelling distances and perceived quality of care in individual hospitals. Representative comments included 'Please remember that many older trauma patients will have carers who are also older and can't travel far', 'an MTC probably provides better care for all levels of injury', 'for me it depends which hospital they're trying to take me to . . . I would never let them take me to [non-MTC name]'.

Discussion

Summary

A new expert consensus-derived major trauma triage tool was developed for use in English trauma networks. Purpose, scope, intended population, structure, constituent variables and thresholds were defined. The candidate triage tool

was subsequently externally validated in Phase 2 (see *Chapter 8*), and then implemented into practice in Phase 3 (see *Chapter 9*) of the MATTS project, with prospective evaluation of clinical and cost-effectiveness, acceptability and usability.

Interpretation

There are several potential methods for developing a triage tool, including expert consensus,[164] statistical modelling[74] and machine learning.[73] There are many grounds for supporting an expert consensus process. Firstly, paper-based expert-derived tools, structured as checklists of variables, are intuitive and simple to use in the challenging prehospital environment. Secondly, such a design is currently used by all English ambulance services, reducing the risk of implementing a similarly designed national tool, allowing learning from current experience, and offering the opportunity to refine, rather than overhaul, existing tools. Thirdly, qualitative research conducted during the MATTS project, and elsewhere, has highlighted that speed and simplicity, exemplified by paper-based 'checklists', are highly valued by prehospital clinicians (see *Chapter 5*). Fourthly, consensus development, informed by existing tools, allowed honing of included variables to maximise accuracy and defining variable thresholds to target specificity as suggested by economic evaluations. Fifthly, expert-derived clinical decision rules have been demonstrated to perform well across many disease areas, for example the HEART score in chest pain evaluation.[165] Sixthly, statistical prediction models and machine learning algorithms have increased complexity, often require very large robust datasets for development, may be less interpretable, and are often difficult to implement into clinical practice.[166–168] Methodology guidelines therefore advise existing clinical decision rules should be refined and validated where possible.[169] Finally, machine learning might be expected to poorly perform *ex ante* in 'unbalanced' (i.e. low prevalence) and low signal to noise situations, as might be expected in major trauma triage.[73]

Where stated, the intended patient population for application of current English triage tools is high-energy trauma or suspicion of major trauma (see *Chapter 2*). However, a significant proportion of severe injuries occur with low-energy mechanisms or present atypically.[14] This supports the stated conceptualisation of the MATTS triage tool as an 'injury assessment tool' to maintain user familiarity and avoid missing assessment of seriously injured patients. The MATTS project commissioning brief was to develop a single triage tool; however, it could be expected that a 'one size fits all' approach is unlikely to perform consistently across all injury subgroups and geographic populations. Conversely, using multiple different triage tools is likely to be impractical in the pressured prehospital setting. Given the heterogeneity of major trauma, differential triage tool accuracy and prevalence of major trauma should be expected across age subgroups, blunt/penetrating and high/low-energy trauma, and different anatomical injuries. A Bayesian approach of formulating a pre-test probability of major trauma based on mechanism of injury, with application of corresponding LRs following application of the triage tool, and consequent calculation of post-test probability would therefore be recommended.[170]

The MATTS document analysis of existing adult triage tools identified an array of expert-derived triage tools, with three distinct patterns: 'specific and prescriptive', 'intermediate' and 'sensitive and permissive' (see *Chapter 2*). The final recommended MATTS triage tool has similar variables and cut points to the 'specific and prescriptive' grouping but also adds an element of unstructured clinical judgement. It therefore represents 'evolution not revolution', enhancing and refining existing tools with similar target performance. Clinical judgement, supported by remote decision support from experienced clinicians, was explicitly included in the triage tool to further improve accuracy. This was supported by the findings of the MATTS Phase 1 qualitative study (see *Chapter 5*), and a systematic review by van Rein *et al*. which reported EMS provider judgement could substantially lower the under-triage rate, at the cost of a small increase in over-triage.[56]

Major barriers to implementation of clinical decision rules and prediction models are perceived complexity and lack of transparency.[171] These issues were directly addressed by the expert consensus panel, with specification of detailed variable definitions and provision of additional supporting information. Major trauma triage tools are commonly deployed within a complicated milieu, potentially involving overlapping ambulance service, major trauma network, and specialist services catchment areas (e.g. burns, ortho-plastics). Expertise of ambulance service clinicians can vary widely from ambulance technicians to specialist critical care paramedics. Additional prehospital resources may be available to respond to suspected major trauma cases, including HEMS and prehospital physicians. Major trauma specialist services may also be spread across different hospitals, within or across NHS trusts/healthcare organisations. Moreover, hospital

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TU and MTC designations may differ depending on paediatric or adult presentations. To operate effectively, major trauma triage tools may therefore need to provide additional context and instructions beyond a checklist of triage variables including exclusion criteria, injury-dependent destination advice, and the option for senior clinical support, for example from a dedicated ambulance service 'trauma/critical care desk', to navigate these intricacies.

Limitations

This study has several limitations. It is possible that individual views within the expert panel were not fully consistent with evidence-based triage practice or could be unrepresentative of general clinical opinion. The final tool was also not comprehensively reviewed by prehospital clinician end-users (although a detailed qualitative evaluation was planned a priori during phase of the MATTS project after implementation of the tool into practice). In contrast, the strengths include a comprehensive sample of prehospital, MTC and non-MTC experts, PPI input and conformity with consensus study guidelines. The consensus approach allowed fuller deliberation of the decision problem, compared to other decision-making approaches such as executive decisions or majority rule. Roundtable methodology is better suited to complex, multi-dimension constructs than other consensus methodology such as Delphi process or nominal group technique, which are designed to answer narrow, single issue, questions.[145,146] The inclusion of local experts should ensure this triage tool is directly applicable to the English NHS. Other devolved countries within the UK have introduced similar trauma networks to England, and have comparable national health services, suggesting good generalisability to these settings.

Conclusions

A new candidate national major trauma triage tool for the English NHS trauma networks was developed. Purpose, scope, intended population, structure, constituent variables, variable definitions and thresholds were defined. External validation, implementation and prospective evaluation were subsequently conducted to establish diagnostic accuracy, cost-effectiveness, acceptability and usability.

Chapter 8 Diagnostic accuracy of major trauma triage tools in English regional trauma networks – a case–cohort study

Introduction

The MATTS document analysis (see *Chapter 2*) identified a wide range of major trauma triage tools, differing in structure and content.[29] Previous systematic reviews in children, adults and the elderly have demonstrated varying theoretical accuracy for these tools, with poor-quality studies reporting sensitivities ranging from 10% to 100%, and specificities from 9% to 100%.[29,53,55,65,71] Economic evaluations have established that high specificity should be prioritised for cost-effective triage,[43–46] with the MATTS decision-analytic modelling (see *Chapter 4*), demonstrating that low-sensitivity (28.4%), high-specificity (88.6%) triage performed optimally in the UK setting.

This study reports an external validation of existing triage tools together with the newly developed MATTS candidate triage tool (see *Chapter 7*). Specific objectives were to describe the characteristics of injured patients presenting to English ambulance services, determine the theoretical diagnostic accuracy of selected triage tools, evaluate their net benefit compared to default strategies of bypassing/pre-alerting all or no patients, identify a best-performing triage tool performing closest to optimal under- and over-triage targets, and observe real-life triage performance in English trauma networks.

Methods

Study design

A diagnostic case–cohort study was undertaken to evaluate the accuracy of representative major trauma triage tools and externally validate the newly developed MATTS expert consensus triage tools. Case–cohort studies are recommended for evaluation of diagnostic accuracy in low-prevalence scenarios.[172] In this study design, a random sample of individuals from the study population are included irrespective of reference standard ('sub-cohort'), together with all reference standard positive patients ('cases'), as illustrated in *Appendix 6*, *Figure 29*.[172,173]

Setting

The study was undertaken in four inclusive English regional trauma networks: Birmingham, West Yorkshire, Northwest London and Severn. These are predominantly served by four separate NHS ambulance services: WMAS; Yorkshire Ambulance Service NHS Trust (YAS); London Ambulance Service NHS Trust (LAS); and the South-Western Ambulance Service NHS Foundation Trust (SWAS), respectively. The study trauma networks were chosen as they are principally served by a single ambulance service, have a favourable record for data collection, and represent a diverse range of localities, demographic, socioeconomic and injury profiles. Further details on the participating trauma networks are provided in *Appendix 6*, *Figure 30* and *Tables 44–45*.

Reference standards

The primary reference standard against which triage tool outcomes were assessed was injured patients who would benefit from expedited MTC care, as characterised by the MATTS consensus-based definition (see *Chapter 6*).[161] Several alternative reference standards were considered in secondary analyses, including ISS ≥ 16,[151] the MATTS reference standard excluding open fractures, and urgent trauma interventions. Urgent interventions comprised: advanced airway interventions; transfusion of > 4 units blood products; interventional radiology and/or emergency surgery occurring within 8 hours of ED arrival; secondary transfer to the MTC within 6 hours; or critical care admission occurring within 12 hours of initial ED presentation.

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Index tests

The index tests under consideration were the consensus-derived MATTS specific triage tool (see *Chapter 7*), together with the other MATTS consensus-derived tools (MATTS balanced, MATTS sensitive), current triage tools used by participating ambulance services, and representative international triage tools identified from the previously conducted MATTS document analysis. As described in *Chapter 2*, a total of 53 triage tools were identified between 2012 and 2019. Of these, 25 were evaluated, with 28 excluded due to close similarity with another index tests. The final triage tools that were examined comprised 22 adult, 3 geriatric and 3 paediatric tools, as shown in *Table 10*.

Theoretical diagnostic accuracy was examined, with index tests assessed according to objective data recorded in ambulance service records, regardless of the final triage decision, clinical judgement, or hospital destination. Discretionary variables were excluded. Prediction models and clinical scores were evaluated at their recommended published threshold. Index tests were applied to their intended target demographic, consistent with established definitions for age groups. Paediatric triage tools were therefore applied to children < 16 years, elderly triage tools applied to elderly > 65 years and adult tools applied to all patients over 16. For assessment of the secondary MATTS reference standard excluding open fractures, triage tool variables for open fractures were omitted.

TABLE 10 Triage tool index tests examined in Phase 2 validation study

	Adult tools		Elderly tools		Paediatric tools
1	CRAMS score	23	Ohio tool	26	LAS (paediatric)
2	Dutch	24	US FTDS (Geriatric)	27	NWAS (paediatric)
3	Florida	25	WMAS Silver Safety Net	28	Paediatric checklist
4	LAS (post 2020)				
5	LAS (pre 2020)				
6	MATTS balanced				
7	MATTS sensitive				
8	MATTS specific				
9	MGAP score				
10	North Carolina				
11	Oregon				
12	Prehospital index (PHI)				
13	Triage-Revised Trauma Score (RTST)				
14	South West Ambulance Service				
15	Trauma Triage Rule (TTR)				
16	Trauma Score				
17	Trauma Scorecard				
18	US FTDS				
19	Victoria				
20	Vittel				
21	WMAS				
22	YAS				

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NWAS, North West Ambulance Service.

In an ancillary analysis, the accuracy of actual triage decisions was examined, both overall and separately for each ambulance service. The index test was the observed triage pathway, regardless of the indicated triage tool result based on objective data present in ambulance service records. Patients pre-alerted to a MTC, either bypassed if injured in the catchment area of a non-MTC or directly transported if injured in the catchment area of a MTC, were considered index test positive.

Study population

The study sample was defined from the viewpoint of the ambulance service clinician assessing undifferentiated patients following injury where a major trauma triage tool would plausibly be used, thus providing the true denominator for assessment of diagnostic accuracy. The source population was therefore all patients presenting with acute non-trivial injury to the four participating ambulance services and included trauma networks. Geographical areas, with corresponding ambulance service and trauma network catchments areas, were defined based on postcode sectors. The subsequent study population consisted of consecutive patients, regardless of age, conveyed to a participating trauma network hospital between 1 November 2019 and 28 February 2020. Deaths in the field, non-conveyances, patients transported to participating hospitals by non-study ambulance services, transported to out-of-network hospitals by participating ambulance services, or undergoing secondary inter-hospital ambulance transfers were excluded. Patients from mass-casualty major incidents were also excluded as specialised non-standard triage strategies are necessary in these scenarios. Isolated hypoxic injuries (e.g. drowning, non-judicial hangings) were not eligible, as these rarely result in serious traumatic injury. Due to the existence of separate regional systems for triage, isolated burns were also not included. Critically unwell patients with an unmanageable airway, cardiac arrest or uncontrollable haemorrhage, requiring diversion to the nearest hospital for instantaneous intervention, were ineligible, as such patients would not be subject to triage tool assessment. Other exclusions comprised trivial injuries, non-injury presentations, delayed presentations of non-recent trauma (> 72 hours), and patients with NHS data opt-outs. The final study sample included patients with complete data available allowing calculation of triage tool diagnostic accuracy. Inclusion and exclusion criteria are summarised in *Appendix 6*, *Table 46*. Derivation of the study sample is detailed in *Figure 11*.

Case–cohort derivation: sub-cohort identification

Consecutive patients presenting with injury were identified from YAS, WMAS, LAS and SWAS patient records. Working impression diagnostic codes corresponding to non-trivial injury, use of a trauma-specific intervention, or major trauma-related pre-alerts were selected for inclusion. Ambulance service databases were searched for any cases meeting these criteria who were injured in the defined study area and transported directly to a participating hospital to give the parent

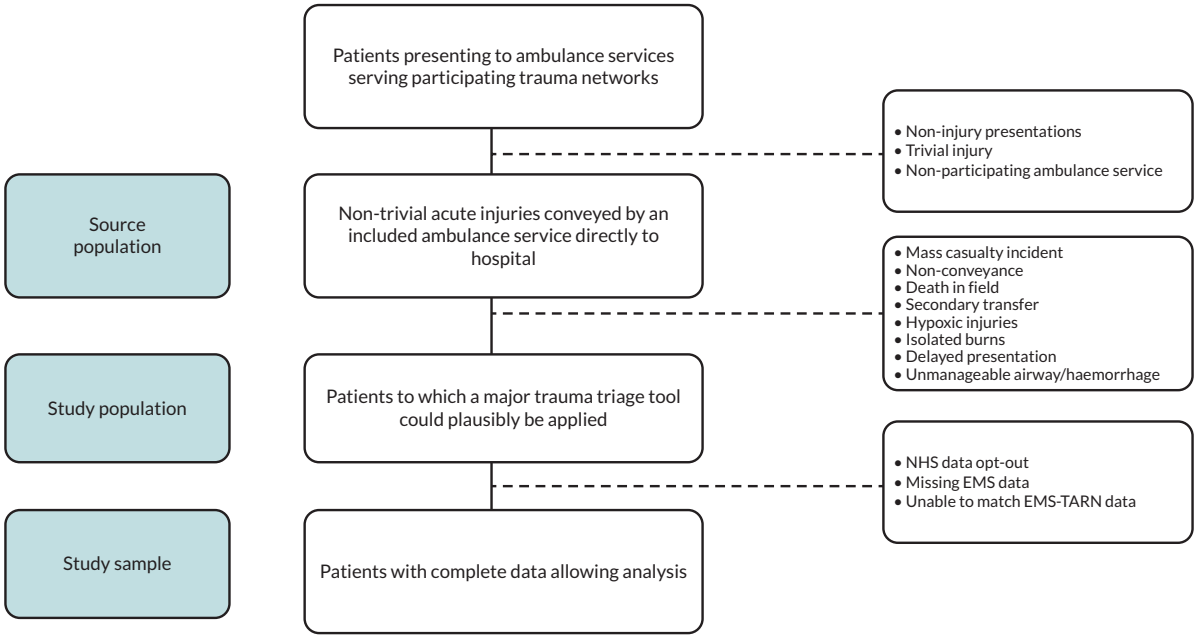


FIGURE 11 Derivation of the Phase 2 case–cohort study sample.

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cohort. A random sample of patients were then included in a sub-cohort. For practical reasons, the random sampling was disproportionately stratified by ambulance service to provide a constant workload for researchers. Exclusion criteria were applied during detailed case review by research paramedics following sampling.

Case–cohort derivation: reference standard positive case identification

The presence of major trauma in patients conveyed to participating hospital by ambulance following injury was determined using data from the TARN, the English national major trauma registry.[174,175] Reference standard criteria were applied centrally to all cases submitted to TARN, and positive cases then linked to ambulance service data. A census sample of all cases conveyed to a selected trauma network hospital during the study period by a participating ambulance service, meeting ambulance service inclusion criteria and reference standard definitions, and matching to an ambulance service case were included. Any included ambulance service cases without a corresponding TARN submission were assumed to be reference standard negative.

Matching index test and reference standard data

In line with study ethical approvals, direct patient identifiers, that is name, date of birth, NHS number, or address were not available in either ambulance service or TARN data. Data linkage between (1) cases meeting reference standard criteria collected by TARN and (2) ambulance service patients with non-trivial injuries was therefore initially conducted deterministically based on the unique ambulance service patient report form number shared across both data sets. Matched cases were subsequently individually checked by research paramedics who examined demographic and incident information in ambulance service and TARN records to confirm an accurate match. In cases where exact deterministic matching was not possible due to missing or inaccurate patient report form number, research paramedics performed probabilistic matching by manually reviewing each reference standard positive case. Demographic (age, sex), non-unique ambulance identifiers (computer-aided dispatch numbers, ambulance call sign) and incident information [incident date/time, hospital destination, hospital arrival date/time, incident description, incident location (outward and partial inward postcode)] were used from TARN data to search for a corresponding record in ambulance service databases. The TARN record was then appended with the unique ambulance service patient report form number, for subsequent deterministic matching with its corresponding prehospital record. The threshold for confirming a positive probabilistic match was the legal standard of 'beyond reasonable doubt'. All matches were independently confirmed by a second researcher and a match was not confirmed in the presence of any uncertainty or disagreement.

A small number of reference standard positive cases were matched to an identified EMS record that was not present in the parent cohort due to the use of a non-selected working impression (WI) code. Ambulance service data for these cases were imported and coded for use in sensitivity analyses. Data flows are presented schematically in *Appendix 6*, *Figure 31*.

Index test data collection

Ambulance service data for patients sampled in the sub-cohort, or matched to non-sampled reference standard positive cases, were imported into a bespoke research database. Collected information comprised demographic, patient characteristics, physiology, incident, mechanism of injury, interventions, treatments, clinical assessment, hospital destination and pre-alert information.

Two ambulance services (WMAS, SWAS) exclusively used electronic patient report forms, one service (YAS) used predominantly electronic records except for a small minority of cases using paper, and the remaining service (LAS) used exclusively paper-based records. Other ambulance service data sources included computer-aided dispatch data, and trauma desk transcripts. Electronic data were a mixture of closed fields, for example timings, vital signs, interventions and free-text data, for example incident descriptions. Paper records were electronically scanned, and comprised written free-text fields, and closed fields with electronic text/number recognition.

Relevant electronic closed field data were imported directly where possible, with free-text data abstracted by hand after review of the patients record by research paramedics. Eligibility against inclusion and exclusion criteria was confirmed manually. A data dictionary was developed a priori *to* standardise all data elements, provide variable definitions and define categorisations. Data abstraction was blinded, with all ambulance service data anonymised and reference standard status not available. Data collection was piloted and guided by a coding dictionary. Weekly meetings were

convened to review data collection, with any uncertainties resolved through consensus. Data were recorded as missing if not present in closed fields, or if not possible to infer from free-text fields. Following data collection, range and consistency checks were performed with implausible values set to missing.

Triage tools and prediction models selected as index tests were then coded algorithmically according to their stated variable thresholds. Each case was consequently classified against the observed data as index test positive or negative. The first recorded vitals sign was used for physiology variables. Where triage tool variables were defined as sustained physiology values, two or more consecutive values meeting the threshold were required. Two independent statisticians undertook coding to ensure accuracy.

Reference standard data collection

Trauma Audit and Research Network is the English national trauma registry database and collects information on patients with major injuries presenting to all trauma receiving hospitals in England. Patients are included in the TARN database if they sustain injury resulting in any of the following: hospital admission for > 72 hours; critical care or high-dependency unit admission; transfer for specialist care; or death. Patients with simple isolated injuries (e.g. radius fracture), pubic rami or femoral neck fractures and aged over 65, prehospital deaths, or diagnosed as dead on ED arrival with no further management instigated, are excluded. The TARN registry therefore aims to include all patients requiring significant treatment for non-trivial injuries sustained from meaningful trauma. Admissible patients are identified by TARN data co-ordinators in member hospitals who collate demographic, injury, treatment, investigation and outcome data from patient records. Independent, trained, TARN injury coders centrally grade individual injuries for each case according to AIS (2008 revision) criteria based on clinical, radiological and post mortem information, and a subsequent ISS is assigned.[176] Each submitted case from participating hospitals during the study period was coded centrally by TARN data analysts according to primary and secondary reference standard criteria. Eligibility against inclusion and exclusion criteria was confirmed manually by research paramedics. Submission of cases to TARN may be delayed due to operational issues, coronial investigations or post-mortems. A final data transfer of TARN cases meeting reference standard criteria was therefore performed 10 months after the end of the study period to maximise case ascertainment. Further details on TARN procedures are provided in *Appendix 6*.

Statistical analyses

The analysis proceeded in six stages. Firstly, the derivation of study population, parent cohort, sub-cohort and reference standard positive cases were enumerated and delineated graphically using flow charts. Secondly, the study sample was characterised, with patient demographics, injury features and missing data examined using descriptive statistics. Thirdly, in the main analysis, the diagnostic accuracy of individual adult triage tools was investigated against primary and secondary reference standards. Sensitivity, specificity, positive and negative predictive values, and positive (LR+) and negative likelihood ratios (LR−) were calculated with their 95% CIs. Results were displayed graphically plotting individual triage tool's paired sensitivity/specificity. Separate sensitivity/specificity plots were then constructed to create the maximum realisable ROC curve (also known as the Pareto front or ROC curve convex hull), including only triage tools with superior specificity for any given sensitivity.[177–179] The maximum realisable ROC curve was formed by linear interpolation between adjacent points within the ROC space with no point lying above the final curve. A decision curve analysis was then performed to illustrate the clinical consequence of implementing the optimal triage tools.[41] Clinical net benefit of the identified tools was compared to default strategies of bypassing/pre-alerting all or no patients. Net benefit was calculated across a range of threshold probabilities, defined as the minimum probability of major trauma at which bypass/pre-alerting would be warranted, calculated as net benefit = sensitivity × prevalence − (1 − specificity) × (1 − prevalence) × the odds at the threshold probability.[42]

Fourthly, subgroup analyses were conducted, examining adult triage tool performance against each reference standard for patients with penetrating versus blunt injury, and higher-energy injury presentations versus ground-level falls. Further subgroup analyses examined triage tool performance in different age ranges, comprising children aged under 16 years (either paediatric specific, or adult tools with paediatric modifications), and the elderly (both adult and elderly-specific tools) aged ≥ 65 years. Diagnostic accuracy metrics were calculated with their 95% CIs and results displayed graphically using Forest plots. Complete-case analyses were performed in the main and subgroup analyses, with exclusion of any cases with missing data preventing calculation of index test status.

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Fifthly, sensitivity analyses were performed to explore the influence of study selection criteria and missing data. The main analysis was repeated, including primary reference standard positive cases involved in acute non-trivial injury events, but where a non-selected WI code had been used. The main analysis was also repeated including eligible patients with missing data under a range of missing data mechanism assumptions. To indicate the range of possible results, best- and worst-case scenario analyses were conducted under a missing not at random assumption, where eligible patients with missing data were classified either as triage tool positive or as triage tool negative, respectively. Multiple imputation using chained equations was also performed to explore the impact of data being missing at random.[180] An inclusive modelling strategy was adopted to develop imputation models for each incomplete variable to increase the plausibility of the missing at random assumption. The reference standard, all triage variables, and any possible auxiliary data fields that might predict missingness in studied variables or the value of the incomplete variable were included. Predictive mean matching was used for non-normal linear variables. Interval limits were used to prevent clinically implausible outlying imputations. Logistic and proportional odds regressions were used for the imputation models of binary and ordinal variables, respectively. Categorical explanatory variables were included using a set of dummy variables. Ten sets of imputed data were generated, and imputations were checked for consistency and plausibility by visually comparing distributions of complete and imputed data and examining summary statistics.

Finally, an ancillary analysis examined the accuracy of actual triage decisions in participating trauma networks (i.e. whether the patient was pre-alerted to the MTC, regardless of the indicated triage tool result). Sensitivity and specificity were calculated with their 95% CIs for the primary reference standard, both overall and across different age groups. Real-life triage decisions in adults were then compared to the indicated result for each triage tool step based on data recorded by ambulance service clinicians. Participating ambulance service triage tools consisted of a checklist of variables grouped into domains or 'steps' and applied in parallel. Physiology (step 1) and anatomical injury (step 2) variables are mandatory, indicating bypass and pre-alerting to MTCs when positive. Mechanism of injury (step 3) and special circumstance (step 4) variables are discretionary, prompting consideration of bypass and pre-alerting to MTCs. Cumulative sensitivity and specificity for the theoretical result of sequential triage tool steps, including discretionary steps, based on recorded data were calculated and compared to the accuracy of final paramedic decision (pre-alert to MTC vs. not). This analysis was then repeated for the secondary reference standards. The details of all individual analyses are summarised in *Appendix 6*, *Table 47*.

Analyses were conducted in R Statistical Software (v4.3.0; R Core Team 2023) and STATA version 17.0 (StataCorp. 2016. Stata Statistical Software: Release 17, StataCorp LP). Multiple imputation was performed using the *ice* procedure and the *mim* command was subsequently used to calculate triage rule sensitivity and specificity, combining results from imputed data sets according to Rubin's rules. Unweighted summary statistics were reported separately for the sub-cohort and case–cohort sample characteristics and reference standard prevalence. Diagnostic accuracy metrics independent of underlying prevalence (sensitivity, specificity, LRs) were also calculated without sample weights. Conversely, Borgan II inverse probability sampling weights were used for positive and negative predictive values to represent non-sampled non-trivially injured patients, and account for the case–cohort study design.[181] Reference standard positive patients received full weighting. Reference standard negative sub-cohort patients were upweighted so that each patient represented 1/sampling fraction. These calculations were conducted separately for each trauma network to account for differential sampling fractions. Furthermore, the size of parent cohort was reduced to account for potential study exclusions and missing data, by applying the same ineligibility and complete-case fraction as observed in sampled cases. Further details on case–cohort sampling fractions and analysis weights are provided in *Appendix 6*, *Figure 32*. The unit of analysis was the individual incident. Direct patient identifiers were unavailable, and it was therefore not possible to account for clustering from in the event of recurrent incidents in the same patient. A statistical analysis plan was pre-specified. A small number of protocol modifications and post hoc analyses were used, as detailed in *Appendix 6*, *Table 48*.

Sample size calculation

An estimated 600 reference standard positive patients were expected across the four participating ambulance service during the 4-month study period. Assuming, based on ACS-COT criteria, a triage tool required sensitivity of 95%,[32] and anticipating that up to 5% of cases would have insufficient data, a sample of 570 cases would result in a 95% CI width of ± 2.0%. According to ACS-COT criteria, a triage tool requires a specificity of approximately 70%.[32] Therefore, to achieve a 95% CI width of ± 2.0%, a sample 2014 reference standard negative patients would be required.

Results

Between 1 November 2019 and 28 February 2020, 47,513 patients with non-trivial injury WI codes were conveyed to study trauma network hospitals by participating ambulance services, forming the source population. Some 2160 patients (4.5%) were randomly sampled into the sub-cohort, of which 183 (8.5%) patients did not meet inclusion criteria. From the eligible 1977 patients, there were a further 124 cases (6.3%) with missing data, precluding evaluation of selected triage tools. The subsequent complete-case sub-cohort study sample therefore consisted of 1853 patients, comprising 55 patients (54 adults, 1 child) meeting primary reference standard criteria, and 1798 (1679 adults, 119 children) who were primary reference standard negative.

During the same study period, there were 1750 TARN cases directly admitted by ambulance to participating hospitals, of whom 1497 were primary reference standard positive. From these, 1042 (69.6%) cases (33 children, 1009 adults) met inclusion criteria and were successfully matched to a corresponding ambulance service record. There were missing data present in a further 83 (7.9%) patients, resulting in a final complete-case sample of 959 primary reference standard positive patients (928 adults, 31 children). Of these, 55 were sampled into the sub-cohort as described above, and 904 were outside the sub-cohort, but matched to EMS cases in the parent cohort.

The final study sample for evaluation of triage tools across all age subgroups consisted of 2757 patients (959 primary reference standard positive patients, 1798 primary reference standard negative patients). Assuming the same proportion of eligible patients and missing data in the source population, the complete-case parent cohort consisted of 40,723 patients (959 reference standard positive and 39,764 reference standard negative patients). The case wise missing data rate in eligible patients was 6.9% (*n* = 205/2962). Variable-wise missing data rates ranged from 59/2962 (2.0%) for pulse rate to 101/2962 (5.5%) for systolic blood pressure. Derivation of the parent cohort, sub-cohort and study samples for primary reference standard positive and negative patients are detailed in *Figures 12*–*14*.

The overall prevalence of major trauma meeting the primary reference standard definition in eligible sub-cohort patients with complete data was 2.9% (*n* = 55/1853, 95% CI 2.3 to 3.9). Assuming an identical proportion of eligible patients

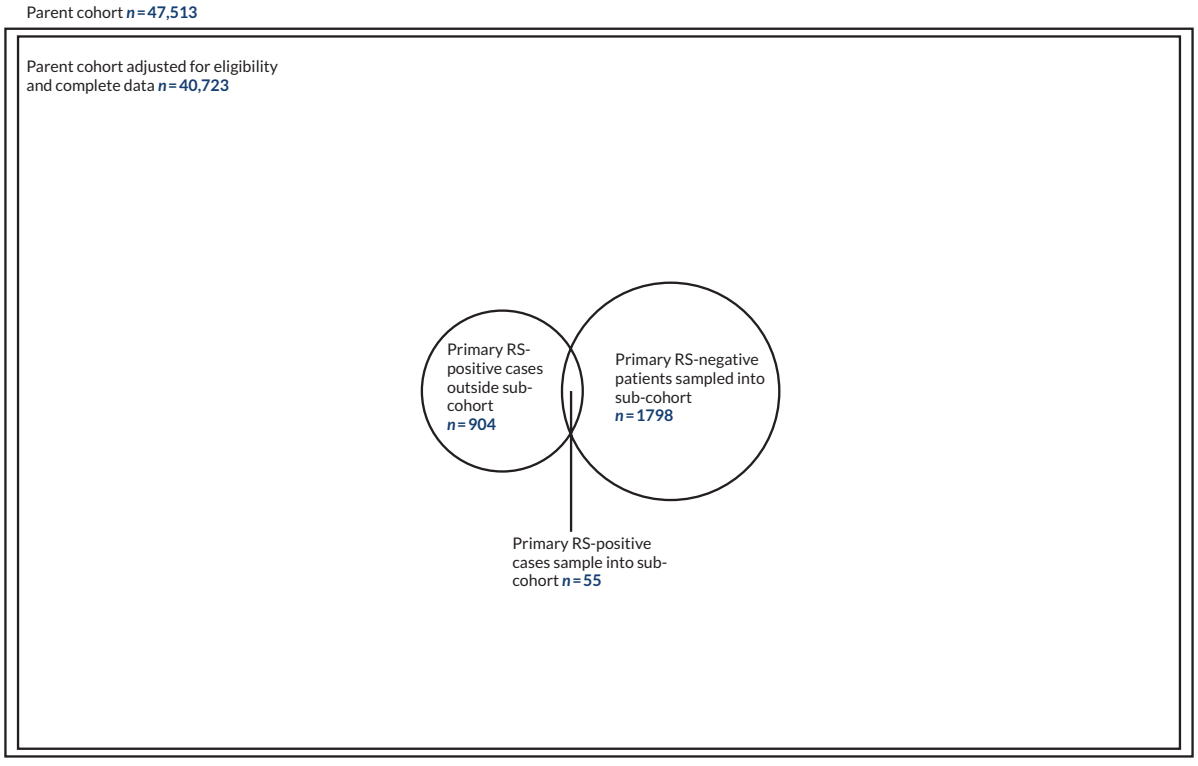


FIGURE 12 Derivation of Phase 2 case–cohort study population, including primary reference standard positive and negative cases in sub-cohort and parent cohort. Note: Areas of circles and squares are proportional to the number of patients.

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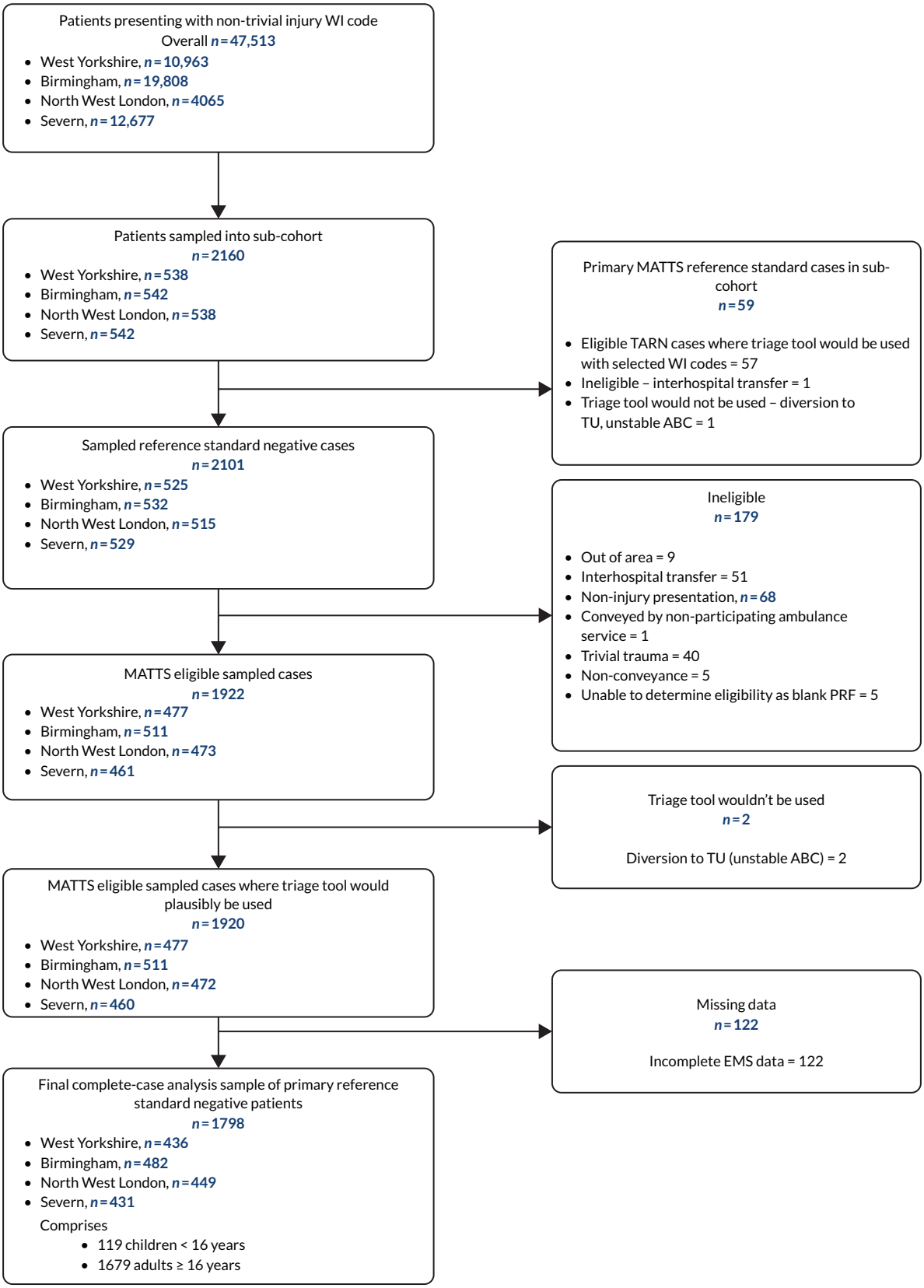


FIGURE 13 Derivation of Phase 2 case–cohort study primary reference standard negative patients.

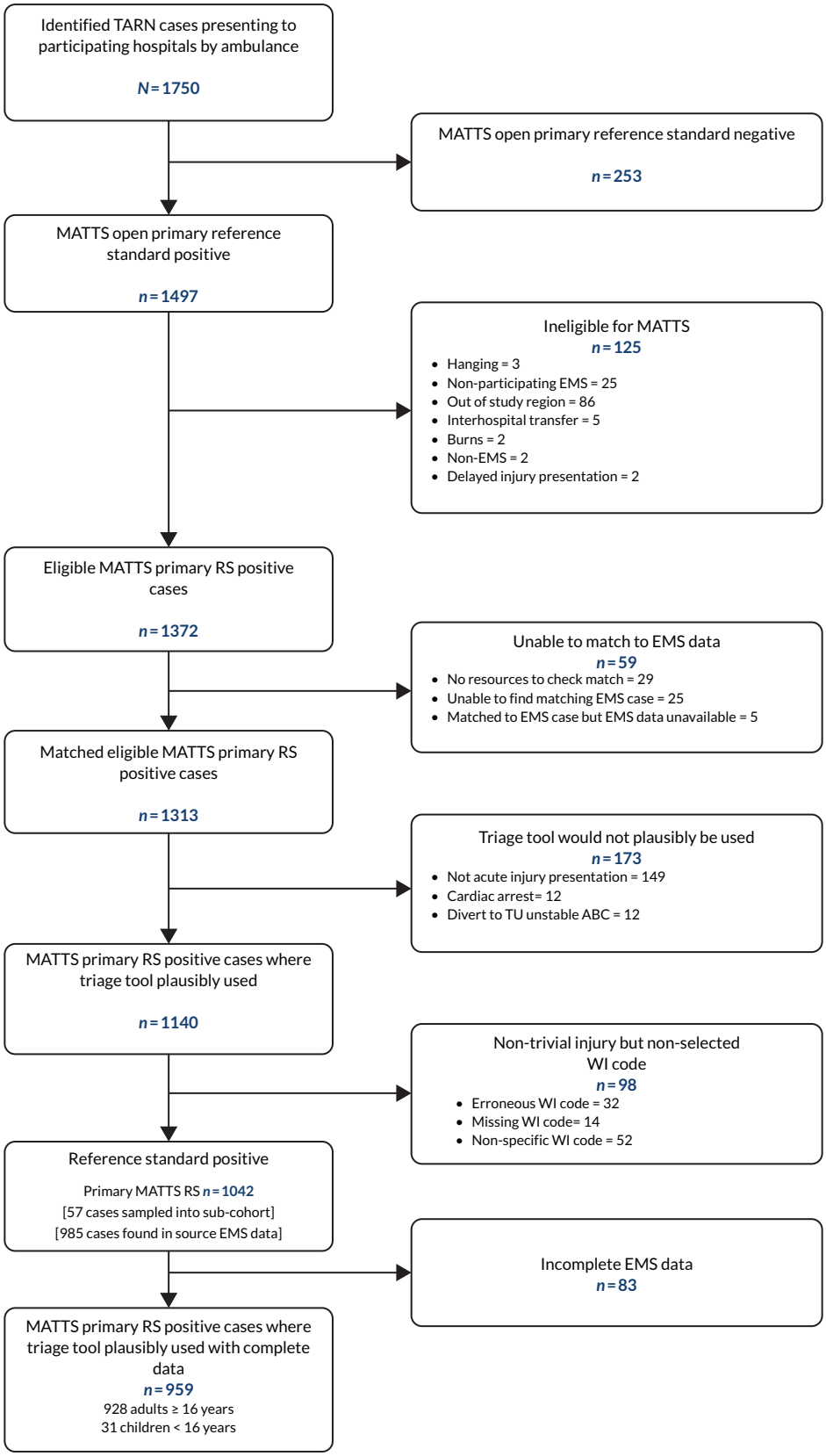


FIGURE 14 Derivation of Phase 2 case–cohort study primary reference standard positive patients.

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with complete data in the parent cohort as observed in the sub-cohort, the weighted prevalence of patients meeting the primary reference standard was 2.4% (*n* = 959/40,728, 95% CI 2.2 to 2.5). Prevalence of major trauma in the sub-cohort varied across reference standards, with a significantly lower number of patients requiring urgent interventions (*n* = 16/1853, 0.9%, 95% CI 0.5 to 1.4). There was also differing prevalence across age subgroups, with major trauma less common in elderly and children, compared to adults aged 16–64 years. Notably, major trauma and urgent interventions were significantly more common in adults aged 16–64 years. Weighted and unweighted prevalence of primary and secondary reference standards are shown for differing age groups in *Appendix 6*, *Table 49*.

Included sub-cohort patients presenting to ambulance services with non-trivial injury were predominantly elderly (median age 73 years), female (52.6%), and sustained accidental (88.1%) blunt trauma (97.7%) from ground-level falls (70% of injury mechanisms). There were notable differences between patients with and without major trauma. Cases meeting primary reference standard criteria were younger (median age 61 years vs. 73 years) and more likely to be male (58.5% vs. 46.8%). There was a larger proportion of penetrating trauma (5.9% vs. 2.2%), high-energy mechanisms (e.g. falls > 1 m 35.4% vs. 6.1%) and rural trauma (18.9% vs. 10.6% urban). These patients were more likely to be assigned higher emergency call categories (category 1 21.8% vs. 5.2%), have a HEMS response (19.3% vs. 1.3%), be transported with high priority (56.7% vs. 9.0%), and be pre-alerted to EDs (63.0% vs. 10.9%). Characteristics of the included complete-case study sample are detailed in *Table 11*.

Patients meeting the primary reference standard had a median ISS of 18 [interquartile range (IQR) 13–25]. The head and thorax were the most affected body regions, injured in 53.0% and 40.2% of cases, respectively. Injuries were isolated to a single body region in 35.4% of cases. Urgent trauma-related interventions were performed in 30.8%

TABLE 11 Characteristics of complete-case Phase 2 case–cohort study sample

Variable	Category	Reference standard positive (*n* = 959)	Reference standard positive summary statistic	Reference standard negative (*n* = 1798)	Reference standard negative Summary
Demographics					
Age (years)	Age	959	Median 61	1798	Median 73
			IQR 38–79		IQR 40–84
			Range 0–102		Range 0–103
Age groups (%)	Child < 16	31	3.20%	119	6.60%
	Adult 16–64.9	491	51.20%	644	35.80%
	Elderly > 65	437	45.60%	1035	57.60%
Sex (%)	Female	398	41.50%	944	53.20%
	Male	560	58.50%	831	46.80%
Residence (%)	No fixed abode	5	0.50%	17	1.00%
	Own home	870	91.80%	1491	83.50%
	Rehabilitation centre	4	0.40%	8	0.50%
	Residential home	12	1.30%	147	8.20%
	Nursing home	3	0.30%	103	5.80%
	Other	54	5.70%	20	1.10%
Injury characteristics					
Mode of injury	Blunt	902	94.10%	1758	97.80%
	Penetrating	57	5.90%	40	2.20%

TABLE 11 Characteristics of complete-case Phase 2 case–cohort study sample (*continued*)

Variable	Category	Reference standard positive (*n* = 959)	Reference standard positive summary statistic	Reference standard negative (*n* = 1798)	Reference standard negative Summary
Mechanism of injury	Cutting/piercing/stabbing	56	5.80%	40	2.20%
	Gunshot	1	0.1%	0	0%
	Fall > 1 m	232	24.20%	109	6.10%
	Fall < 1 m	339	35.40%	1274	70.90%
	RTA (motorcycle)	40	4.20%	20	1.10%
	RTA (motor vehicle)	76	7.90%	66	3.70%
	RTA (bicycle)	30	3.10%	22	1.20%
	RTA (pedestrian)	107	11.20%	45	2.50%
	Struck by/collision with object	45	4.70%	85	4.70%
	Struck by/collision with person	21	2.20%	106	5.90%
	Other/unknown	12	1.30%	31	1.70%
Injury intent	Accident	801	83.50%	1529	85.00%
	Assault	83	8.70%	156	8.70%
	Deliberate self-harm	34	3.60%	16	0.90%
	Other	2	0.20%	11	0.60%
	Unknown/unclear	39	4.10%	86	4.80%
Injury location	Sports area	10	1.00%	32	1.80%
	Farm	6	0.60%	4	0.20%
	Home	433	45.20%	901	50.10%
	Health facility	4	0.40%	14	0.80%
	Industrial/construction area	19	2.00%	9	0.50%
	Place for recreation	27	2.80%	28	1.60%
	Residential institution	13	1.40%	179	10.00%
	Public institution	6	0.60%	36	2.00%
	Street	367	38.30%	386	21.50%
	Trade or service area	31	3.20%	73	4.10%
	Other	43	4.50%	136	7.60%
Rural or urban	Urban	783	81.10%	1461	89.40%
	Rural	183	18.90%	174	10.60%
Vital signs					
Systolic blood pressure	Median	959	137	1798	142
	IQR		120–156		126–161
	Range		41–279		50–258
Respiratory rate	Median	959	20	1798	18
	IQR		17–22		16–20
	Range		0–56		Nov-67

continued

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TABLE 11 Characteristics of complete-case Phase 2 case–cohort study sample (*continued*)

Variable	Category	Reference standard positive (*n* = 959)	Reference standard positive summary statistic	Reference standard negative (*n* = 1798)	Reference standard negative Summary
Peripheral oxygen saturations	Median	959	97	1798	97
	IQR		94–99		96–99
	Range		0–100		68–100
GCS	Median	959	15	1798	15
	IQR		14–15		15–15
	Range		Mar-15		Mar-15
Pulse rate	Median	959	86	1798	84
	IQR		72–101		73–97
	Range		0–194		28–180
Incident characteristics					
Call category	Category 1	209	21.80%	94	5.20%
	Category 2	522	54.40%	799	44.40%
	Category 3	177	18.50%	745	41.40%
	Category 4	12	1.30%	48	2.70%
	Category 4	37	3.90%	110	6.10%
	Unknown	2	0.20%	2	0.10%
HEMS response	Yes	185	19.30%	23	1.30%
	No	774	80.70%	1775	98.70%
Mode of transport	Land	936	97.60%	1795	99.80%
	Helicopter	23	2.40%	3	0.20%
High-priority leaving scene	Yes	544	56.70%	163	9.00%
	No	415	43.30%	1635	91.00%
Pre-alert	No	301	31.40%	1591	88.50%
	Yes	604	63.00%	196	10.90%
	Unknown/unclear	54	5.60%	11	0.60%
Closest hospital	LEH	66	6.90%	191	10.60%
	TU	702	73.20%	1301	72.40%
	MTC	190	19.80%	304	16.90%
	Unknown/unclear	1	0.10%	2	0.10%
Destination hospital	LEH	2	0.20%	140	7.80%
	TU	389	40.60%	1223	68.00%
	MTC	568	59.20%	435	24.20%

of these cases (*n* = 295/959), with critical care admissions required in 11.4% of patients (*n* = 109/959). Mortality at 30 days was 8.2% (79/880). Characteristics of the included complete cases meeting primary reference standard criteria are detailed in *Table 11*.

Main analysis

In the main analysis, the accuracy of 22 adult triage tools was evaluated against the primary MATTS reference standard in patients aged over 16 years. In general, an inverse relationship between specificity and sensitivity was observed across triage tools, with an increasing false-positive fraction as the proportion of false negatives decreased (*Table 12* and *Figure 15*). A Pareto front, with higher specificity for a given sensitivity of four optimal triage tools, was evident, comprising: Trauma score; MATTS specific tool; MATTS balanced tool; and the MATTS sensitive tool (see *Figure 15*). Within this set of triage tools, the sensitivity/specificity trade-off varied from 9.9%/99.2%, 37.3%/95.1%, 58.0%/87.0% to 72.4%/75.8%, respectively. Reflecting the low prevalence of the primary reference standard, positive predictive values were comparatively low, varying from 25.9% (trauma score) to 7.0% (MATTS sensitive). Conversely, negative predictive values were uniformly high, differing narrowly between 97.8% and 99.1%. Notably, the SWAS, MATTS specific triage tool, and Trauma Score had moderate or high positive LRs of 6.79, 7.73, and 11.89, respectively. However, except for the MATTS sensitive tool (0.36), negative LRs were over 0.48 for other tools, indicating weak diagnostic evidence in the event of a negative result.

The decision curve analysis indicated that the MATTS sensitive or balanced tools should be implemented if maximising sensitivity and avoiding under-triage was the main priority, to the extent that over 32 (MATTS sensitive tool) or between 16 and 32 (MATTS balanced tool) unnecessary MTC pre-alerts would be tolerated for each true-positive major trauma case. Conversely, if specificity and minimising over-triage was the main concern, the Trauma Score would be optimal if between only three and six false-positive pre-alerts would be tolerated for each correctly identified major trauma case. Between these positions, the MATTS specific tool was the best choice if between 6 and 16 false positives would be accepted for each true-positive case meeting the primary reference standard. Decision curves for the optimal triage tool evaluated in adult patients against the primary reference standard are presented in *Appendix 6*, *Figure 33*.

Relative tool performance was similar when evaluated against secondary reference standards, with the same four triage tools (Trauma score, MATTS specific tool, MATTS balanced tool, MATTS sensitive tool) maximising accuracy and demonstrating Pareto dominance. Sensitivities were generally similar against the MATTS reference standard excluding open fractures, slightly lower against the ISS ≥ 16 reference standard, and higher for the urgent interventions reference standard. Specificities did not significantly differ across secondary reference standards. Diagnostic performance of the selected triage tools against secondary reference standards is detailed in *Appendix 6*, *Tables 50–52* and *Figure 34*.

Subgroup analyses: mechanism of injury

Diagnostic performance of triage tools in different mechanism of injury subgroups against the primary reference standards is summarised in forest plots in *Figure 16*, with further details presented in *Appendix 6*, *Tables 53–56* and *Figure 35*. Clear spectrum effects were apparent in triage tool performance across adult subgroups with differing injury characteristics. Triage tools demonstrated markedly higher sensitivity and lower specificity for the primary MATTS reference standard in penetrating (sensitivity/specificity range: 96.4%/31.6% to 16.4%/100%) compared to blunt injury trauma (range: 70.9%/76.7% to 9.5%/99.1%). The same four triage tools (Trauma score, MATTS specific tool, MATTS balanced tool, MATTS sensitive tool) formed the maximum realisable ROC curve, with PHI, RTST, YAS, LAS and North Carolina tools also contributing to the Pareto front in penetrating injury cases.

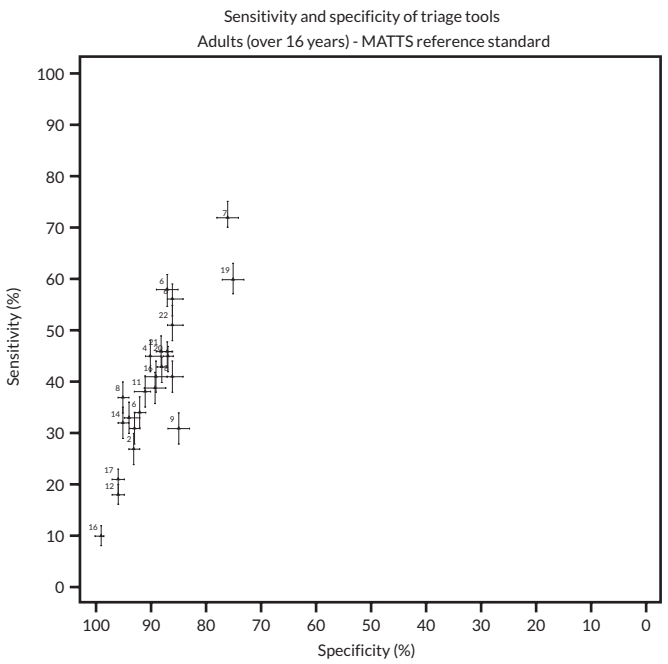
A similar pattern of difference in diagnostic accuracy across triage tools was also apparent in ground-level falls (relatively lower sensitivity/higher specificity) compared to higher-energy (relatively higher sensitivity/lower specificity) mechanisms of injury. For both subgroups, the Trauma score, MATTS specific, MATTS balanced and MATTS sensitive tools again appeared optimal, with the SWAS tool also joining the Pareto front for higher-energy trauma. Sensitivity/specificity varied from 6.1%/99.1% to 57.5%/79.4% across these tools for ground-level falls, and between 12.4%/99.4% and 81.9%/61.2% for higher-energy mechanisms.

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TABLE 12 Diagnostic accuracy metrics for selected adult triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years

Number	Tool name	*N*	TP	FP	TN	FN	Sensitivity (%)	LCL (%)	UCL (%)	Specificity (%)	LCL (%)	UCL (%)	PPV	LCL (%)	UCL (%)	NPV	LCL (%)	UCL (%)	Positive LR	LCL	UCL	Negative LR	LCL	UCL
1	CRAMS	2607	310	107	1572	618	33.4	30.4	36.4	93.6	92.5	94.8	12.0	9.7	14.8	98.2	98.1	98.4	5.24	4.27	6.43	0.71	0.68	0.75
2	Dutch	2607	251	113	1566	677	27.0	24.2	29.9	93.3	92.1	94.5	9.4	7.6	11.7	98.1	97.9	98.2	4.02	3.27	4.94	0.78	0.75	0.82
3	Florida	2607	379	239	1440	549	40.8	37.7	44.0	85.8	84.1	87.4	6.9	5.9	8.1	98.3	98.1	98.5	2.87	2.49	3.30	0.69	0.65	0.73
4	LAS (post-2020)	2607	414	176	1503	514	44.6	41.4	47.8	89.5	88.1	91.0	10.3	8.6	12.2	98.5	98.3	98.6	4.26	3.64	4.98	0.62	0.58	0.66
5	LAS (pre-2020)	2607	518	238	1441	410	55.8	52.6	59.0	85.8	84.2	87.5	9.3	8.0	10.8	98.7	98.6	98.9	3.94	3.46	4.49	0.52	0.48	0.56
6	MATTS balanced	2607	538	219	1460	390	58.0	54.8	61.1	87.0	85.3	88.6	10.4	8.9	12.1	98.8	98.7	98.9	4.45	3.88	5.09	0.48	0.45	0.52
7	MATTS sensitive	2607	672	407	1272	256	72.4	69.5	75.3	75.8	73.7	77.8	7.0	6.2	8.0	99.1	99.0	99.2	2.99	2.72	3.28	0.36	0.33	0.41
8	MATTS specific	2607	346	82	1597	582	37.3	34.2	40.4	95.1	94.1	96.1	16.6	13.3	20.6	98.4	98.2	98.5	7.63	6.08	9.58	0.66	0.63	0.69
9	MGAP	2607	289	253	1426	639	31.1	28.2	34.1	84.9	83.2	86.6	4.7	4.0	5.6	98.0	97.8	98.2	2.07	1.78	2.40	0.81	0.77	0.85
10	North Carolina	2607	385	181	1498	543	41.5	38.3	44.7	89.2	87.7	90.7	9.1	7.7	10.9	98.4	98.2	98.5	3.85	3.29	4.50	0.66	0.62	0.69
11	Oregon	2607	350	146	1533	578	37.7	34.6	40.8	91.3	90.0	92.7	10.0	8.7	12.6	98.3	98.1	98.5	4.34	3.64	5.17	0.68	0.65	0.72
12	PHI	2607	168	66	1613	760	18.1	15.6	20.6	96.1	95.1	97.0	10.5	8.0	13.8	97.9	97.7	98.1	4.61	3.50	6.05	0.85	0.83	0.88
13	RTST	2607	289	121	1558	639	31.1	28.2	34.1	92.8	91.6	94.0	10.3	8.4	12.7	98.2	98.0	98.3	4.32	3.55	5.26	0.74	0.71	0.78
14	SWAS	2607	300	80	1599	628	32.3	29.3	35.3	95.2	94.2	96.3	15.1	12.0	18.9	98.2	98.1	98.4	6.79	5.37	8.57	0.71	0.68	0.74
15	Trauma Score	2607	92	14	1665	836	9.9	8.0	11.8	99.2	98.7	99.6	25.9	15.5	40.1	97.8	97.6	97.9	11.89	6.82	20.74	0.91	0.89	0.93
16	Trauma Score card	2607	318	131	1548	610	34.3	31.2	37.3	92.2	90.9	93.5	10.4	8.5	12.7	98.2	98.1	98.4	4.39	3.64	5.30	0.71	0.68	0.75
17	TTR	2607	193	66	1613	735	20.8	18.2	23.4	96.1	95.1	97.0	12.5	9.5	16.3	98.0	97.8	98.1	5.29	4.05	6.92	0.82	0.80	0.85
18	US Field Triage	2607	401	206	1473	527	43.2	40.0	46.4	87.7	86.2	89.3	8.4	7.1	9.9	98.4	98.2	98.6	3.52	3.04	4.08	0.65	0.61	0.69
19	Victoria	2607	559	422	1257	369	60.2	57.1	63.4	74.9	72.8	76.9	5.6	4.9	6.3	98.7	98.5	98.8	2.40	2.17	2.64	0.53	0.49	0.58
20	Vittel	2607	417	211	1468	511	44.9	41.7	48.1	87.4	85.8	89.0	8.1	6.9	9.5	98.4	98.3	98.6	3.58	3.09	4.13	0.63	0.59	0.67
21	WMAS	2607	425	205	1474	503	45.8	42.6	49.0	87.8	86.2	89.4	8.9	7.5	10.4	98.5	98.3	98.6	3.75	3.24	4.34	0.62	0.58	0.66
22	YAS	2607	476	238	1441	452	51.3	48.1	54.5	85.8	84.2	87.5	8.6	7.4	10.0	98.6	98.4	98.7	3.62	3.17	4.14	0.57	0.53	0.61

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.



No.	Tool name
1	CRAMS
2	Dutch
3	Florida
4	LAS (post-2020)
5	LAS (pre-2020)
6	MATTS balanced
7	MATTS sensitive
8	MATTS specific
9	MGAP
10	North Carolina
11	Oregon
12	PHI
13	RTST
14	SWAS
15	Trauma Score
16	Trauma Scorecard
17	TTR
18	US Field Triage
19	Victoria
20	Vittel
21	WMAS
22	YAS

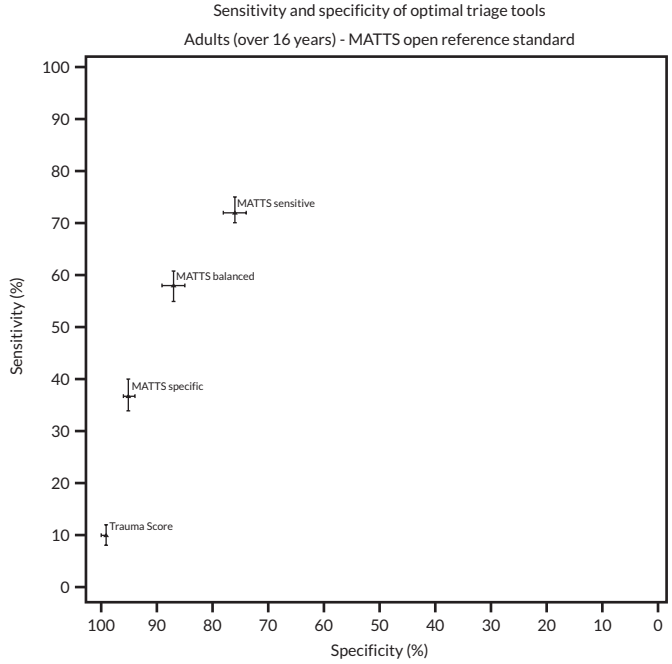


FIGURE 15 Sensitivity–specificity plot for selected adult triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years. Note: Left panel shows all 24 triage tools. Right panel shows maximum realisable ROC curve/Pareto front of optimal tools, excluding tools with poorer accuracy.

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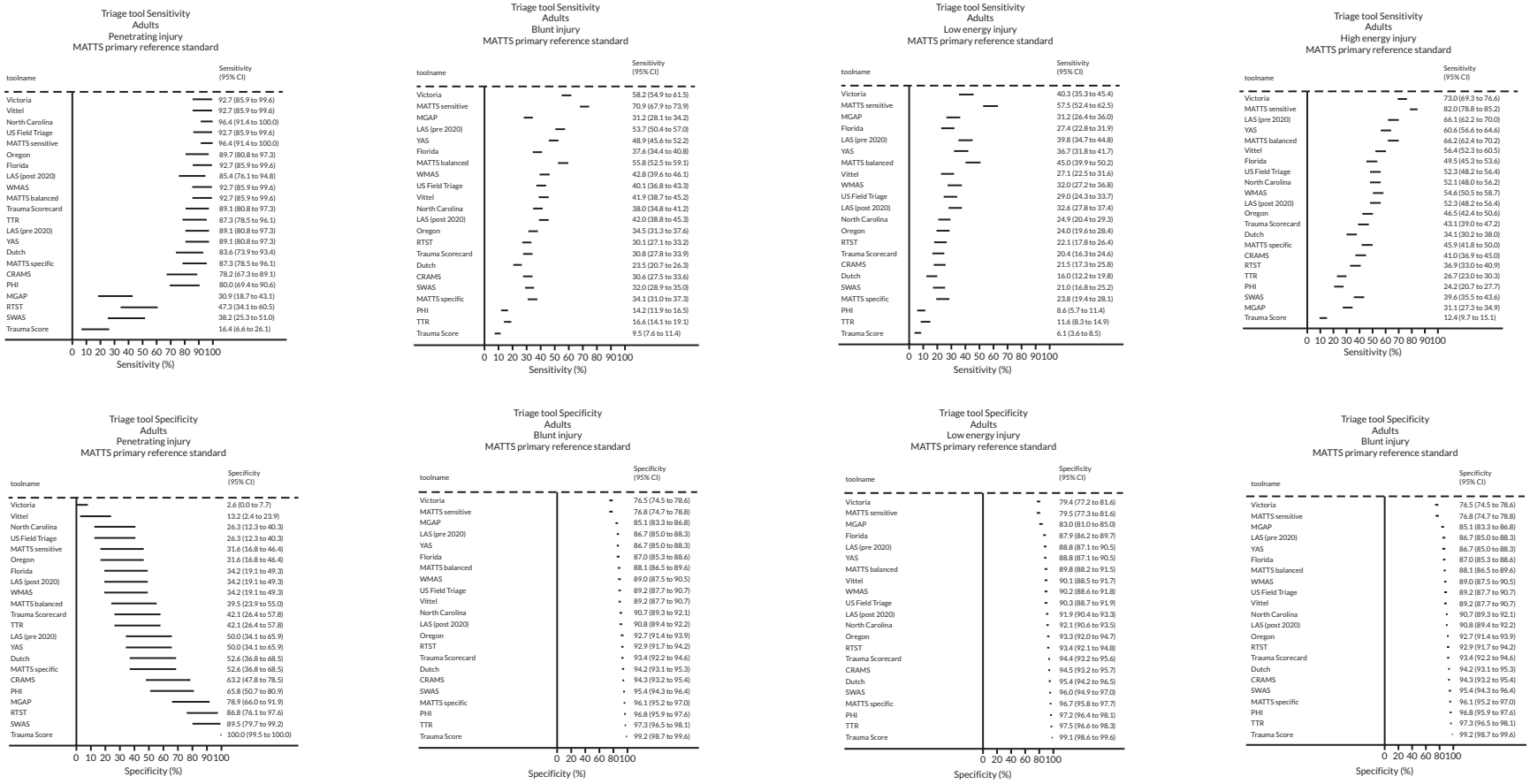


FIGURE 16 Forest plots for selected triage tools evaluated against the primary reference standards in subgroups of different injury characteristics (adults aged over 16 years).

Subgroup analysis: age groups

Diagnostic performance of triage tools in different age subgroups against the primary reference standards is summarised in Forest plots *Figure 17*, with further details presented in *Appendix 6*, *Tables 57–59* and *Figure 36*.

In elderly patients, adult triage tools demonstrated lower sensitivity and higher specificity for all reference standards. Distinct geriatric triage tools [WMAS silver, US Field Triage (Geriatric)] had notably lower specificity and higher sensitivity than generic adult tools. The Trauma Score, MATTS specific, MATTS balanced and the MATTS sensitive tools again appeared to perform optimally, with the [WMAS Silver Safety net and US Field Triage (Geriatric)] tool also forming the Pareto front. Within these tools, the sensitivity/specificity trade-off varied between 6.2%/99.3% (Trauma Score) and 67.3%/49.6% (US Field Triage (Geriatric)) for the primary reference standard.

Triage tool accuracy in adults aged between 16 and 64 years demonstrated slightly higher sensitivity and lower specificity across all tools and reference standards compared to the main analysis. The same triage tools (Trauma score, MATTS specific tool, MATTS balanced tool and the MATTS sensitive tool) remained optimal as in the main analysis, but with the SWAS triage tool also forming the Pareto front.

For children, sensitivity was generally higher, and specificity lower across all reference standards compared to the triage tool performance observed in adults, but estimates were very imprecise. There were no noticeable patterns in performance between the three dedicated paediatric triage tools (NWAS Paediatric Tool, LAS Paediatric Tool and the Paediatric Checklist) and the MATTS consensus-derived and participating ambulance service tools. The Paediatric Checklist, YAS and MATTS sensitive tools formed the Pareto front, with the sensitivity/specificity trade-off varying between 58.1%/89.1% (Paediatric checklist) and 93.5%/39.5% (MATTS sensitive) for the primary reference standard.

Sensitivity analyses

Main analysis findings were not materially changed in sensitivity analyses exploring the influence of study selection criteria and missing data. Including additional primary reference standard positive adult cases involved in acute non-trivial injury events, but where a non-selected WI code was used, resulted in negligible changes in sensitivity estimates, with specificity remaining unchanged. Best- and worst-case missing data scenarios, and multiple imputation, also

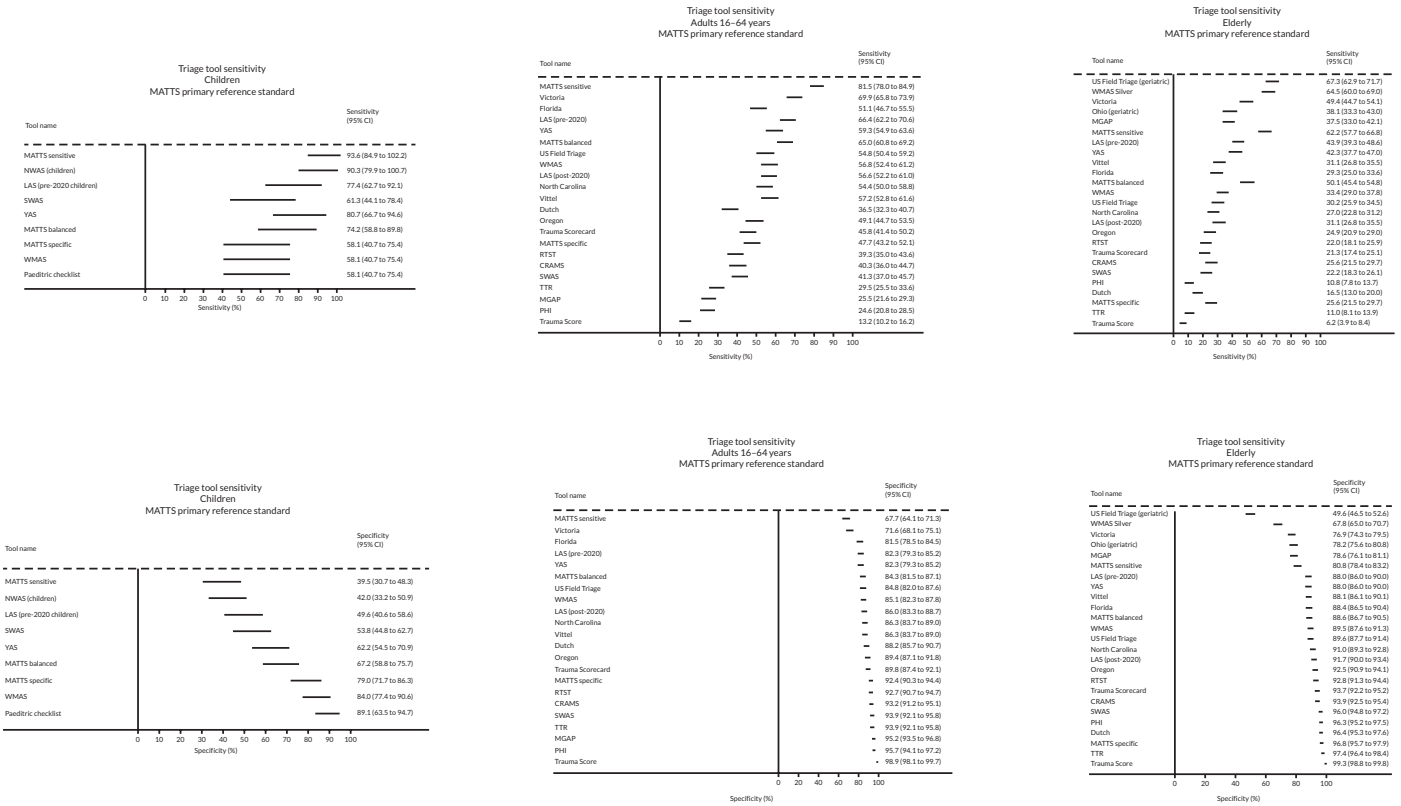


FIGURE 17 Forest plots for selected triage tools evaluated against the primary reference standards in subgroups of different ages.

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resulted in minor changes in sensitivity/specificity, with the same four triage tools (Trauma score, MATTS specific tool, MATTS balanced tool, MATTS sensitive tool) remaining dominant. The results of sensitivity analyses are presented in detail in *Appendix 6*, *Tables 60–63*.

Ancillary analysis: real-life triage decisions

Observed triage decisions (i.e. whether the patient was pre-alerted to the MTC, regardless of the indicated triage tool result) demonstrated overall sensitivity of 46.7% (95% CI 43.5 to 49.9) and specificity of 94.5% (95% CI 93.4 to 95.6) for all ages against the primary MATTS reference standard. There was a clear trend of decreasing sensitivity and increasing specificity from younger to older ages (sensitivity 80.6% in under 16 years falling to 22.7% in over 90 years; specificity 92.4% in under 16 years, increasing to 98.4% in over 90 years, *Figure 18*). Of note, a negligible proportion (< 0.5% across all age groups) of patients not conveyed to a MTC with pre-alert underwent an urgent trauma intervention.

In adult patients, there was a marked variation in triage decision-making against the primary reference standard across ambulance services, ranging from low sensitivity (26%) and high specificity (98%) in SWAS, to higher sensitivity (67%) and lower specificity (89%) in LAS. Observed triage decisions differed from the indicated triage tool result in adults across all ambulance services, with ambulance service clinician judgement resulting in higher specificity than mandatory triage tool steps (*Table 13* and *Figure 18*). Theoretical application of discretionary mechanism of injury (step 3) variables appeared to provide a small increase in sensitivity, with a compensatory small reduction in specificity. Adding special circumstances (step 4) variables resulted in much higher sensitivity, but a very large fall in specificity.

These results were largely unchanged in analyses examining the secondary ISS ≥ 16 reference standard and omitting open fractures from the primary reference standard. A large increase in sensitivity was seen for both the theoretical application of triage tools and actual triage decisions (80.0%), when evaluated against the urgent trauma interventions reference standard. Specificity was not materially changed and remained high (94.0%). Full details of these analyses are provided in *Appendix 6*, *Tables 64–66*.

Discussion

Summary

Patients presenting to four English trauma networks by ambulance with non-trivial injury were most commonly elderly females with blunt trauma from ground-level falls. The overall prevalence of major trauma was low (MATTS reference standard, 2.9%). In adults, an inverse relationship between theoretical sensitivity and specificity for major trauma was observed across studied triage tools, with four optimally performing tools creating the maximum realisable ROC curve: Trauma score (sensitivity 9.9%, specificity 99.2%), MATTS specific tool (sensitivity 37.3%, specificity 95.1%), MATTS balanced tool (sensitivity 58.0%, specificity 87.0%) and the MATTS sensitive tool (sensitivity 72.4%, specificity 75.8%). Spectrum effects were apparent, with higher sensitivity and lower specificity in patients aged 16–65 years, penetrating trauma, and higher-energy mechanisms of injury. Conversely, in elderly patients and low-energy transfer mechanisms, triage tools demonstrated lower sensitivity and higher specificity. For children, sensitivity was generally higher and specificity lower, but estimates were imprecise. Observed prehospital triage decisions in participating trauma networks demonstrated overall sensitivity of 46.7% (95% CI 43.5 to 49.9) and specificity of 94.5% (95% CI 93.4 to 95.6). The accuracy of prehospital triage decisions differed from the indicated theoretical ambulance service triage tool results in adults, with real-life decisions demonstrating higher specificity.

Interpretation

The theoretical performance of triage tools fell well short of recommended ACS-COT targets (sensitivity 95%, specificity 65–75%).[32] This discrepancy likely reflects the challenges of assessment of injured patients in the field. Contributory factors could include the heterogeneity of injury presentations, limited available information, confounding from comorbidities, intoxication and medications, assessment early in the natural history of the injury, and the austere and time-pressured prehospital environment. Moreover, in addition to potentially not being achievable, targeting ACS-COT triage benchmarks may also be undesirable. Given the low prevalence of major trauma in injured patients presenting to ambulance services, high specificity is necessary to maintain an acceptable positive predictive value.[37] Economic

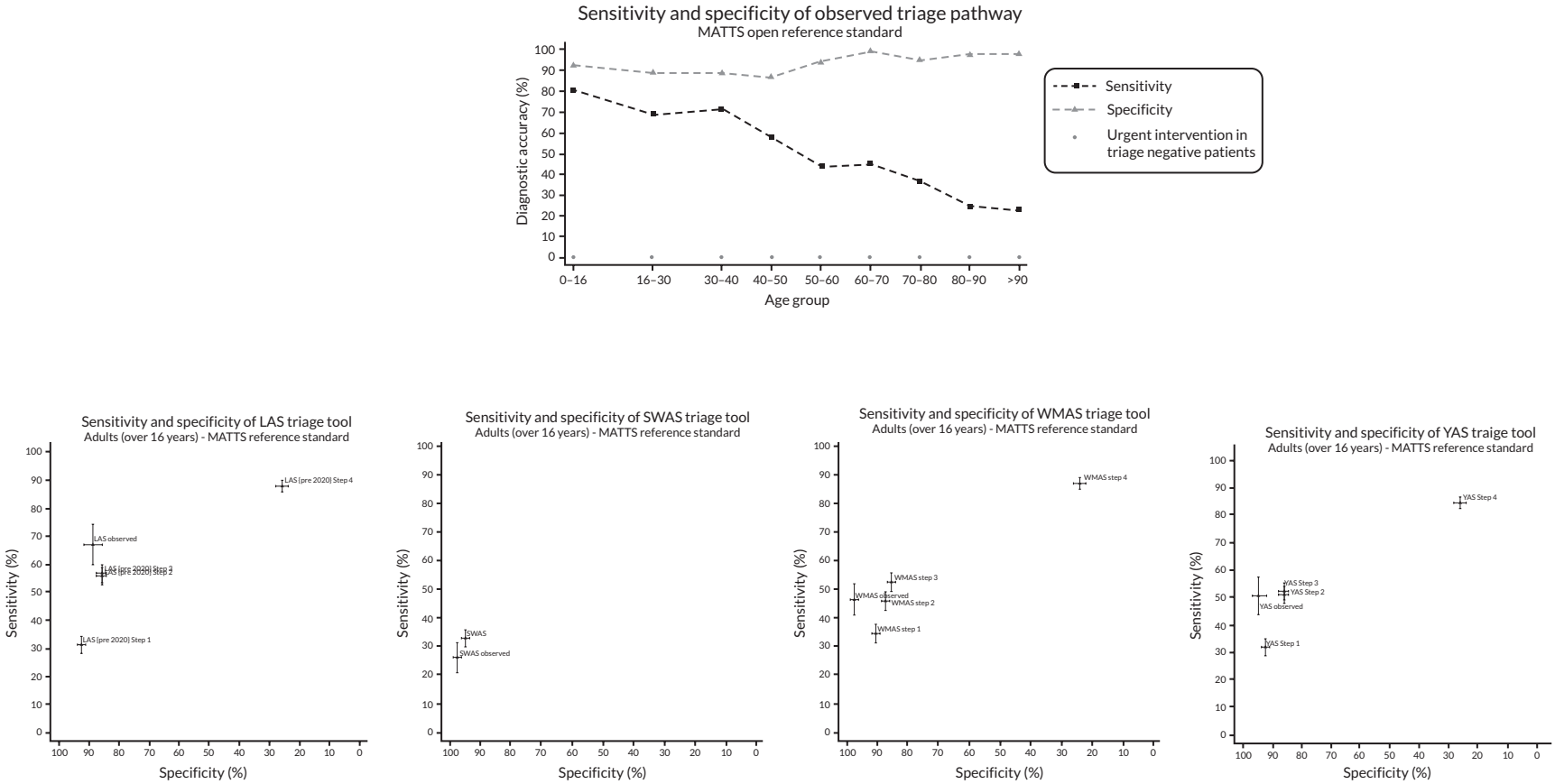


FIGURE 18 Sensitivity and specificity of observed triage decisions in the Phase 2 case–cohort study. Note: Top panel: Sensitivity and specificity of observed triage decisions across different patient age groups; Bottom panel: Sensitivity–specificity plots for participating ambulance services observed triage decisions and theoretical triage tool results evaluated against the primary MATTS reference standard in patients aged over 16 years.

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TABLE 13 Diagnostic accuracy metrics for participating ambulance services observed triage decisions and theoretical triage tool results evaluated against the primary MATTS reference standard in patients aged over 16 years

Tool number	Tool name	*n*	Sensitivity (%)	LCL (%)	UCL (%)	Specificity (%)	LCL (%)	UCL (%)	TP	FP	TN	FN
1	LAS (pre-2020) step 1	2607	31.3	28.3	34.2	92.6	91.3	93.8	290	125	1554	638
2	LAS (pre-2020) step 2	2607	55.8	52.6	59.0	85.8	84.2	87.5	518	238	1441	410
3	LAS (pre-2020) step 3	2607	56.7	53.5	59.9	85.8	84.2	87.5	526	238	1441	402
4	LAS (pre-2020) step 4	2607	87.7	85.6	89.8	26.0	23.9	28.1	814	1243	436	114
5	WMAS step 1	2607	34.5	31.4	37.5	91.2	89.8	92.5	320	148	1531	608
6	WMAS step 2	2607	45.8	42.6	49.0	87.8	86.2	89.4	425	205	1474	503
7	WMAS step 3	2607	52.6	49.4	55.8	85.9	84.3	87.6	488	236	1443	440
8	WMAS step 4	2607	86.9	84.7	89.0	24.4	22.3	26.4	806	1270	409	122
9	YAS step 1	2607	31.3	28.3	34.2	92.6	91.3	93.8	290	125	1554	638
10	YAS step 2	2607	51.3	48.1	54.5	85.8	84.2	87.5	476	238	1441	452
11	YAS step 3	2607	52.3	49.0	55.5	85.8	84.2	87.5	485	238	1441	443
12	YAS step 4	2607	84.5	82.2	86.8	26.0	23.9	28.1	784	1243	436	144
13	SWAS	2607	32.3	29.3	35.3	95.2	94.2	96.3	300	80	1599	628
14	LAS observed	583	66.9	59.7	74.0	88.7	85.7	91.8	111	47	370	55
15	WMAS observed	749	46.6	41.0	52.2	98.0	96.7	99.3	142	9	435	163
16	YAS observed	620	51.0	44.1	57.8	94.2	92.0	96.5	105	24	390	101
17	SWAS observed	655	25.9	20.5	31.3	97.8	96.3	99.2	65	9	395	186

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

evaluations of field triage, including the MATTS project, have also demonstrated that the ACS-COT targets are not cost-effective, and specificity should be prioritised.[43,44]

Together with the Trauma Score, the expert consensus developed MATTS triage tools contributed to the maximum realisable ROC curve in adults, collectively achieving better sensitivity and specificity than other tools. From these, the MATTS specific triage tool appeared to perform closest to the optimal low sensitivity/high specificity trade-off indicated by previous economic evaluations.[43] In clinical practice, a Bayesian approach is often intuitively taken with the possibility of a diagnosis formulated from the estimated prevalence of disease and clinical presentation, together with the observed diagnostic test results. Tests providing strong evidence will have high positive and negative LRs, providing significant shifts from pre- to post-test probability. Overall, the MATTS specific triage tool demonstrated a positive LR (LR+) of 7.7 and negative LR (LR−) of 0.66. On average, there is a 3.1% chance of major trauma when an acutely injured adult patient presents to ambulance services. After a positive triage decision for bypassing/pre-alerting the MTC, there will be a 22% chance that patient will turn out to have major trauma. Conversely, if the triage decision is negative, then there will be a 98% chance that the patient does not have major trauma. Performance across injury subgroups varied, with this tool acting as a 'rule out' test in penetrating trauma (prevalence 5%, LR+ = 1.83, LR− = 0.26, post-test probability 9% if positive, 1% if negative) and low-energy transfer trauma mechanisms (prevalence 1.8%, LR+ = 7.4, LR− = 0.79, post-test probability 12% if positive, 1% if negative); and a 'rule in' test in high-energy transfer trauma mechanisms (prevalence 8.1%, LR+ = 3.01, LR− = 0.45, post-test probability 21% if positive, 4% if negative).

The MATTS specific tool also demonstrated favourable theoretical performance across age strata, forming part of the maximum realisable ROC curve in elderly patients. Although sensitivity was lower, the higher specificity conforms

with economic modelling targets in this subgroup, which emphasise minimisation of over-triage. The tool represents a 'rule in' and 'rule out' test for this lower prevalence subgroup (pre-test probability 1.9%, LR+ = 8.04, LR− = 0.77, post-test probability 13% if positive, 1% if negative). Supportive management and rehabilitation may be more important treatment priorities in silver trauma, with less indication for time-critical resuscitation, surgery and interventional radiology. This was reflected by the fivefold lower prevalence of urgent interventions observed in elderly patients compared to younger adults (0.3% vs. 1.5%). If negative, the MATTS specific tool provides very strong evidence that an urgent intervention will not be needed (pre-test probability 0.3%, LR+ = 16.1, LR− = 0.48, post-test probability 5% if positive, 0% if negative). Under-triaged patients therefore represent relatively lower acuity cases, with the opportunity for deferred interventions or secondary transfer to MTCs.

Interpretation of theoretical triage tool performance in the paediatric subgroup is challenged by the low numbers of injured children presenting to ambulance services and low prevalence of major trauma. Consequently, small sample size and limited numbers of major trauma cases in this subgroup resulted in very imprecise results. There is consequently considerable uncertainty about the theoretical diagnostic accuracy of studied triage tools in children. Furthermore, there are no UK paediatric economic evaluations to indicate the optimal under-/over-triage target. Although the MATTS specific triage tool did not form part of the maximum realisable ROC curve in children, a US economic evaluation of paediatric major trauma triage suggested avoiding over-triage should again be prioritised, possibly supporting use of this tool which demonstrated relatively higher specificity.[46] In the absence of precise results, together with the MATTS commissioning brief requesting a single national triage tool, MATTS qualitative research indicating that simplicity is favoured, and a focus on specificity, it does not appear unreasonable for the MATTS specific tool to be implemented for patients of all ages until definitive evidence for children is available.

The reference standard against which triage tools and decisions should be assessed is arguable. The MATTS definition of major trauma was specifically developed to capture the concept of benefit from direct MTC care and should provide the most relevant reference standard for inclusive NHS trauma networks.[161] Significant open fractures were included in this definition to concord with NICE guidance recommending early specialist management of such injuries.[182] A corresponding open fracture triage tool variable was consequently incorporated into the MATTS expert-derived triage tools. This could represent a form of incorporation bias where index test results are included in the reference standard, falsely elevating sensitivity and specificity. Reassuringly, the sensitivity analysis excluding open fractures from both the index test and MATTS reference standard was materially unchanged.

Conversely, the traditionally used reference standard of ISS has many limitations, particularly its focus on the degree of anatomical trauma per se, rather than the potential to benefit from MTC care.[151] Intervention-based reference standards, such as the US consensus definition, may better reflect the need for MTC care, but do not account for benefit arising from MTC supportive care and rehabilitation.[3,161] The evaluation of multiple reference standards in the current study provides a comprehensive and holistic assessment of triage performance, with the MATTS specific tool performing favourably across varying definitions of major trauma.

It should be noted that when the theoretical performance of triage tools was evaluated, it assumed that triage tools were applied to all non-trivially injured patients, were scored according to observed data recorded in ambulance service records, discretionary triage variables (e.g. *consider* bypass to a MTC in patients taking anticoagulants) were not applied, there was full compliance with the result, and no additional clinical acumen was applied. In reality, previous evidence indicates that triage decisions often differ from that indicted by the theoretical triage tool result.[56] Such practice is observed to improve triage accuracy, generally increasing sensitivity with a slight decrement to specificity.[162] Although aligning with sensitivity/specificity targets indicated by economic modelling, the MATTS specific triage tool therefore requires prospective evaluation after implementation into practice to gain a clear picture of real-life performance.

In common with existing research,[56] ambulance service triage decisions in participating trauma networks were observed to differ from the indicated theoretical ambulance service's triage tool results. This could result from inconsistent triage tool application, discretionary triage tool use in selected patients, application of additional clinical judgement to over-rule indicated triage tool results, or the influence of remote senior clinical support provided by trauma desks. Previous qualitative research has demonstrated that prehospital triage making is often heuristic with triage tools used less commonly as experience increases.[141] It is perhaps not surprising that subjective real-life decisions outperformed triage

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tool accuracy, as clinical judgement has been consistently demonstrated to be superior to objective clinical decision rules in multiple studies across many disease areas.[72,183] The observed real-life triage decisions demonstrated improved specificity, and were closely aligned to empirical cost-effectiveness accuracy targets.[44–46] This finding supports the explicit incorporation of unstructured clinical judgement and senior clinical support into the MATTS specific triage tool.

Differences were apparent in prehospital triage decisions observed across participating trauma networks. This may reflect the underlying use of different ambulance service triage tools. Theoretical accuracy of mandatory triage tool steps (SWAS most specific, LAS most sensitive, WMAS/YAS intermediate) appeared to correlate with real-life triage decision-making (SWAS most specific, LAS most sensitive, WMAS/YAS intermediate). Alternatively, the variation could reflect differences in philosophies (inclusive vs. exclusive focus), geographies (urban vs. rural), or network organisation (e.g. remote decision support). Similar spectrum effects to those observed with theoretical triage tool accuracy were apparent across different age groups, with decreasing sensitivity and increasing specificity for triage decisions from younger to older ages for the primary reference standard. Interestingly, the proportion of false negatives requiring urgent trauma interventions remained negligible (< 1%) across all age groups, perhaps reflecting well-honed clinical judgement in selecting patients perceived to benefit most from MTC care.

The four included English trauma networks comprised a diverse mix of urbanisation, socioeconomic status, geographies and injury profiles. Consecutive patients presenting to ambulance services were included and the study population consequently appears representative of injured patients presenting to ambulance services, reflecting the three different major trauma disease entities (children, younger adults and silver trauma). The results of this study should therefore be generalisable throughout the UK NHS. The exploration of spectrum effects across different adult ages and injury acuities should also provide an indication of performance in alternative subgroups. Patients on the peripheries of trauma networks, transported to study hospitals by non-participating ambulance services and vice versa, were excluded. It is possible, although unlikely, that the case-mix of these cases differs systematically from included patients and theoretical triage tool performance may differ. Moreover, real-life triage decisions could differ compared to patients injured closer to MTCs, influenced by travel times, unfamiliarity with neighbouring trauma networks hospitals, or mandated travel time limits for bypass journeys.

Comparison to literature

As discussed previously (see *Chapter 2*), several systematic reviews have examined the theoretical diagnostic accuracy of adult major trauma triage tools.[53–56] These have reported very heterogeneous results at high risk of bias, often due to skewed trauma registry study populations, making comparison to the current results difficult. The most valid constituent studies have been performed by Newgard (2016) and Voskens (2017),[29,44] who externally validated the 2011 ACS-COT FTDS and Dutch field triage protocol, respectively. Encouragingly, the results of these studies are consistent with those from the current study. Newgard's reported prevalence of 3.1%, sensitivity of 66.2% and specificity of 87.8% for an ISS ≥ 16 reference standard is very similar to those observed herein (prevalence 2.3%, sensitivity 70%, specificity 87%).[44] Voskens demonstrated a sensitivity of 36.2% and specificity of 92.6% for an ISS ≥ 16 reference standard. After consideration of expected spectrum effects from a higher prevalence of major trauma (8.8% vs. 3.1%) and younger population (median age 45 vs. 75), the results broadly agree with the current findings (ISS ≥ 16 reference standard, sensitivity 26%, specificity 93%).

The theoretical diagnostic accuracy findings in elderly patients are also consistent with the existing evidence base (see *Chapter 3*).[71] For example, a relatively well-conducted study by Newgard *et al.*[92] demonstrated relatively lower sensitivity and higher specificity for the 2011 FTDS in this age subgroup (prevalence 6%, sensitivity 37%. specificity 90%), similar to that reported in the current results (prevalence 1.8%, sensitivity 30%, specificity 90%). Although systematic reviews of theoretical diagnostic accuracy of paediatric triage tools exist,[65] they consist of lower-quality studies. Taken together with the imprecise results of the current study, meaningful comparison is difficult.

Limitations

This study has several strengths. The 'single-gate' ('fishing for all cases in the same pond') case–cohort design avoids the selection bias inherent in 'two-gate' case-control study designs where there is separate selection into the study sample based on reference standard status.[184] The main advantage of the case–cohort study design over traditional diagnostic cohort studies is that detailed index test data are only needed on the cases and sub-cohort individuals, not all patients

in the parent cohort, saving resources where detailed data collection is required. Moreover, the same random sub-cohort can be used for studying multiple different reference standards. Recommendations for data collection in retrospective studies using routine data were followed to minimise information bias.[185,186] Other common sources of bias in diagnostic accuracy studies, including test, diagnostic review, incorporation and disease progression biases, were avoided.[81]

Nevertheless, there are some potential limitations with a detailed critical appraisal of potential biases, classified according to QUADAS-2 criteria, provided in *Appendix 6*, *Table 67*.[81] There are several possible sources of selection bias. The use of WI codes to define the study population may not be fully accurate, although only a negligible number of patients were excluded for non-injury presentations and very few major trauma cases were identified where a non-defined WI code was used. Allaying concerns, there were no differences in results when these cases were included in sensitivity analyses. Cases with missing data were excluded from the main analysis, but sensitivity analyses demonstrated that results were robust to missing at random and extreme missing not at random assumptions. Inaccurate matching of TARN and ambulances service records could also result in selection bias. Only a very small proportion of reference standard positive TARN cases were not matched to a corresponding ambulance service record (< 5%). Given the meticulous process of case matching performed by research paramedics, it is likely that these represent non-eligible cases from non-study ambulance services, rather than actual unmatched cases. Also, there is a low probability that any genuinely unmatched ambulance service record would be randomly sampled as a 'non-case'.

The use of routine data may have resulted in information bias from index test or reference standard misclassification with potentially unpredictable effects on sensitivity and specificity estimates. However, data collection methods were specially designed to mitigate this risk and the similarity of findings to previous well-conducted research gives confidence in the current results. Reference standard classification was dependent on TARN inclusion criteria, complete-case ascertainment by TARN, TARN coding and accurate matching of TARN and prehospital data. There is a small possibility of non-identification of reference standard positive cases due to the TARN inclusion criterion relating to admission duration, for example young penetrating trauma patients discharged < 72 hours. Moreover, some reference standard positive cases may not have been enrolled in TARN due to submission delays arising from post-mortems or operational challenges – a particular concern in TUs where there is no financial incentive for case submissions. This risk was mitigated by a 'catch up' TARN data transfer 10 months after study inclusion dates and by selection of highly performing trauma networks with an excellent track record of TARN submissions.

There is also the potential for differential verification bias if cases conveyed to a TU did not receive an urgent intervention that was otherwise indicated due to lack of availability or expertise outside the MTC. Such a case might incorrectly be classified as reference standard negative, biasing sensitivity and specificity estimates. Nevertheless, it is relatively unlikely that in this scenario that other domains of the reference standard would be negative, and the MATTS reference standard was operationalised to attenuate this risk by including patients who underwent urgent secondary transfers to the MTC or died in the ED after active treatment within 6 hours of injury.

Conclusions

Four triage tools, demonstrating a trade-off between theoretical sensitivity and specificity, were identified in adult patients as forming the maximal realisable ROC curve, comprising Trauma score, MATTS specific tool, MATTS balanced tool and the MATTS sensitive tool. The ideal tool depends on the prevalence of major trauma, and relative valuation of false-positive and false-negative cases. MATTS health economic modelling, in common with previous cost-effectiveness evaluations, suggests that the MATTS specific tool offers the optimum trade-off between under- and over-triage. This tool demonstrated favourable theoretical performance across different ages, mechanism of injury subgroups, and differing reference standards for major trauma. Real-life ambulance service triage decisions demonstrated improved specificity, more closely aligned to empirical cost-effectiveness accuracy targets, than theoretical triage tool results, supporting the explicit incorporation of unstructured clinical judgement and senior clinical support into the MATTS specific triage tool. Further prospective investigation of triage decisions following implementation of this triage tool is required to gain a full picture of real-life performance.

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Chapter 9 Major trauma triage using the Major Trauma Triage Study tool: a cohort study

Introduction

During the MATTS project, a candidate national triage tool was developed through an expert consensus process following examination of available tools, qualitative research examining how major trauma triage currently works and review of available evidence.[187] The MATTS specific triage tool ('MATTS tool') targeted a reference standard reflecting the need for early MTC care, and prioritised a relatively high specificity to sensitivity trade-off, established through economic modelling.[43] External validation of theoretical triage tool performance, in comparison to other UK and international tools, suggested that the MATTS tool would perform optimally at typical cost-effective WTP thresholds.

The aim of this study was to investigate major trauma triage decisions using the MATTS tool following implementation into representative English ambulance services. Specific objectives were: to establish the diagnostic accuracy of ambulance service triage decisions; determine the theoretical diagnostic accuracy of the MATTS triage tool; quantify agreement with real-life triage decisions; examine triage tool use, including senior clinical advice; and evaluate spectrum effects across important injury subgroups.

Methods

Study design

A multicentre, prospective cohort study, with nested case–cohort substudy,[172] was conducted to evaluate the performance of the newly implemented MATTS major trauma triage tool. Study procedures followed consensus recommendations for the conduct and reporting of diagnostic accuracy studies.[81,188] Concurrently performed qualitative and economic evaluations are reported in *Chapters 11* and *12*, respectively.

Study Setting

The study was conducted between 1 November 2021 and 15 May 2022 in six inclusive trauma networks served by WMAS (North-West Midlands and North Wales, Birmingham and the Black Country, and Central England networks) and YAS (West Yorkshire, South Yorkshire, and North Yorkshire and Humberside networks), with a collective population of 10.6 million people. The participating trauma networks comprised a mixture of urban, semiurban, and rural localities. Major trauma services for adults (≥ 16 years) and children (< 16 years) generally overlapped, but there were separate, paediatric only, MTCs in the South Yorkshire and Birmingham trauma networks. Further details are provided in the *Appendix 7*, *Tables 68–69* and *Figure 37*.

Study intervention

The newly developed MATTS triage tool was implemented in WMAS and YAS on the 25 October 2021 and 1 October 2021, respectively. As described in *Chapter 7*, the triage tool was designed to be applied to all injured patients and consisted of a checklist of variables grouped into physiological ('Step 1') and anatomical injury domains ('Step 2'). Additional unstructured clinical judgement ('Step 3') could be applied over and above the triage variables in conjunction with telephonic advice from senior prehospital clinicians staffing a remote ambulance service 'trauma desk'. Inclusion and exclusion criteria, supporting information, and definitions of variables were also provided. The triage tool was introduced through each ambulance service's weekly e-mail briefing, organisational private computer networks, and distributed in electronic and paper-based versions, prior to implementation. Formatting differed slightly across each service as presented in *Figure 19*.

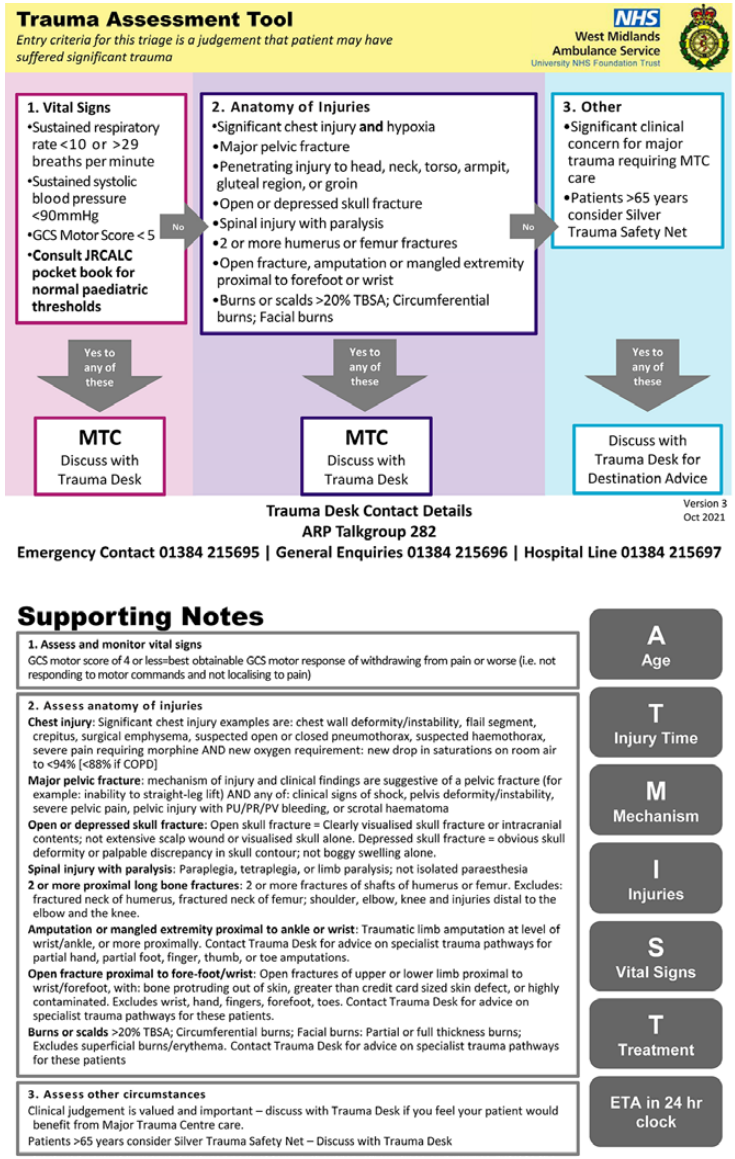


FIGURE 19 Major Trauma Triage Study triage tool implemented in WMAS (left) and YAS (right).

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Study population

The source population comprised injured patients of any age presenting to participating ambulance services and trauma networks. From this, two study populations were examined: (1) the main cohort and (2) a nested case–cohort sample.

Consecutive patients were included in the main cohort if they were conveyed to hospital following an injury by land or air ambulance. Patients were identified by injury-related ambulance service diagnostic WI codes, use of a trauma-related prehospital intervention, or activation of a major trauma ED pre-alert. Patients transported by non-study ambulance services, transported to non-participating trauma network hospitals, non-conveyances, deaths in the fields, isolated hypoxic injuries (e.g. drowning, hangings), isolated burns, non-injury presentations, non-recent trauma presentations and patients from mass-casualty major incidents were excluded. During data collection, it became apparent that some hospitals had incomplete-case ascertainment of major trauma outcome status, either self-reported or when compared to expected submission rates identified in NHS Hospital Episode Statistics data.[189] Eligible patients presenting with injury from the catchment areas of these hospitals were therefore excluded to avoid selection bias (see *Appendix 7*, *Figure 38* for further details). Important population subgroups where triage performance might be expected to differ were pre-specified, and comprised: different age (children, < 16 years; adults, 16–64 years; and elderly, ≥ 65 years) and geographical (rural, urban) strata.

An additional case–cohort sample was defined for more extensive data collection. This allowed a more comprehensive characterisation of the study cohort, and additional analyses examining injury mechanism subgroups, theoretical triage tool performance, triage compliance and manual examination of triage pathways. Nested within the main cohort population, this sample comprised a random 'sub-cohort' of injured patients presenting to ambulance services from the main cohort (sampled irrespective of major trauma status), together with all major trauma cases. Thus, similar statistical precision was retained, with the benefit of efficient collection of detailed information on a smaller sample of patients. Analyses examining theoretical triage tool use, rather than overall triage decisions for injured patients, were restricted to patients where a triage tool would be plausibly used. Thus, any patients presenting with triage tool exclusions were excluded, including advanced directives, advanced frailty, palliative/end-of-life care, unmanageable airway, breathing, or circulation requiring diversion to nearest trauma-receiving hospital for immediate management, > 60 minutes travel from a MTC, and traumatic cardiac arrest.

Data collection

Electronic data from ambulance service patient report forms were linked to data from the TARN to provide a full picture of prehospital triage decisions and major trauma outcomes.

Prehospital data were collected from ambulance service electronic patient report forms for injured patients and imported into the study database. Inclusion criteria were applied using electronic filters with ineligible cases excluded. Routinely collected closed field data were included directly into the study database following range and consistency checks. Collected information comprised ambulance service identifiers, demographics, patient characteristics, physiology, incident details, mechanism of injury, interventions, treatments and clinical assessment information. The primary variables of interest for the main cohort were incident location, hospital destination and ED pre-alert status.

Major trauma status was determined using data from the TARN, the English national trauma registry. TARN data collection has been reported in detail previously in *Chapter 8*.[175,190] Briefly, injured patients are included if they meet any of the following criteria: hospital admission for > 72 hours; critical care or high-dependency unit admission; transfer for specialist care; or death. Patients with simple isolated injuries (e.g. radius fracture), pubic rami or femoral neck fractures and aged over 65, prehospital deaths, or diagnosed as dead on ED arrival with no further management instigated are excluded. A core data set of demographic, injury, treatment, investigation, and outcome data is collected by trained TARN co-ordinators from all relevant patient records. Independent, trained, TARN injury coders centrally grade individual injuries for each case according to AIS (2008 revision) criteria based on clinical, radiological and post-mortem information, and a subsequent ISS is assigned.[151,176] Data for TARN cases from participating study hospitals were imported in the study database and examined manually by research paramedics to ensure eligibility.

Data linkage between eligible injured ambulance service cases and TARN cases was conducted deterministically based on a unique ambulance service patient report form number shared across both data sets. In cases where exact deterministic matching was not possible due to missing or inaccurate patient report form number, research paramedics performed probabilistic matching by manually reviewing each TARN case. Demographic (age, sex), non-unique ambulance identifiers (computer-aided dispatch numbers, ambulance call sign) and incident information [incident date/time, hospital destination, hospital arrival date/time, incident description, incident location (outward and partial inward postcode)] was used from TARN data to search for a corresponding record in ambulance service databases. All matches were independently confirmed by a second researcher and a match was not confirmed in the presence of any uncertainty or disagreement.

A random sample of eligible ambulance service patients, and all eligible major trauma cases, underwent additional hand coding by research paramedics in the case–cohort sub-population,[172] to provide additional information beyond that available in closed data fields. More detailed information on cohort characteristics and triage tool criteria were collected from free-text data fields, coded by research paramedics after review of each patient's record. Data abstraction was blinded, with all ambulance service data anonymised and reference standard status not available. A data dictionary was developed a priori *to* standardise all data elements, provide variable definitions and define categorisations. Data were recorded as missing if not present in closed fields, or if not possible to infer from free-text fields.

Index tests

In the main cohort, the accuracy of prehospital triage decisions for detecting major trauma was examined as the primary index test. Prehospital triage decisions were deemed positive for suspected major trauma if the patient was conveyed to a MTC with a pre-alert, and negative if conveyed to a non-MTC hospital (TU or LEH) or MTC without pre-alert. This concords with NICE major trauma service delivery guidelines, which state the purpose of a triage tool is to identify patients for bypass to a distant MTC,[28] and to determine ED pre-alert calls, allowing mobilisation of a multidisciplinary hospital trauma team. In secondary index tests, prehospital triage decisions were also evaluated according to hospital destination regardless of pre-alert calls (MTC vs. non-MTC hospital) and triage pathway (bypass to MTC or direct transport to MTC with pre-alert vs. other triage pathway). MTC destination and pre-alert status were determined from routinely collected ambulance service data. Triage pathway was defined algorithmically based on travel distance between the incident location and the nearest and destination hospitals.

In the case–cohort sub-population, theoretical triage tool performance was examined. Theoretical triage tool result, based on research paramedics coded ambulance data (positive triage tool variable vs. no objective evidence of a positive triage variables), irrespective of actual hospital destination, clinical judgement, or pre-alert status, was evaluated. Research paramedics also hand-coded triage decisions, hospital destination and triage pathway, as defined above for the main cohort, based on information available in the patient record.

Reference standards

For the primary reference standard, major trauma was defined according to the previously established consensus definition developed earlier in the MATTS project (the 'MATTS reference standard'), described in detail in *Chapter 6*.[161] Other secondary reference standard definitions for major trauma were also examined, including ISS ≥ 16,[151] the US consensus standard for trauma centre need,[3] and the MATTS reference standard without open fractures. Major trauma status was established from TARN data. ISS was pre-calculated by TARN, with other reference standards algorithmically coded by the research team. Any injured ambulance service case not identified as having major trauma was classified as reference standard negative, representing false-positive and true-negative cases. All reference standard cases were classified as positive or negative, with no indeterminate cases.

Outcomes

Diagnostic accuracy of index tests against reference standards was evaluated using sensitivity, specificity, positive and negative predictive values, together with their 95% CIs. Monitoring for adverse events related to triage tool use was also performed by research paramedics' review of ambulance and TARN records. Ambulance

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service, hospital and trauma network incident reporting processes were also scrutinised. Triage compliance was investigated, comparing absolute and chance-corrected agreement (Gwets AC1 with 95% CIs) between the theoretical triage tool result and the actual triage decision (conveyed to MTC with pre-alert vs. other triage pathway). The proportion of cases with objective evidence of triage tool use and senior clinical support, indicated within the clinical record, was also investigated.

Analyses

The main cohort analysis proceeded in six stages. Firstly, the derivation of the main cohort population was detailed. Secondly, sample characteristics were examined using descriptive statistics. Thirdly, in the primary analysis, the accuracy of prehospital triage decisions (conveyance to a MTC with an ED pre-alert) against the MATTS reference standard for major trauma was calculated. Fourthly, subgroup analyses were performed, repeating the primary analysis separately in different age (children, < 16 years; adults, 16–64 years; and elderly, ≥ 65 years) and geographical (rural, urban) strata. In addition to diagnostic accuracy metrics, sensitivity/specificity plots were constructed, classifying results according to their impact defined by the corresponding positive and negative LRs. Likelihood ratios > 10/< 0.1 were categorised as providing strong evidence, 3–10/0.33–0.1 moderate evidence, and 1–3/0.33–1 weak evidence.[191] Fagan's nomograms were also used to show pre- and post-test probability of major trauma before and after prehospital triage decisions.[192,193] Fifthly, in sensitivity analyses, alternative definitions for prehospital triage decisions and secondary major trauma reference standards were investigated in the main cohort. Prehospital triage decisions were also evaluated according to hospital destination, regardless of pre-alert calls (MTC vs. non-MTC hospital) and triage pathway (bypass to MTC or direct transport to MTC with pre-alert vs. another triage pathway). Other definitions for major trauma were also examined, including ISS ≥ 16, the US consensus standard for MTC need, and the MATTS reference standard without open fractures. Sixthly, adverse events related to triage tool were enumerated.

Case–cohort sample analyses were then performed in six further stages. Firstly, the accuracy of prehospital triage decisions (conveyance to a MTC with an ED pre-alert) against the MATTS reference standard for major trauma was determined in mechanism (blunt vs. penetrating trauma, and low vs. high injury) and location of injury subgroups (MTC vs. non-MTC catchment area) strata. Secondly, theoretical triage tool performance was examined against the primary MATTS and other secondary major trauma reference standards. Thirdly, theoretical accuracy was determined in subgroup analyses examining different age (children, < 16 years; adults, 16–64 years; and elderly, ≥ 65 years) and geographical (rural, urban) strata. Fourthly, the accuracy of triage decisions, hospital destination and triage pathway coded by Research Paramedics was evaluated against the primary reference standard. Fifthly, triage compliance was examined, comparing agreement between the theoretical triage tool result and the actual triage decision (conveyed to MTC with pre-alert vs. other triage pathway). Finally, the proportion of cases where there was evidence of triage tool use was described.

Analyses were conducted in R Statistical Software (v4.3.0; R Core Team 2023) and STATA version 18.0 (StataCorp. 2023. Stata Statistical Software: Release 18. StataCorp LP). As hospital destination and pre-alert status are closed data fields in ambulance service patient records, missing data analyses were not required for the main cohort analyses. Complete-case analyses were performed for evaluations using the case–cohort sub-population. For these analyses, inverse probability sampling weights were used for positive and negative predictive values, proportions and agreement statistics, to represent non-sampled injured patients, account for the case–cohort study design and provide inference for the full cohort. The unit of analysis was the individual incident. Direct patient identifiers were unavailable, and it was therefore not possible to account for clustering from recurrent incidents in the same patient. All analyses were pre-specified in a statistical analysis plan, except for high- and low-energy injury subgroups, and weighted analysis of triage tool use, senior advice and agreement, which were defined post hoc. An a priori sample size calculation assumed a major trauma prevalence of 0.8% and triage performance of sensitivity 95% and specificity of ≥ 70% based on ACS-COT targets.[31,32] A sample of 57,125 injured patients would be required to provide a 95% CI coverage of 2.0% for sensitivity and ≤ 1% for specificity.

Results

Sample derivation and characteristics

From 27 October 2021 to 14 April 2022, there were 50,075 source population patients attended by WMAS and YAS with injury diagnostic WI codes, use of a trauma related prehospital intervention, or activation of a major trauma ED pre-alert. Of these, 38,010 (75.9%) were eligible for inclusion in the main cohort. Some 5174 TARN cases were identified from included hospitals over the same period, of whom 3428 were eligible. Of these eligible TARN records, successful matches were found in the ambulance data for 3306 (96.4%) patients. The overall prevalence of major trauma meeting the primary reference standard definition in eligible patients was 2.2% (*n* = 838/38,010 95% CI 2.06 to 2.36). Derivation of the main cohort is detailed in *Figure 20*.

From eligible source population patients, 3627 (9.5%) cases were sampled into the sub-cohort, of whom 292 (8.8%) were TARN cases and 75 (2.0%) met primary reference standard criteria. The remaining 763 reference standard positive cases, who were not sampled in the sub-cohort, were also included in the case–cohort sub-population. Derivation of the case–cohort sub-population is detailed in *Figure 21*.

Included patients presenting to ambulance services with non-trivial injury were predominantly elderly (median age 74 years), female (52.3%), and sustained accidental (86.3%) blunt trauma (88.9%) from ground-level falls (64.8% of injury mechanisms). Characteristics of the study population are presented in *Table 14*. Further details on data completeness and unmatched cases are provided in *Appendix 7*, *Tables 70–71*.

Main cohort analyses

In the primary analysis, prehospital triage decisions, in terms of conveyance to a MTC with an ED pre-alert, demonstrated a sensitivity of 55.3% (95% CI 51.8% to 58.7%), specificity of 94.3% (95% CI 91.4% to 94.6%), positive predictive value of 18.1% (95% CI 16.5% to 19.5%) and negative predictive value of 98.9% (95% CI 98.8% to 99.0%)

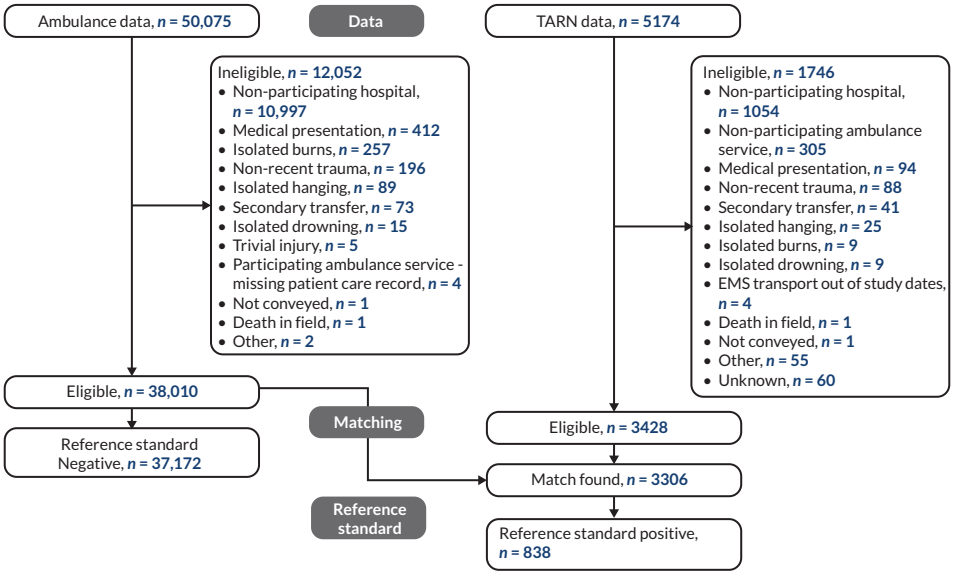


FIGURE 20 Derivation of primary reference standard positive and negative patients in the Phase 3 main cohort.

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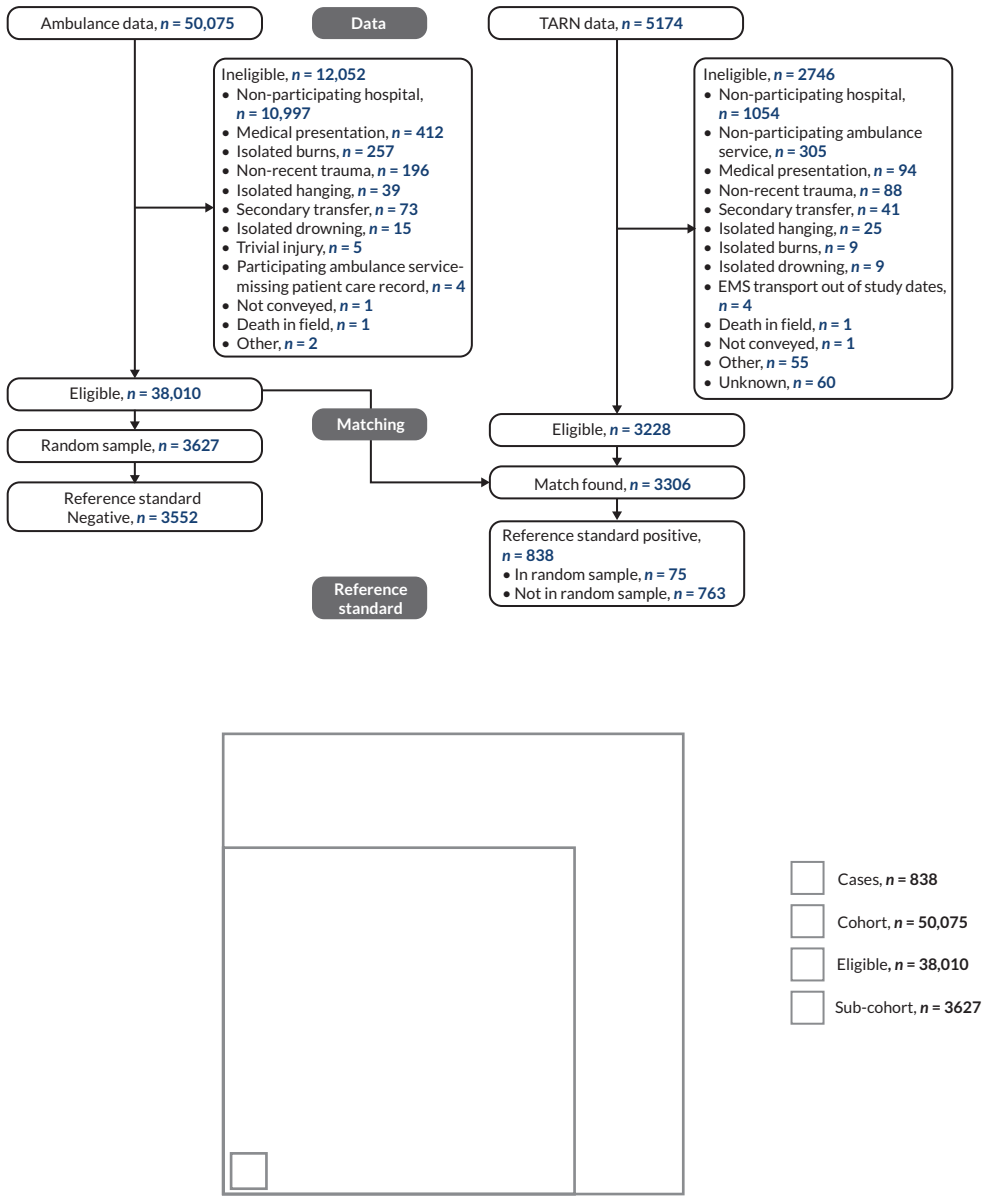


FIGURE 21 Derivation of primary reference standard positive and negative patients in the Phase 3 case–cohort sub-population.

TABLE 14 Characteristics of the Phase 3 main study cohort

		Reference standard negative *N* = 37,172	Reference standard positive *N* = 838	Total *N* = 38,010
Age	*n*	36,964	838	37,802
	Mean (SD)	64.7 (25.6)	56.8 (23.6)	64.5 (25.6)
	Median (IQR)	74.0 (46.0–85.0)	60.0 (36.2–77.0)	74.0 (46.0–85.0)
	Minimum–maximum	0–111	0–99	0–111
Sex	*n*	36,357	817	37,174
	Male	17,245 (47.4%)	502 (61.4%)	17,747 (47.7%)
	Female	19,112 (52.6%)	315 (38.6%)	19,427 (52.3%)

TABLE 14 Characteristics of the Phase 3 main study cohort (*continued*)

		Reference standard negative *N* = 37,172	Reference standard positive *N* = 838	Total *N* = 38,010
GCS total	*n*	34,426	731	35,157
	Mean (SD)	14.6 (1.3)	13.5 (3.3)	14.6 (1.4)
	Median (IQR)	15.0 (15.0–15.0)	15.0 (14.0–15.0)	15.0 (15.0–15.0)
	Minimum–maximum	3–15	3–15	3–15
Systolic blood pressure	*n*	33,622	681	34,303
(mmHg)	Mean (SD)	143.4 (27.5)	136.5 (31.9)	143.3 (27.6)
	Median (IQR)	142.0 (125.0–161.0)	136.0 (118.0–156.0)	142.0 (124.5–161.0)
	Minimum–maximum	0–256	0–239	0–256
Respiratory rate (breaths/min)	*n*	35,308	740	36,048
	Mean (SD)	18.8 (4.7)	20.7 (6.5)	18.8 (4.8)
	Median (IQR)	18.0 (16.0–20.0)	20.0 (18.0–24.0)	18.0 (16.0–20.0)
	Minimum–maximum	0–136	0–72	0–136
Oxygen saturation (on air)	*n*	23,766	452	24,218
	Mean (SD)	96.6 (4.0)	93.7 (9.7)	96.5 (4.2)
	Median (IQR)	97.0 (96.0–98.0)	96.0 (93.0–98.0)	97.0 (96.0–98.0)
	Minimum–maximum	0–109	0–100	0–109
Oxygen saturation (on oxygen)	*n*	461	84	545
	Mean (SD)	91.7 (12.1)	96.3 (5.0)	92.4 (11.4)
	Median (IQR)	95.0 (89.0–99.0)	98.0 (96.0–99.0)	96.0 (90.0–99.0)
	Minimum–maximum	0–100	79–100	0–100
Injury place[a]	*n*	3475	825	4300
	Home	1912 (55.0%)	374 (45.3%)	2286 (53.2%)
	Residential institution	477 (13.7%)	19 (2.3%)	496 (11.5%)
	Road	658 (18.9%)	306 (37.1%)	964 (22.4%)
	Other	428 (12.3%)	126 (15.2%)	554 (12.9%)
Injury intent[a]	*n*	3396	788	4184
	Assault	236 (6.9%)	69 (8.8%)	305 (7.3%)
	Accident	2889 (85.1%)	643 (81.6%)	3532 (84.4%)
	Intentional self-harm	78 (2.3%)	35 (4.4%)	113 (2.7%)
	Other	193 (5.7%)	41 (5.2%)	234 (5.6%)
Blunt or penetrating injury[a]	*n*	3552	838	4390
	Blunt	3172 (89.3%)	730 (87.1%)	3902 (88.9%)
	Penetrating	107 (3.0%)	62 (7.4%)	169 (3.8%)
	Other	273 (7.7%)	46 (5.5%)	319 (7.3%)

continued

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TABLE 14 Characteristics of the Phase 3 main study cohort (*continued*)

		Reference standard negative *N* = 37,172	Reference standard positive *N* = 838	Total *N* = 38,010
Attendance[a,b]	*n*	3552	838	
	Technician	2232 (62.8%)	406 (48.4%)	2638 (60.1%)
	Paramedic	3041 (85.6%)	762 (90.9%)	3803 (86.6%)
	Critical care paramedic	27 (0.8%)	98 (11.7%)	125 (2.8%)
	HEMS	11 (0.3%)	100 (11.9%)	111 (2.5%)
	Physician	18 (0.5%)	81 (9.7%)	99 (2.3%)

a Calculated in case–cohort sample.
b Could be attended by more than one clinician type.

for major trauma defined by the MATTS reference standard. Accuracy varied across different age subgroups, with lower sensitivity and higher specificity evident in elderly patients compared to children and adults aged 16–65 years. No difference in triage performance was observed between rural and urban areas. Outcomes for the primary and subgroup analyses are summarised in *Table 15* and *Figure 22*.

In secondary analyses, alternative definitions for prehospital triage decisions and major trauma were investigated in the main cohort, as detailed in *Appendix 7*, *Tables 72–73*. Designating positive triage as bypass to a MTC (for patients injured in a non-MTC hospital catchment area), or MTC conveyance with pre-alert (for patients injured closest to a MTC), indicated slightly higher sensitivity and specificity. Defining prehospital triage decisions in terms of destination hospital (MTC vs. non-MTC) demonstrated much higher sensitivity and notably lower specificity. Defining major trauma according to ISS ≥ 16 and the US consensus standard for trauma centre need resulted in slightly lower and markedly higher sensitivity, respectively, with specificity materially unchanged. Using the MATTS reference standard without open fractures did not meaningfully change findings. No adverse events related to triage tool use were identified or reported during the study period.

Case–cohort analyses

The accuracy of prehospital triage decisions (conveyance to a MTC with an ED pre-alert) against the primary MATTS reference standard varied across different mechanism of injury subgroups. Sensitivity was much higher for penetrating (95.0%) and high-energy trauma (68.7%) compared to blunt (52.2%) and low-energy trauma (29.5%), with correspondingly lower specificity (75.2% vs. 94.0%; and 85.4% vs. 96.4% respectively). For patients injured within the catchment area of a MTC, triage decisions demonstrated slightly higher sensitivity and lower specificity compared to patients injured closer to a TU or LEH. Research paramedic hand coding of triage decisions, hospital destination and triage pathways yielded indistinguishable findings to algorithmic results from the main cohort analysis. Full details are presented in *Appendix 7*, *Tables 74–75*.

The diagnostic accuracy of theoretical triage tool results was examined in the case–cohort sub-population against the primary MATTS reference standard. Sensitivity was 51.1% (95% CI 47.6% to 54.5%), specificity was 93.6% (95% CI 92.7% to 94.4%), positive predictive value was 15.2% (95% CI 12.5% to 18.0%) and negative predictive value was 98.8% (95% CI 98.5% to 99.2%). Theoretical diagnostic accuracy results calculated for age strata, geographical settings, injury mechanism subgroups and secondary reference standards demonstrated a similar qualitative pattern to those reported for prehospital triage decisions, as detailed in *Appendix 7*, *Tables 76–77*.

It was unclear whether the triage tool had been used in most cases in the case–cohort sample (2941/4,390, population weighted proportion 65.5%), with clear evidence of use present for 445/4390 (weighted proportion 6.3%), and a clear indication the tool was not used in 994/4390 (weighted proportion 28.1%) of patients. Senior clinical advice was documented to have been sought in 707/4390 of patients (weighted proportion 9.3%). Tool use and senior advice were higher in major trauma cases (weighted proportions 31.5% vs. 5.8%, and 49.8% vs. 8.4%, respectively). There was good agreement between the theoretical triage tool result (based on recorded prehospital data) and the observed triage

TABLE 15 Accuracy of triage decisions (conveyance to MTC with pre-alert) for major trauma (MATTS primary reference standard) both overall and in important subgroups

Triage decision[a]	Reference standard negative	Reference standard positive	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Main cohort, primary MATTS reference standard						
N	37,167	838	55.3% (51.8% to 58.7%)	94.3% (94.1% to 94.6%)	18.0% (16.5% to 19.5%)	98.9% (98.8% to 99.0%)
Negative	35,060 (94.3%)	375 (44.7%)				
Positive	2107 (5.7%)	463 (55.3%)				
Elderly subgroup, primary MATTS reference standard						
N	22,265	378	42.3% (37.3% to 47.5%)	96.1% (95.8% to 96.3%)	15.5% (13.3% to 17.7%)	99.0% (98.9% to 99.1%)
Negative	871 (3.9%)	160 (42.3%)				
Positive	2107 (5.7%)	463 (55.3%)				
Adult subgroup, primary MATTS reference standard						
N	13,008	429	65.7% (61.0% to 70.2%)	91.5% (91.0% to 92.0%)	20.3% (18.2% to 22.4%)	98.8% (98.6% to 99.0%)
Negative	11,902 (91.5%)	147 (34.3%)				
Positive	1106 (8.5%)	282 (65.7%)				
Paediatric subgroup, primary MATTS reference standard						
N	1686	31	67.7% (48.6% to 83.3%)	93.4% (92.1% to 94.5%)	15.8% (9.6% to 22.0%)	99.4% (99.0% to 99.8%)
Negative	1574 (93.4%)	10 (32.3%)				
Positive	112 (6.6%)	21 (67.7%)				
Rural subgroup, primary MATTS reference standard						
N	5441	186	55.4% (47.9% to 62.7%)	95.4% (94.8% to 95.9%)	29.0% (24.3% to 33.7%)	98.4% (98.1% to 98.8%)
Negative	5189 (95.4%)	83 (44.6%)				
Positive	252 (4.6%)	103 (55.4%)				
Urban subgroup, primary MATTS reference standard						
N	31,159	652	55.2% (51.3% to 59.1%)	94.2% (93.9% to 94.4%)	16.5% (14.9% to 18.1%)	99.0% (98.9% to 99.1%)
Negative	29,337 (94.2%)	292 (44.8%)				
Positive	1822 (5.8%)	360 (55.2%)				

a TU/LEH/MTC with no pre-alert MTC with pre-alert.

decision, with 3842/4390 patients having concordant outcomes (population weighted data, 90.4% absolute agreement, Gwet's AC1 statistic 0.89, 95% CI 0.89 to 0.89, *Figure 23*).

Discussion

Summary

There was low prevalence of major trauma in injured patients presenting to ambulance services (2.2%). Prehospital triage decisions using the new MATTS triage tool demonstrated a sensitivity of 55.3% (95%CI 51.8% to 58.7%) and specificity of 94.3% (95% CI 91.4% to 94.6%), based on MTC pre-alerts. There was evidence of triage tool use in a

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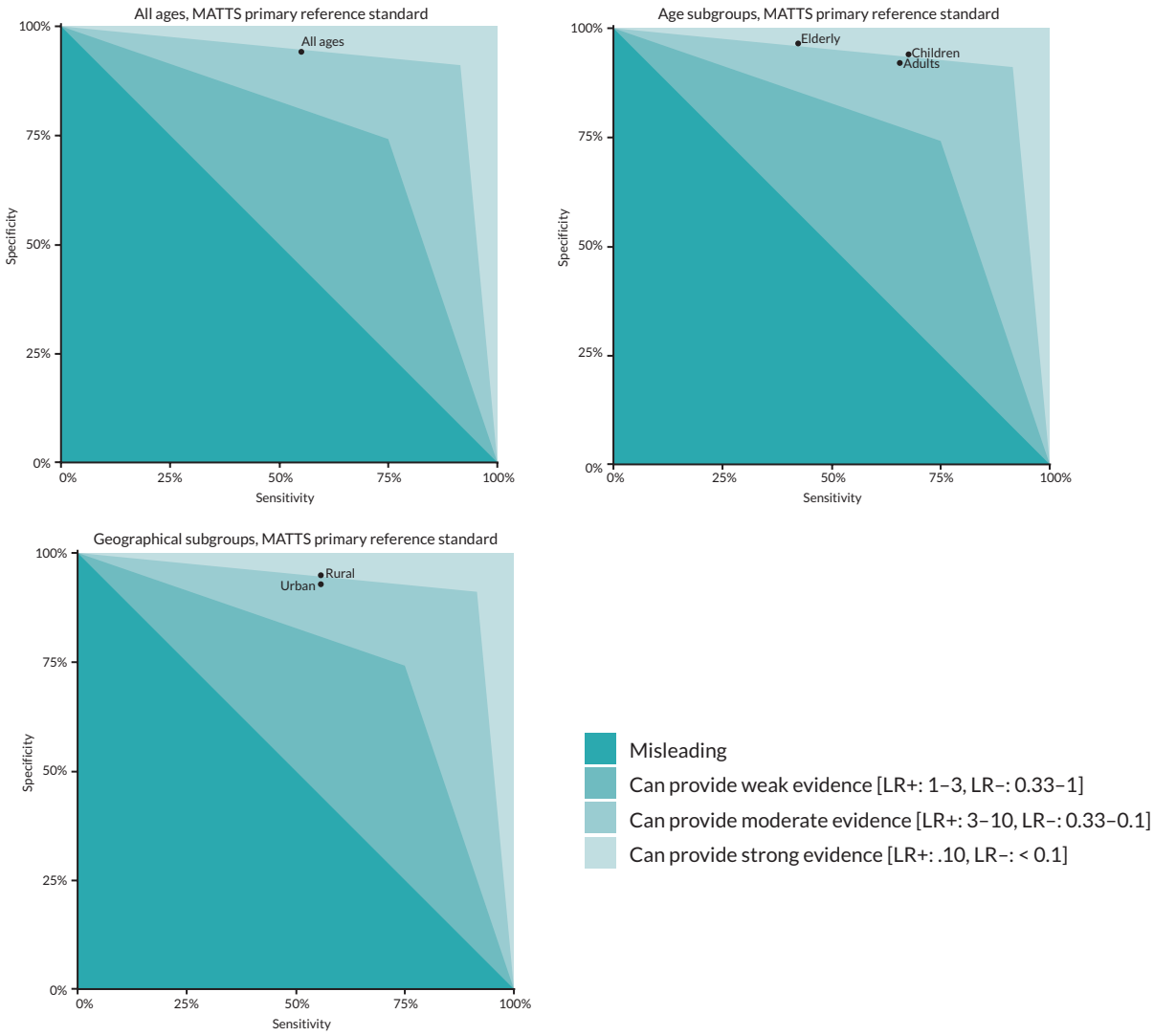


FIGURE 22 Sensitivity–specificity plots showing accuracy of triage decisions (defined as MTC pre-alert or not) for major trauma (defined by the MATTS primary reference standard) in the main cohort, overall and by subgroups.

minority of patients (6.3%), with senior clinical advice sought in 9.3% of cases. Theoretical triage tool sensitivity was 51.1% (95% CI 47.6% to 54.5%) and specificity was 93.6% (92.7% to 94.4%, based on recorded prehospital data). Agreement between the theoretical triage tool result and the observed triage decision was good (absolute agreement 90.4%, Gwet's AC1 statistic 0.89, 95% CI 0.89 to 0.89). There were notable differences in the accuracy of triage decisions, and theoretical triage tool performance, across different ages, mechanism of injury subgroups and alternative reference standards for major trauma. Notably, accuracy of triage decisions was very high for patients requiring urgent major trauma-related interventions (US consensus reference standard, sensitivity 87.0%, specificity 93.5%).

Interpretation

The observed triage accuracy is consistent with recommendations to minimise the false-positive fraction,[43,44] has been shown to be cost-effective at plausible WTP thresholds and is similar to that expected after external validation of the MATTS tool in Phase 2 of the MATTS project. Of note, triage performance was favourable for important subgroups including children, penetrating trauma and high-acuity major trauma cases meeting the US consensus criteria for trauma centre need, significantly altering the post-test probability to cross credible probability thresholds to rule in (≥ 20%) or rule out (≤ 1%) major trauma (see *Appendix 7*, *Figure 39*). Low sensitivity was evident in elderly major trauma, but the benefit of MTC care is less clear-cut in this subgroup.[26,27,45] Moreover, there was a very low proportion of false-negative cases with ISS≥ 16 that required time-critical interventions (*n* = 3/422, 0.7%, US consensus criteria) suggesting lower acuity in these false-negative cases with the opportunity for secondary transfer if required.

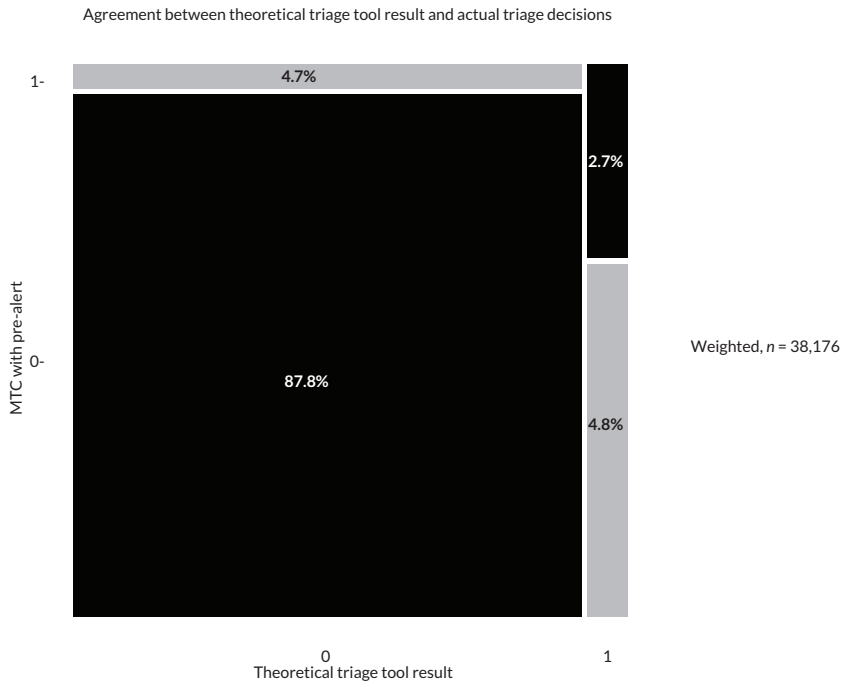


FIGURE 23 Mosaic plot showing agreement between triage decision (MTC pre-alert or not) and theoretical triage tool result. Note: Results weighted for case–cohort study design.

The definition used to classify triage as positive or negative will dictate accuracy results. The ultimate purpose of a triage tool is to ensure that appropriate patients receive expeditious specialist management in a MTC, including initial assessment and resuscitation by a multidisciplinary trauma team.[28] It could therefore be argued that the index test is most appropriately defined as conveyance to a MTC with an ED pre-alert. The ACS-COT definition, based solely on hospital destination (MTC vs. non-MTC),[31,32,57] may not truly reflect the effectiveness of prehospital triage, as patients injured within the catchment area of a MTC will be transported there regardless, and there is no attention to rapidity of care. However, simplistically considering prehospital triage as a binary outcome may not be realistic as hospitals may have differing levels of trauma team activation,[194] and patients conveyed to a MTC without a pre-alert, or where a trauma team is not activated following a pre-alert, have a greater potential to receive early specialist care than those transported to a TU.

Qualitative research, including that from the MATTS project (see *Chapters 5* and *11*), has suggested that ambulance clinicians consult triage tools infrequently, making largely heuristic triage decisions.[162] Consistent with this, explicit evidence of triage tool use was present in only a minority of patients, particularly those ultimately confirmed as major trauma. Despite this, there was good agreement between theoretical triage tool results and actual triage decisions, suggesting a strong correlation between prehospital provider clinical judgement and triage tool results. It has been suggested previously that additional clinical judgement improves triage performance, and in the current study there was a small, but statistically non-significant, increase in sensitivity and specificity with real-life triage decisions (sensitivity 55% vs. 51%; specificity 94.3% vs. 93.6%). Senior clinical advice was obtained in half of major trauma cases, which may have contributed to this increased detection of major trauma.

The inclusion of 8/26 English adult and child MTCs, serving approximately 20% of the English population, should support generalisability of results across the UK NHS. The catchment areas of each participating ambulance service comprise a wide range of urban, rural and socioeconomic settings; and regional demographics (detailed in *Appendix 7*, *Table 69*) are similar to median English values. However, there are some factors that could affect local external validity. Triage performance could vary in remote localities, more developed inclusive trauma networks where TUs have increased capabilities, or networks with collaborative MTC structure where specialties are spread across multiple acute hospitals. Structures (e.g. trauma desk provision), processes (e.g. pre-alerting) and clinical practice patterns (e.g. opinion, practice, education, training and experience) may also vary between ambulance services, private and voluntary prehospital providers and trauma networks. Patients at the peripheries of included trauma networks were not studied,

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and triage decisions could conceivably be different for patients conveyed by non-participating ambulance services to study trauma networks and vice versa. Patients from areas with incomplete TARN data collection were also excluded, although there are no obvious reasons why triage accuracy should differ for these patients.

Comparison to previous literature

Two systematic reviews have examined major trauma triage decisions in adults. Van Rein (2018) examined studies using hospital destination as the index test and serious injury as the reference standard.[56] Only two studies investigating unselected injured patients presenting to EMS were included. Meisler *et al.* (2010) observed prevalence of 12.6% for ISS ≥ 16, sensitivity of 32% and specificity of 76% when using the Triage protocol of Denmark.[58] Newgard *et al.* (2017) reported a prevalence of 3.3% for ISS ≥ 16, sensitivity of 64% and specificity of 70% for inclusive US trauma systems using the 2006 FTDS.[59] A further similar study by Newgard *et al.*[101] was identified from a systematic review by Lupton *et al.* (2023), reporting a prevalence of 5.8% for ISS ≥ 16, sensitivity of 73% and specificity of 64%. More recently, Lokerman *et al.* (2023) evaluated triage decisions based on hospital destination against a reference standard of ISS ≥ 16, before and after introduction of an app-based prediction model in the Netherlands.[60] Prevalence was 2.5/2.9% before and after app introduction, sensitivities were 68/73% and specificities 68/73%.

Direct comparison with these preceding studies is difficult, as results will be strongly influenced by prevalence of major trauma and the distribution of patients between catchment areas of MTCs and non-MTCs. However, the findings appear largely comparable, with broadly similar prevalence (2.5%), sensitivity (66%) and specificity (62%) seen in the relevant secondary analysis of the current study examining hospital destination (MTC vs. non-MTC). The lower specificity in the current study, despite using a higher specificity triage tool, may be explained by a relatively larger proportion of injured patients (32%) arising from a MTC catchment area. These patients will always be transported to the MTC regardless of major trauma status, resulting in a perceived and fixed 'over-triage' if hospital destination is used as the index test.

Limitations

This study has several strengths including objective index test determination, detailed data collection, large sample size, exploration of multiple reference standards, and conformity with diagnostic study design and conduct recommendations. However, there are limitations that could influence internal validity. Correct reference standard classification was dependent on TARN inclusion criteria, case ascertainment, complete data collection and accurate matching of TARN and prehospital data. A comprehensive and successful matching process (> 95%, no differences between matched and unmatched cases) and exclusion of any hospitals with questionable TARN data collection should have minimised the potential for information bias. However, it is possible that some ostensibly true-negative patients were misclassified from not receiving indicated interventions because of transport to a TU, that would have been received if they had in fact been correctly taken to a MTC. Restricting the study population to patients from the catchment area of a MTC (excellent case ascertainment and no risk of reference standard misclassification) reassuringly provided similar results. Other limitations are similar to those in the Phase 2 validation study, including the small risk of selection bias from inaccurate WI codes and missing data (triage tool analysis only); information bias from use of routine data; and possible differential verification bias for reference standards including urgent trauma interventions. These are described in detail in *Appendix 6*.

Conclusions

Triage with the MATTS triage tool demonstrated expected performance, achieving the desired under-/over-triage trade-off target with minimisation of the false-positive fraction. National implementation could ensure cost-effective, and evidence-based triage, and provide standardisation across trauma networks. The finding that low-energy, silver trauma, will often (and likely unavoidably) be conveyed to non-MTCs supports strengthening of inclusive trauma networks with investment in TUs and robust secondary transfer pathways.

Chapter 10 Accuracy of prehospital triage following implementation of the Major Trauma Triage Study major trauma triage tool: a before-and-after study

Introduction

Triage using the newly implemented MATTS tool demonstrated expected performance, with sensitivity of 55.3% (95% CI 51.8% to 58.7%) and specificity of 94.3% (95% CI 91.4% to 94.6%, based on MTC pre-alerts). Comparing triage outcomes before and after implementation could provide additional information on the potential effectiveness of the MATTS triage tool.

The aim of this study was therefore to compare the accuracy of prehospital triage for injured patients before and after implementation of the MATTS major trauma triage tool in two English ambulance services. Specific objectives were to: compare sensitivity and specificity of actual triage decisions before and after introduction of the MATTS tool; contrast the theoretical diagnostic accuracy of previously used triage tools and the new MATTS tool; and examine the agreement between the theoretical triage tool result and actual triage decision.

Methods

Study design

A before-and-after comparative study was conducted to evaluate the diagnostic performance of the newly implemented MATTS triage tool in YAS and WMAS compared to previously used tools.[195] Study procedures followed consensus recommendations for the conduct and reporting of observational studies.[196] This study was a post hoc secondary analysis of data collected during the Phase 2 case–cohort study (see *Chapter 8*), and Phase 3 cohort study, with nested case–cohort substudy (see *Chapter 9*).

Setting, study population and data collection

The study was conducted across two time periods, before and after implementation of the MATTS triage tool, in WMAS and YAS. The first study period ('before group') comprised Phase 2 of the MATTS project between 1 November 2019 and 28 February 2020. The second study period ('after group') was performed during Phase 3 between 1 November 2021 and 15 May 2022. Inclusion criteria and data collection were substantially consistent across both study periods, although the nomenclature used to categorise WI codes differed across the two time periods, and between ambulance services. Only YAS and WMAS patients were included in the study population.

Index tests and reference standards

The triage tools used by WMAS and YAS during the 'before' period are presented in *Appendix 8*, *Figure 40*. The MATTS triage tool was introduced into clinical practice in WMAS and YAS on the 25 October 2021 and 1 October 2021, respectively. Formatting of the MATTS tool differed slightly across each service. The accuracy of prehospital triage decisions (conveyed to a MTC with a pre-alert vs. other triage pathway) for detecting major trauma was the primary index test. Theoretical triage tool performance was also examined as a secondary index test. Discretionary variables were excluded. For the primary reference standard, major trauma was defined according to the consensus definition developed earlier in the MATTS project (see *Chapter 6*).[161] Other secondary reference standard definitions for major trauma were also examined, comprising ISS ≥ 16 and the US consensus standard for trauma centre need.[3,151]

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Analyses

The analysis proceeded in five stages. Firstly, characteristics of YAS and WMAS patients before and after implementation of the MATTS triage tool were compared descriptively. Secondly, in the primary analysis, the accuracy of prehospital triage decisions against the MATTS reference standard for major trauma was compared within each ambulance service, before (Phase 2 case–cohort study sample) and after (Phase 3 cohort study sample) implementation of the MATTS triage tool. Fischer's exact test and two-sample tests of proportions, stratified by ambulance service, were used to separately compare sensitivity and specificity across the study periods. Thirdly, the theoretical accuracy of triage tools used during each study period was similarly compared within each ambulance service using Phase 2 and Phase 3 case–cohort samples. Fourthly, triage compliance was examined, comparing agreement between the theoretical triage tool result and the actual triage decision (conveyed to MTC with pre-alert vs. other triage pathway) for each study period and ambulance service. Absolute percentage agreement and chance-corrected agreement (Gwet's AC1) were compared using weighted case–cohort study data.[197] Finally, analyses were repeated for the secondary reference standards of ISS ≥ 16 and the US consensus standard for trauma centre need. Analyses were conducted in R Statistical Software (v4.3.0; R Core Team 2023) and STATA version 18.0 (StataCorp. 2023. Stata Statistical Software: Release 18. StataCorp LP). The unit of analysis was the individual incident. Marginal case–cohort analyses were weighted using inverse probability weights when required to provide inference for the parent cohort.[198]

Results

Between 1 November 2019 and 28 February 2020, 1448 patients were included from the Phase 2 case–cohort into the 'before' group. This consisted of 319 and 211 consecutive cases meeting the MATTS reference standard, and 428 and 436 randomly sampled patients without major trauma, in WMAS and YAS, respectively. Between 1 November 2021 and 15 May 2022, 38,010 patients were included from the Phase 3 cohort study into the 'after' group. There were 427 and

TABLE 16 Comparison of YAS and WMAS patients before and after implementation of the MATTS triage tool

		BEFORE: Case–cohort study		AFTER: Cohort study	
		Reference standard negative *N* = 918	Reference standard positive *N* = 530	Reference standard negative *N* = 37172	Reference standard positive *N* = 838
Age	*n*	918	530	36964	838
	Mean (SD)	64.3 (27.2)	57.5 (27.2)	64.7 (25.6)	56.8 (23.6)
	Median (IQR)	75.0 (43.0–86.0)	61.0 (37–79)	74.0 (46.0–85.0)	60.0 (36.2–77.0)
	Minimum–maximum	0–103	0–102	0–111	0–99
Sex	*n*	902	529	36357	817
	Male	395 (43.8%)	313 (59.2%)	17245 (47.4%)	502 (61.4%)
	Female	507 (56.2%)	216 (40.8%)	19112 (52.6%)	315 (38.6%)
GCS total	*n*	918	530	34426	731
	Mean (SD)	14.6 (1.2)	13.4 (3.2)	14.6 (1.3)	13.5 (3.3)
	Median (IQR)	15 (15–15)	15 (14–15)	15.0 (15.0–15.0)	15.0 (14.0–15.0)
	Minimum–maximum	3–15	3–15	3–15	3–15
Systolic blood pressure	*n*	889	526	33622	681

TABLE 16 Comparison of YAS and WMAS patients before and after implementation of the MATTS triage tool (*continued*)

		BEFORE: Case–cohort study		AFTER: Cohort study	
		Reference standard negative *N* = 918	Reference standard positive *N* = 530	Reference standard negative *N* = 37172	Reference standard positive *N* = 838
(mmHg)	Mean (SD)	144.8 (26.2)	139.2 (28.9)	143.4 (27.5)	136.5 (31.9)
	Median (IQR)	142 (126–161)	137 (121–154)	142.0 (125.0–161.0)	136.0 (118.0–156.0)
	Minimum–maximum	75–258	41–233	0–256	0–239
Respiratory rate (breaths/min)	*n*	918	530	35308	740
	Mean (SD)	18.6 (5.9)	20.4 (5.9)	18.8 (4.7)	20.7 (6.5)
	Median (IQR)	18 (16–20)	20.0 (16–22)	18.0 (16.0–20.0)	20.0 (18.0–24.0)
	Minimum–maximum	11–57	3–60	0–136	0–72
Injury place	*n*	874	519	12117	825
	Home	490 (56.1%)	262 (50.5%)	7497 (61.9%)	374 (45.3%)
	Residential institution	84 (9.6%)	2 (0.4%)	1014 (8.4%)	19 (2.3%)
	School, other institution, or public ad- ministrative area	23 (2.6%)	3 (0.6%)	89 (0.7%)	4 (0.5%)
	Medical hospital or health service	6 (0.7%)	1 (0.2%)	62 (0.5%)	1 (0.1%)
	Athletics or sports area	18 (2.1%)	2 (0.4%)	165 (1.4%)	9 (1.1%)
	Road, street or highway	181 (20.7%)	205 (39.5%)	1888 (15.6%)	306 (37.1%)
	Trade or service area	25 (2.9%)	13 (2.5%)	270 (2.2%)	24 (2.9%)
	Industrial or construction area	5 (0.6%)	13 (2.5%)	31 (0.3%)	10 (1.2%)
	Farm	3 (0.3%)	5 (1.0%)	24 (0.2%)	13 (1.6%)
	Place for recreation	15 (1.7%)	6 (1.2%)	164 (1.4%)	32 (3.9%)
	Other	24 (2.7%)	7 (1.4%)	913 (7.5%)	33 (4.0%)
Injury intent	*n*	868	520	8993	788
	Assault	69 (8.0%)	69 (8.0%)	623 (6.9%)	69 (8.8%)
	Accident	434 (83.5%)	434 (83.5%)	7800 (86.7%)	643 (81.6%)
	Intentional self-harm	19 (3.7%)	19 (3.7%)	258 (2.9%)	35 (4.4%)
	Other	15 (2.9%)	15 (2.9%)	312 (3.5%)	41 (5.2%)
Major trauma	MATTS reference standard		530/26,016 (2.0%)[a]		838/38,010 (2.2%)
	MATTS reference standard (excluding open fractures)		502/25,787 (1.9%)[a]		710/38,010 (1.9%)
	ISS ≥ 16		485/25,722 (1.8%)[a]		981/38,010 (2.6%)
	US consensus standard		193/25,589 (0.8%)[a]		146/38,010 (0.4%)

a Weighted case–cohort data providing inference for parent cohort.

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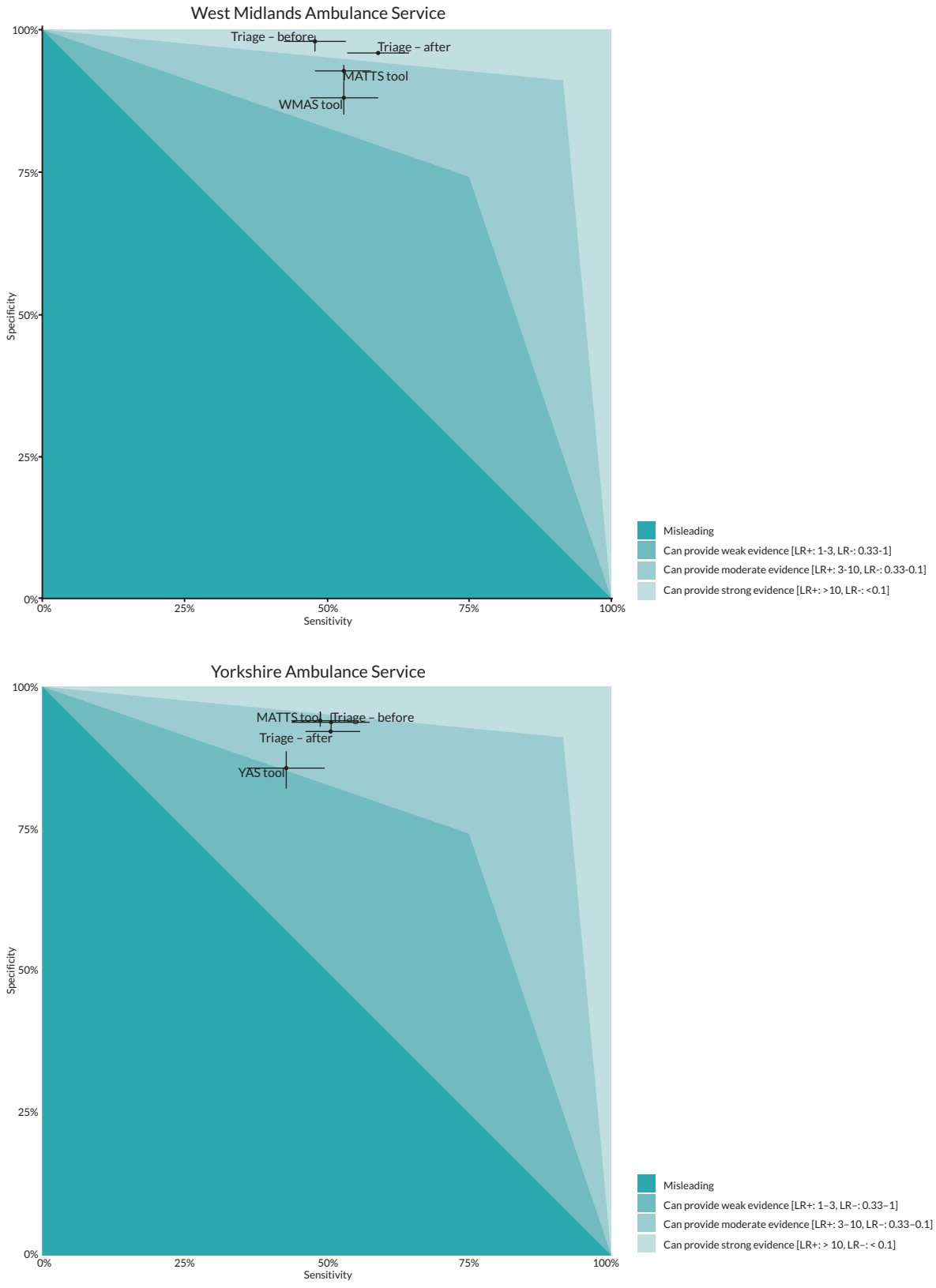


FIGURE 24 Sensitivity–specificity plots showing theoretical triage tool and triage decision accuracy before and after implementation of the MATTS triage tool. Note: Plots are categorised according to the corresponding LR and the consequent strength of evidence provided.

411 cases with major trauma as per the MATTS reference standard, and 20,679 and 16,493 cases without major trauma in WMAS and YAS, respectively. Of the patients without major trauma, 3552 were randomly sampled into the 'after' case–cohort study (WMAS: 1790; YAS: 1762). Patient characteristics were similar across both study periods as detailed in *Table 16*. The prevalence of the primary MATTS reference standard was 2.0% in the 'before' study group and 2.2% in the 'after' study group.

Triage decisions were similar in both ambulance services before and after implementation of the MATTS tool. In YAS, neither sensitivity (0.0% difference, 95% CI −8.3% to 8.3%, $p = 1.0$) nor specificity (2.0% difference, 95% CI −0.2% to 4.3%; $p = 0.17$) significantly differed. In WMAS, sensitivity was higher following implementation of the MATTS tool (11.0% difference, 95% CI 3.8% to 18.2%; $p < 0.01$), with no significant difference in specificity (2.0% difference, 95% CI 0.7% to 3.3%; $p = 0.06$).

Theoretical specificity of the new MATTS tool was significantly higher than the previously used WMAS and YAS tools (WMAS: 87.8% vs. 92.8%, 5.0% difference, 95% CI 1.9% to 8.1%; $p < 0.01$; YAS: 86.0% vs. 94.4%, 8.4% difference, 95%

TABLE 17 Sensitivity and specificity of triage decisions[a] for major trauma[b] before and after implementation of the MATTS triage tool in WMAS and YAS

Study period	Triage tool	Sensitivity (%)	95% LCL (%)	95% UCL (%)	Specificity (%)	95% LCL (%)	95% UCL (%)	TP	FP	TN	FN
WMAS											
Before[c]	WMAS	48.3	42.5	53.5	97.7	96.8	99.2	154	11	471	165
After[d]	MATTS	59.0	54.3	63.7	96.0	95.7	96.3	252	825	19,854	175
YAS											
Before[c]	YAS	51.2	44.3	57.7	94.3	91.8	96.2	108	25	411	103
After[d]	MATTS	51.3	46.2	55.8	92.4	91.6	92.4	211	1250	15,243	200

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

a Conveyance to a MTC with a pre-alert.
b MATTS reference standard.
c Case–cohort study data.
d Cohort study data.

TABLE 18 Theoretical sensitivity and specificity of triage tools[a] for major trauma[b] before and after implementation of the MATTS triage tool in WMAS and YAS

Study period	Triage tool	Sensitivity (%)	95% LCL (%)	95% UCL (%)	Specificity (%)	95% LCL (%)	95% UCL (%)	TP	FP	TN	FN
WMAS											
Before[c]	WMAS	53.0	47.5	58.5	87.8	85.1	90.9	169	59	423	150
After[c]	MATTS	52.9	48.3	57.7	92.8	91.8	94.2	226	129	1661	201
YAS											
Before[c]	YAS	42.7	36.3	49.7	86.0	82.7	89.3	90	61	375	121
Afterc	MATTS	49.1	44.2	53.8	94.4	92.9	95.1	202	99	1663	209

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

a Objective evidence of positive triage tool variable in patient record; discretionary variables ignored.
b MATTS reference standard.
c Case–cohort study data.

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TABLE 19 Agreement between indicated theoretical triage tool result and actual triage decisions before and after implementation of the MATTS triage tool in WMAS and YAS

Study period	Triage tool	Triage decisions	Gwet's AC1	95% LCL	95% UCL	Per cent agreement	95% LCL	95% UCL
WMAS								
Before[a]	WMAS	MTC Pre-alert	0.87	0.86	0.88	89.0%	88.5%	89.5%
After[a]	MATTS	MTC Pre-alert	0.89	0.88	0.90	90.6%	90.2%	91.0%
YAS								
Before[a]	YAS	MTC Pre-alert	0.74	0.69	0.79	83.0%	80.0%	85.9%
After[a]	MATTS	MTC Pre-alert	0.89	0.88	0.90	90.3%	89.8%	90.7%

LCL, lower 95% confidence limit; UCL, upper 95% confidence limit.
a Case–cohort study data.

CI 4.6% to 11.4%; $p < 0.01$). Theoretical sensitivity of the MATTS triage tool did not significantly differ from either of the preceding tools (WMAS: 53.0% vs. 52.9%, 0.1% difference, 95% CI −7.2% to 7.2%; $p = 1.0$; YAS: 42.7% vs. 49.1%, 6.4% difference, 95% CI −2% to 14.2%; $p = 0.13$). The accuracy of triage decisions and theoretical triage tool results for each study period and ambulance service are presented in *Tables 17* and *18* and *Figure 24*. Findings were qualitatively similar for the secondary reference standards of ISS ≥ 16 and the US consensus standard for trauma centre need, as detailed in *Appendix 8*, *Tables 78–81*.

Agreement between the theoretical triage tool result and the actual triage decision was generally good across all study periods and ambulance services, with Gwet's AC1 statistics varying from 0.74 to 0.89. However, chance-corrected and absolute agreement were significantly higher following implementation of the MATTS triage tool in both WMAS (Gwet's AC1: 0.87 vs. 0.89, per cent agreement: 89.0% vs. 90.6%, $p < 0.01$) and YAS (Gwet's AC1: 0.74 vs. 0.89, per cent agreement: 83.0% vs. 90.3%, $p < 0.01$). *Table 19* provides further details on agreement between theoretical triage tool results and actual triage decisions, with results displayed graphically in *Appendix 8*, *Figure 41*.

Discussion

Summary

When evaluated according to objective information in prehospital records, the MATTS triage tool demonstrated similar theoretical sensitivity, and increased specificity, compared to the previously used YAS and WMAS triage tools. However, despite this, the accuracy of actual triage decisions was broadly unchanged before and after implementation of the MATTS tool. The theoretical result indicated by the MATTS tool aligned more closely with real-life triage decisions than with previously used tools. These findings were qualitatively unchanged in sensitivity analyses examining alternative reference standards for major trauma.

Interpretation

In response to evidence from economic evaluations,[43–46] the MATTS triage tool was developed to prioritise specificity relative to existing more sensitive tools used in some English ambulance services. The definitions and cut points for MATTS variables consequently have a higher threshold for positivity than the preceding YAS and WMAS triage tools, for example GCS motor score≤ 4 compared to GCS total ≤ 13. The observed higher theoretical specificity of the MATTS triage tool is therefore expected, but the finding of similar sensitivity is less predictable as a trade-off in accuracy usually exists.[199] Inclusion of more predictive variables, or the additional open fracture variable in the MATTS triage tool, with this injury type also included in the MATTS reference standard definition, could explain this finding.

At face value, it may be surprising that actual triage decisions were unchanged following implementation of the more specific MATTS tool. There are several possible reasons to account for this counterintuitive result. The new tool was introduced without a dedicated training programme. While representative of typical NHS practice, and serendipitous in avoiding the Hawthorne effect,[200] this may mean that triage tool use was not fully embedded into practice, with the original triage tools used across both study periods. However, the concurrently performed qualitative evaluation (see *Chapter 11*) suggests that most on-scene providers had previously seen and used the new MATTS tool. Moreover, the 'after' data collection period occurred up to 1 month after implementation of the new triage tool, allowing time for full integration into prehospital triage processes.

Previously used WMAS and YAS triage tools incorporated clinical judgement through non-mandatory mechanism of injury and patient characteristic variables. Conversely, the new MATTS tool includes an unstructured clinical judgement step. Similarity of triage accuracy decisions, despite different theoretical tool performance, could be explained by clinical judgement operating in different directions across the study periods to produce the same outcome. There was discordance between the indicated theoretical tool result and the actual triage decision in 10–17% of cases supporting this hypothesis. Evidence for the benefit of clinical judgement has been inconsistent,[162,201–203] but an increasing body of recent literature suggests improved triage performance compared to a fully protocolised approach.[56] This is supported by the current study, where actual triage decisions disagreed with the indicated tool outcome in a significant minority of patients but demonstrated better accuracy overall.

The population that a triage tool is used for is important in determining accuracy for that subgroup of cases ('spectrum effects') and will also influence the overall number of false-negative cases, by possible exclusion of patients where major trauma is not considered. The MATTS triage tool was designed for use in all injured patients.[47] However, previous research has found that prehospital triage consists largely of instinctive system 1 thinking, with triage tools formally used only by inexperienced staff or in uncertain 'grey' cases.[52,162] Such selective tool use would limit the potential impact of any new triage tool intervention.

Comparison to literature

There is a paucity of studies directly comparing triage decisions resulting from use of different triage tools, with existing studies generally showing a limited effect from new tools. A large recent study by Lokerman *et al.*[60] used a similar uncontrolled before-and-after design to evaluate a major trauma diagnostic prediction model, operationalised as an electronic app, in two regions of the Netherlands.[60] An overall increase in sensitivity was observed from 68.2% to 79.1% ($p = 0.01$), with no change in specificity (79.1% vs. 79.6%, $p = 0.13$). However, there was distinct variation between regions, with under- and over-triage unchanged in one of the two studied areas. Interestingly, use of the app was detected in only 2.4% of injured patients ($n = 978/40{,}311$); and when use was registered, agreement between the theoretical app result and actual triage decision was low, with only 50% of positive cases transported to a higher-level trauma centre. Inpatient mortality did not significantly differ before and after app introduction. Direct comparison with the current study is difficult as both the index test (hospital destination) and reference standard (ISS ≥ 16) differ. Other, older, studies are limited by selected trauma registry populations. For example, Hansen *et al.* (2021) showed a significant decrease in the proportion of Danish trauma patients admitted to a trauma centre after implementation of a new regional trauma triage guideline, with no change in under-triage or long-term mortality.[204]

Limitations

In addition to the usual sources of selection bias, information bias and confounding, uncontrolled before-and-after studies are also at risk of systematic error from secular trends, regression to the mean, and differences in study procedures across study periods.[205] The 'before' and 'after' study times were separated by the COVID-19 pandemic, but patient characteristic and the epidemiology of trauma appear to have been similar in the two study groups.[206] No lockdowns or social restrictions were in place during any data collection period, although face-mask wearing was mandatory in public indoor venues for a brief period in the 'after' group (December 2021 and January 2022). No other obvious changes occurred in trauma networks over this period. Meaningful changes in major trauma triage, and important secular trends, therefore, seem unlikely. The relatively long study periods, undifferentiated population, and consistent before/after results suggest a low likelihood of regression to the mean. Due to system-level changes, available WI codes differed before and after new triage tool implementation for both

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ambulances services. Additionally, WMAS used a revised electronic patient record in the second study period. Despite every effort to ensure consistency, it is possible that variation in the spectrum of included patients, or data measurement, across study periods could have influenced results. A full risk-of-bias assessment according to ROBINS-I criteria is detailed in *Appendix 8*, *Table 82*.[207]

Conclusions

Although more specific, implementation of the MATTS triage did not significantly change the accuracy of triage decisions following implementation. However, compliance was improved, with theoretical MATTS triage tool results aligning more closely with real-life triage decisions.

Chapter 11 'Quite frankly I'm absolutely swimming in algorithms on my ambulance': a qualitative analysis of clinician views on a new major trauma triage tool

Introduction

The newly developed MATTS specific triage tool was implemented in WMAS and YAS in October 2021 and underwent prospective evaluation (see *Chapter 9*) demonstrating sensitivity of 55.3% and specificity of 94.3% for triage decisions. While these quantitative results show 'what' happens overall when the new tool is implemented, they do not focus on the 'why' and 'how' of prehospital major trauma triage. Qualitative research, exploring in-depth behaviour, opinions and attitudes, may provide important insights to further improve trauma triage performance.[143]

This mixed-methods study, consisting of a survey and focus groups, aimed to explore user experiences of the new MATTS triage tool. Specific objectives were to describe awareness, availability and application of the tool; analyse how the tool is used in real-world practice; investigate its perceived value; establish any barriers or facilitators to its use; and to identify any suggested areas for improvement.

Methods

Study design and setting

A survey and focus groups were undertaken to explore clinician views following implementation of the MATTS triage tool. The study was conducted in WMAS and YAS between March and July 2022. Procedures followed best practice recommendations for conduct and reporting of qualitative research, focus groups and electronic surveys.[70]

Survey

An anonymous web-based questionnaire examined the views of on-scene ambulance clinicians attending injured patients in the field and trauma desk personnel. The survey was iteratively developed following feedback from Research Paramedics and piloting. The final survey contained introductory information, a copy of the new triage tool, and questions exploring: respondent background; exposure to the tool; how and when the tool is used; tool acceptability; and views on specific triage variables, exclusion criteria and ED pre-alerting. A mixture of closed-ended, Likert scale, and open-ended questions were posed, dependent on the subject. The questionnaire was administered using the Qualtrics platform (Qualtrics, Provo, UT).

In YAS, an electronic survey link was distributed in the weekly e-mail newsletter sent to all operational staff on 4 consecutive weeks. Additional participants were identified personally by Research Paramedics attending three EDs and eight ambulance stations during day shifts. For these respondents, the survey was completed on their own electronic device (smart phone, tablet, or computer) and the opportunity to enter a prize draw to receive conference tickets was offered. In WMAS, Research Paramedics attended six ambulance hubs during day shifts with potential respondents provided with a brief verbal explanation of the survey, offered a small gift (e.g. chocolate bar), and asked to complete the survey on a laptop provided to them. Trauma desk personnel were approached directly with an e-mail containing a link to the online survey.

Survey data were analysed descriptively using Microsoft Excel and SPSS (IBM, Armonk). Closed-ended questions were summarised across the entire sample and stratified by respondent group (on-scene providers vs. trauma desk personnel). Available case analyses were performed, including participants who only partially completed the survey where possible. Open questions using free-text responses were transcribed into tables and data scrutinised to identify within and between question themes. Sample size was determined by available respondents but aimed for > 50 respondents in line with previous recommendations to achieve data saturation.[142]

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Focus groups

Four online focus groups were conducted to explore experiences of using the new MATTS triage tool. Three groups of clinicians were identified: 'on-scene' ambulance clinicians (participating in two focus groups), trauma desk personnel (single focus group), and TU and MTC ED consultants (single focus group). Each focus group contained a distinct group of clinicians to enable people to speak freely about their experience and identify tensions in their interactions with other services. Personnel from both ambulance service regions attended each focus group to facilitate comparison between areas.

Ambulance clinicians were invited to participate through each service's weekly operational e-mail briefings. All trauma desk personnel and all consultants from a single MTC and TU were contacted directly with an e-mail invite. Focus groups were held online, using Microsoft Teams (Microsoft, Redmond, WA, USA). Two experienced qualitative researchers with previous experience of running online focus groups facilitated the sessions. A third researcher with a clinical background attended as an observer and made notes which were added to the analysis. A topic guide was developed, including: introduction of the MATTS tool to the service; its use in practice; barriers and enablers to implementation; and suggested areas for improvement. The topic guide was adapted for relevance to each group of clinicians and then used flexibly to follow up issues raised within each session. The focus groups lasted for 1.5 hours and were recorded and transcribed verbatim. All participants were offered a £40 payment.

Transcripts were 'sense checked' for errors and analysed by the two researchers who had facilitated the groups. A preliminary coding framework was developed based on the topic guide, preceding survey findings, and review of the first focus group transcript. The researchers used this framework to jointly undertake the coding of the first focus group, refining the coding framework and adding subcategories and illustrative quotes to an Excel spreadsheet. Once this had been agreed, the two researchers independently coded the other three focus groups, refining the coding framework and adding further quotes. As the ED consultant data contained significantly different material, the coding framework was substantially adapted, and this transcript was coded into a separate coding framework using the same process of refinement and identification of illustrative quotes. Quotes were identified by participant type (ambulance clinician – AC, trauma desk – TD, ED) and a focus group and participant number. Empirical research has suggested that three focus groups are enough to identify the most prevalent themes within a data set.[142,208]

Results

A total of 259 ambulance clinicians (147 from WMAS, 111 from YAS) started the survey, of whom 24 exited without providing any further information, 194 fully completed and 41 partially completed the questionnaire. A total of 13 trauma desk personnel fully completed, and 2 partially completed, the survey. The characteristics of survey respondents are summarised in *Table 20*.

Most on-scene providers had previously seen (84%, *n* = 197/234) and used (75%, *n* = 147/197) the new triage tool. However, use was infrequent (most commonly monthly, 36%, *n* = 53/147) with many respondents using the tool only in specific cases (65%, *n* = 91/139), rather than all injured patients. All trauma desk respondents had seen and used the triage tool, applying it in all cases (100%, 13/13), on a daily basis (53%, 8/15).

The new triage tool was viewed positively by ambulance clinicians and trauma desk respondents who felt it was easy to use, well formatted, had clear instructions, and helped make quick, accurate and consistent decisions (< 8% disagreement for each aspect, *Figure 25*). There was also concordance that the triage tool inclusion and exclusion criteria were appropriate (≤ 22% disagreement for each criterion, *Figure 26*). Individual triage variables were viewed favourably, with 88% (*n* = 168/196) of respondents considering all criteria to be good predictors of major trauma. Clinical judgement in 'Step 3' was also strongly supported (> 90% agreement from ambulance clinicians and trauma desk personnel).

The triage tool was viewed as a guideline to support decision-making, rather than a mandatory protocol (ambulance clinicians 66%, *n* = 120/181, trauma desk personnel 100% 13/13). Senior clinical support for triage decisions provided by the trauma desk was generally viewed favourably (ambulance clinicians 55% agreement, *n* = 94/170). On-scene

TABLE 20 Characteristics of survey respondents

Role	On-scene respondents *n* = 235 *n* (%)	Trauma desk respondents *n* = 15 *n* (%)
Doctor	6 (2.6%)	–
Emergency care assistant (or equivalent)	7 (3.0%)	–
Paramedic, *N* (%)	147 (62.6%)	9 (60.0%)
Technician (or equivalent), *N* (%)	38 (16.2%)	–
Critical care paramedic, *N* (%)	–	4 (26.6%)
Other, *N* (%)	17 (7.2%)[a]	1 (6.7%)[b]
Ambulance service		
WMAS	135	8
YAS	100	7
Clinical experience		
Years, median (IQR)	7 (4–16)	17 (12–25)
Major trauma case load		
Median (IQR)	1 (1–2) per month	6 (3–10) per shift

a The majority (*n* = 10) of those selecting 'other' were student paramedics.
b Advanced nurse practitioner.

respondents most frequently reported seeking clinical support when having a clinical suspicion of major trauma, but where triage variables were negative (67%, *n* = 114/170). However, trauma desk personnel indicated that advice was sought for a wider range of patients, including whether to apply the tool and to confirm major trauma cases, even if clearly positive for triage tool variables (62%, 8/13).

Emergency department pre-alerts provided in structured format (95% of all respondents, 157/166) and most frequently undertaken by the trauma desk (trauma desk personnel 85%, *n* = 11/13; on-scene providers 59%, *n* = 87/146). MTC pre-alerts were declined occasionally or often (ambulance clinicians: 28%, *n* = 44/155; trauma desk: 39% *n* = 5/13), with frustrations raised regarding interruptions from hospital staff, and conflicting interpretation of the triage tool results.

There were no meaningful differences apparent in responses across different subgroups of ambulance clinicians (emergency care assistants, technicians, paramedics) or experience levels. Moreover, results were similar between each ambulance services, except for higher support for the trauma desk from WMAS clinicians. Survey responses are presented in detail in *Appendix 9*, *Table 83*.

Focus groups

A total of 26 clinicians attended four focus groups, comprising: on-scene prehospital providers (2 focus groups), trauma desk personnel (1) and ED physicians (1). Meeting participants and characteristics are detailed in *Table 21*. Seven themes were identified: tool awareness, availability, and format; tool application; clinical judgement and triage decision-making; triage performance; patient subgroups: elderly and children; trauma desk interaction; and pre-alerts. These themes are explored below with illustrative comments and supportive quotes detailed in *Appendix 9*, .

Awareness, availability and format

All prehospital providers and ED physicians were aware of the new triage tool, which was available to participants in electronic and 'hard copy' formats, depending on region, role and practice location. Occasional difficulties in tool access were described, either not having the hard copy on their person or connectivity problems affecting online access. Participants almost universally reported that using the new MATTS triage tool was an improvement on previous

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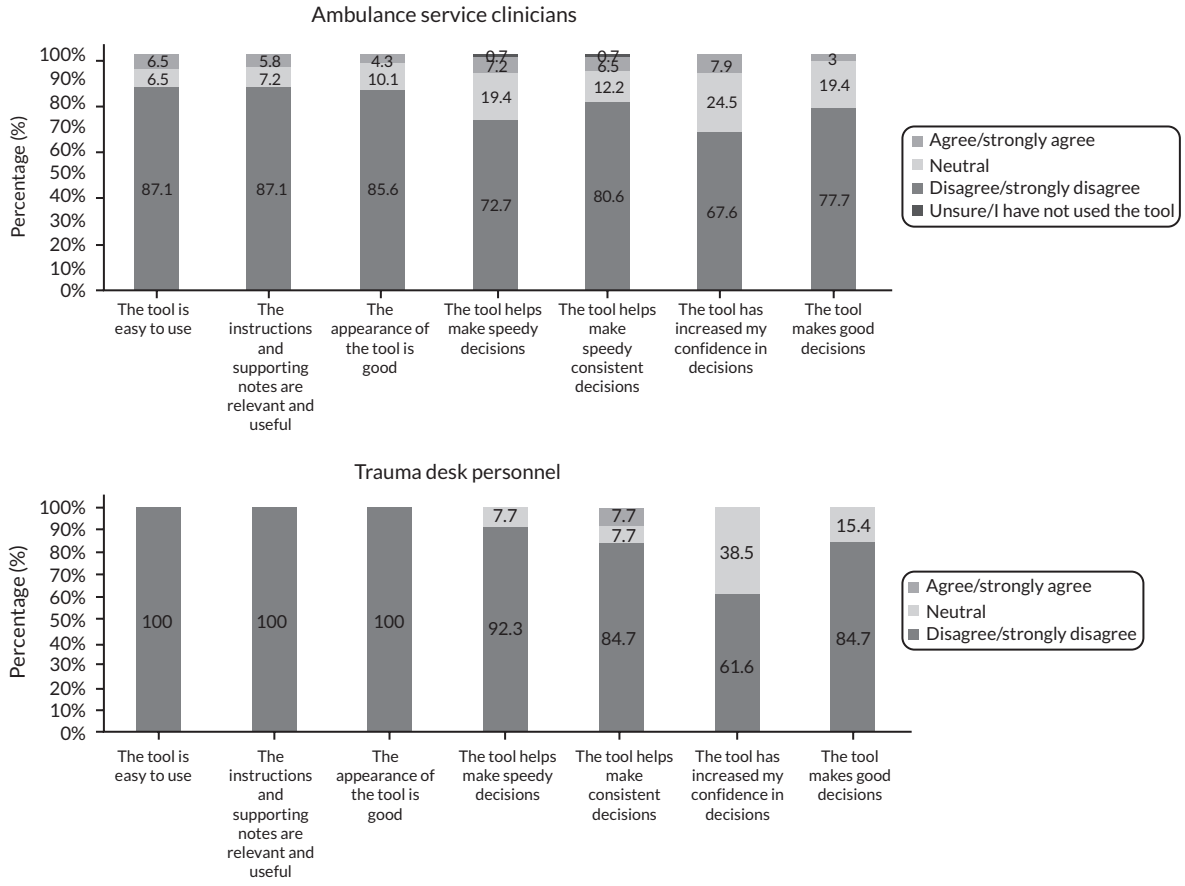


FIGURE 25 Stakeholder views on using new MATTS triage tool.

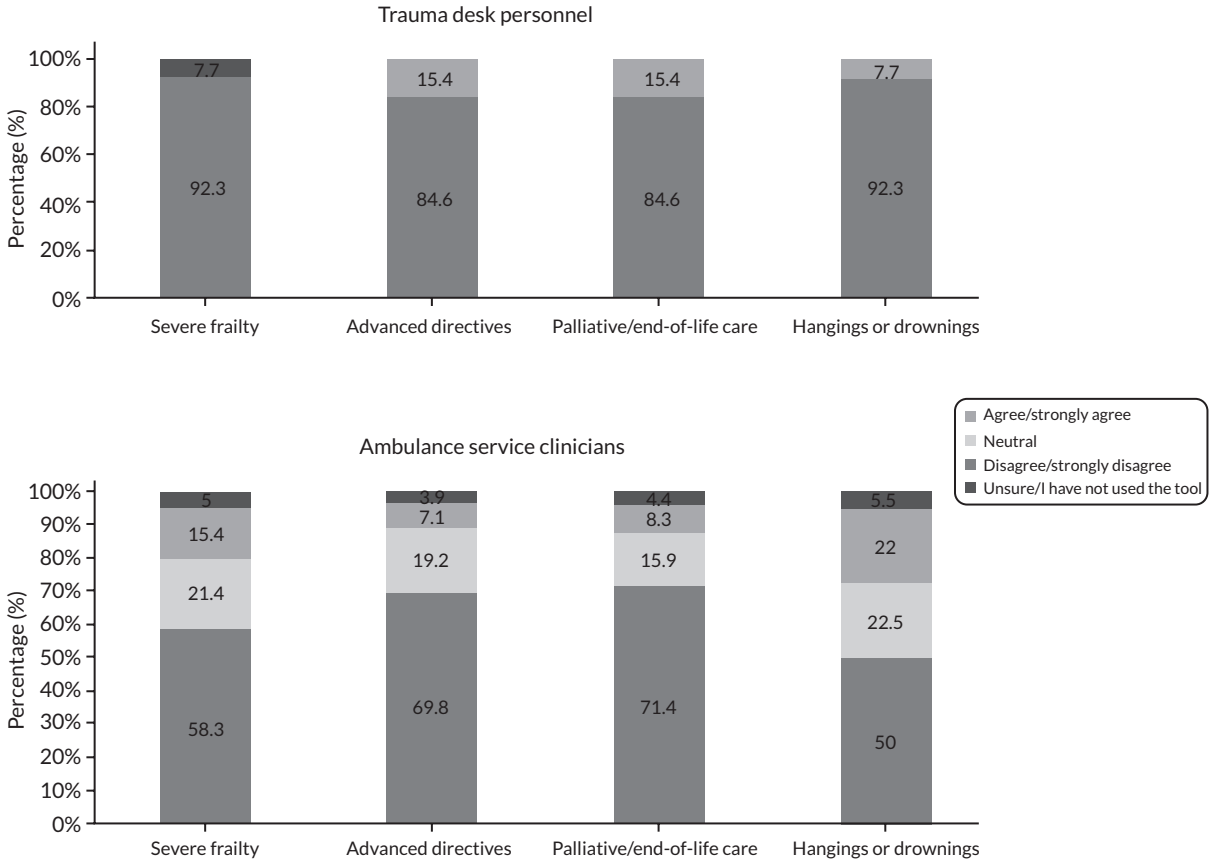


FIGURE 26 Stakeholder views on inclusion/exclusion criteria of the MATTS triage tool.

TABLE 21 Characteristics of focus group participants

	Focus group 1 (PH 1)	Focus group 2 (PH 2)	Focus group 3 (TD 1)	Focus group 4 (ED 1)
	On-scene prehospital providers	On-scene prehospital providers	Trauma desk personnel	ED physicians
Number	7	9	2	8
Service/region				
WMAS	5	6	1	2
YAS	2	3	1	6
Role				
Paramedic	3	7	2	–
Student paramedic	3	1	–	–
Technician	1	1	–	–
MTC ED physician	–	–	–	6
TU ED physician	–	–	–	2
Experience				
< 2 years	1	1	–	–
2–5 years	3	3	–	2
6–10 years	–	2	–	4
More than 10 years	3	2	2	4
Not known	–	1	–	–

versions. They felt it was easier to use and welcomed improved clarifications and explanations within the supporting notes. All participants had received limited or no training on use of the tool but described it as self-explanatory.

Application

It was clear that the triage tool was not used routinely by prehospital providers for all injured patients as intended, but was rather used selectively in four specific circumstances: by inexperienced staff; for grey area cases; as a *'double-check'*; and as a *'tick box'* for navigating handovers with EDs. Moreover, it was acknowledged that some ambulance clinicians attempted to commit the tool to memory and would not normally refer to it directly. Two barriers to wider prehospital application were identified: competition from other guidelines and the presumed superiority of unstructured clinical judgement. In contrast to variable prehospital application, the triage tool was routinely used by MTC and TU ED physicians during major trauma pre-alert calls to adjudicate bypass decisions, determine the need for reception into a resuscitation area, and to inform hospital trauma team activation.

Clinical judgement and triage decision-making

Prehospital providers highlighted that the tool's triage criteria were not always able to capture the subtlety of the clinical situation. If the tool was applied, providers would often use their clinical judgement to interpret triage variables and inform triage decisions. Conveyance decisions also appeared to be influenced by contextual factors, including opinions about the capabilities of local TUs, journey times with potentially deteriorating patients, and the skillset of the crew attending. There were also concerns about the disciplinary consequences of missing major trauma and a suggestion that the tool's clinical judgement step could be manipulated as a *'get out clause to cover their backs'*. These findings were corroborated by ED physicians, with MTC staff raising some concern that subjective use of Step 3 could lead to over-triage, although the overall impact of prehospital clinical judgement was valued.

Performance

Triage using the new MATTS tool was thought to be performing well by all stakeholder groups, and it was recognised that expecting perfect accuracy was unrealistic. There was appreciation that there was a focus on higher specificity, and

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a recognition that MTCs and TUs may be impacted differently by this change in focus. Removal of mechanism of injury triage criteria, present in previous tools, was highlighted as beneficial in avoiding unnecessary conveyance to MTCs. However, there was some concern from ambulance clinicians that this could cause conflict with receiving EDs who were perceived as still focused on this aspect. For trauma desk staff, the new tool was seen as more helpful in identifying those needing a MTC, but it potentially gave less support in differentiating between those who needed a TU and those who could be seen at a LEH.

Patient subgroups: elderly and children

The new triage tool was felt to be primarily aimed at adult patients, with the scope for defining age thresholds and refining vital sign thresholds in children. All participants agreed that elderly patients sustaining 'silver trauma' were difficult to identify; however, there were conflicting opinions between MTC and TU physicians around which elderly patients should be selected by the triage tool. A particular issue for participants from the WMAS region was how the new MATTS triage tool integrated with their existing prehospital 'silver safety net' tool designed for use in injured patients aged ≥ 65 years.

Trauma desk interaction

There were notable differences in how stakeholders used the trauma desk for support and decision-making between the two ambulance services. In WMAS, the CCP-staffed trauma desk was viewed as an invaluable support for triage decisions, and ambulance clinicians felt they would be held accountable if they had not made contact. In contrast, within YAS, the trauma desk, run by less experienced staff, was seen to have a less significant role, partly due to resourcing issues affecting its function. While involvement of the trauma desk could be valuable, it was also highlighted as a potentially detrimental to optimal prehospital care, particularly when decisions needed to be made quickly. Trauma desk clinicians highlighted the difficulties in eliciting the correct information and understanding the support required by crews due to differences in crews' abilities, and difficulties in assessing the clinical situation over the phone without visual clues.

Pre-alerts

It was apparent that while structured pre-alerts were attempted, they often followed an interactive, unstructured, and discursive approach. This was often viewed negatively from the prehospital viewpoint, contrasting with the hospital perspective that additional information helped triage accuracy. There were mixed views and experiences on the pre-alert being made by the trauma desk rather than directly from ambulance clinicians. While some felt it helped save them from lengthy conversations with the ED, others described how it could cause delays, information loss ('*Chinese whispers*'), or even failure for the pre-alert to be passed on occasion.

Discussion

Summary

The new MATTS triage tool was well known, widely available and positively viewed. However, it was used infrequently by prehospital providers in selected cases only. Barriers to wider triage tool use included a plethora of other prehospital algorithms and the perceived superiority of clinical acumen. When used, the tool was considered a guideline with additional clinical judgement often applied. Remote decision support provided by a 'trauma desk' was valued with caveats around mandatory consultation. Major trauma pre-alerts followed an interactive, negotiated, approach, with ED physicians arbitrating triage decisions. The need for further refinement and guidance when using the tool with paediatric and elderly patients was highlighted.

Interpretation

Using a combination of quantitative and qualitative research is necessary to provide a comprehensive evaluation of the new MATTS triage tool.[209] This survey and focus group data enrich interpretation of diagnostic accuracy results by offering a provider perspective on the implementation process and real-life practice. Narrative findings are also useful in interpreting the findings of triage tool validation and for triangulation with the quantitative results.[143] Findings were consistent across survey respondents and focus groups, likely reflecting the common sampling frame.

The new MATTS tool has several novel features in addition to the revised choice of triage variables, including exclusion criteria, variable definitions, an explicit role for clinical judgement, and incorporation of remote senior decision support from a trauma desk. Reassuringly, all these aspects were received favourably by stakeholders and there were no major issues or flaws reported. Only relatively few minor improvements (e.g. electronic formatting, refinement of paediatric vital sign thresholds) were suggested. A lack of specific training was reported following a 'top down' introduction, but this was not felt to be a barrier to awareness, use or implementation.

Prospective evaluation of the new MATTS triage tool demonstrated a sensitivity of 55.3% and specificity of 94.3% for actual prehospital triage decisions (MTC bypasses and pre-alerts), consistent with cost-effectiveness targets favouring high specificity. Theoretical triage tool performance, based on objective recorded information, showed slightly lower sensitivity of 51.1% and specificity of 93.6%. There was disagreement between the indicated and observed triage decision in 16% of cases, confirming the finding of selective triage tool use and application of clinical judgement reported in the current study. In common with preceding studies and other disease areas, clinical acumen appears to improve overall accuracy, reinforcing the view of providers that experience and expertise outperform protocols.[72,202]

The reality that triage tools are optionally used as guidelines, and this selective application may improve effectiveness, has several potential implications. Firstly, the tools might be better viewed as a protocol for inexperienced prehospital providers, a guideline or aide-memoire for senior providers, and as an arbitration tool for receiving hospitals. Secondly, there may be limited scope to influence outcomes from changes in triage tool criteria in isolation. Thirdly, to benefit from better overall triage performance achieved through subjective clinical judgement, some incorrect individual clinical decisions will need to be accepted. Fourthly, strategies to increase triage tool use and adherence may be counterproductive. Finally, given the value placed on clinical acumen and transparency of decision-making, it seems unlikely that unexplainable, black-box, artificial intelligence algorithms would be better adhered to than simple triage checklists in the future. Even if desirable, wider tool application may be unrealistic given lack of familiarity secondary to the low (monthly) incidence of major trauma cases and profusion of other competing guidelines.

Despite the use of simple and objective tools, prehospital major trauma triage is known to be a non-linear, dynamic and instinctive process.[52,141] Interestingly, this subjective approach seems to extend into the prehospital–hospital interface with flexibly conducted pre-alert calls. ED physicians, informed by the triage tool and following negotiation with prehospital providers, appeared to view themselves as the final arbiters of pre-alert calls. Previous evaluations of major trauma triage tools have examined hospital destination or MTC pre-alerts as outcomes.[55,56,65,71] Given that the final triage decision could change following hospital input (i.e. bypass declined, hospital trauma team not activated, or patient not received into a resuscitation area), alternative index test definitions may be better to evaluate under- and over-triage. The extent that ED physicians can influence triage decisions will vary across trauma networks according to local pre-alert processes. In some regions (e.g. LAS), pre-alert calls are conveyed via the ambulance service control room, removing the potential for interaction or negotiation with the on-scene ambulance service clinician.

Remote clinical support provided by senior trauma desk clinicians was viewed favourably overall and further development and refinement of this role could offer an alternative strategy to improve triage performance. However, the case for trauma desk input appeared to be nuanced. Adding value to triage decisions was balanced by qualifications regarding over-consultation, a risk of delaying urgent care in the field, difficulties in accurately assessing incidents remotely, and adding unnecessary complexity to straightforward cases. Taken together, a net-positive benefit of the trauma desk could be achieved by ensuring access to advice from highly trained staff, but empowering staff, especially experienced senior providers, with the latitude to exercise discretion in consultations. There were also divergent views on the role of the trauma desk as a conduit in making pre-alert calls on behalf of prehospital providers.

A cross-cutting theme evident across several topics and focus groups was the potential influence of disciplinary and medico-legal consequences on decision-making. The need for prehospital providers to be seen to follow process, even if felt to be unnecessary or detrimental, to *'cover themselves'*, was recurrently mentioned. On the one hand, this might ensure appropriate restraint to unfettered clinical judgement, and increase standardisation, reproducibility and transparency of decisions. However, on the other hand, there were frustrations that such an atmosphere contributed to inefficiencies or could lead to over-triage. It was unclear whether an optimal balance had been reached in current practice, with an ongoing tension between clinical independence and clinical governance apparent.

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The MATTS project was commissioned to develop a single, national, 'one size fits all' triage tool, and overall, the MATTS specific tool was viewed as performing well. However, children were highlighted as a potential area for further triage tool development, possibly with addition of age-specific instructions or triage variables. This would fit with the Phase 2 external validation results which suggested a relatively lower theoretical accuracy for the MATTS specific tool in this subgroup compared to other bespoke paediatric tools. However, major trauma is very rare in children, limiting the potential to develop data-driven, evidence-based, modifications. Elderly patients with major trauma were also recognised as difficult to identify, but participants, particularly MTC staff, acknowledged that very careful selection of patients who can benefit from MTC care is required. Furthermore, the reported difficulties of integrating the WMAS 'silver safety net' tool and the clear antipathy to the multiplying number of prehospital algorithms suggest that individual age-specific triage tools are unlikely to be well received.

Comparison to previous literature

Consistent with the current study, there is a consensus across previous qualitative research, including the Phase 1 focus groups (see *Chapter 5*), that major trauma triage decisions are primarily determined by clinical intuition.[52,141] This mirrors the wider literature on clinical decision rules, where an *'iterative and dynamic decision-making process that changes throughout the patient encounter, contingent on multiple contextual features'* has been observed.[51,210] Notable findings of the current study including selective application, using decision aids retrospectively after a decision has been made, and applying rules without referring to a memory aid, have also been previously reported.[141,210,211] As a newly implemented intervention, there are no previous qualitative investigations of the MATTS triage tool. No studies examining major trauma pre-alert calls were found. There is also a paucity of research into dedicated trauma desks. Bruce *et al.* retrospectively examined trauma desk consultations in Scotland, suggesting improved prehospital critical care team activation times and reduced stand-down rates. Sinclair *et al.* reported slightly increased sensitivity, with minimally reduced specificity for major trauma following trauma desk implementation, in a retrospective, uncontrolled, before-and-after study.[212,213]

Limitations

This study has several strengths, including a relatively large sample, broad representation of stakeholders, and conduct consistent with best practice and reporting guidelines. However, there are potential weaknesses that could limit validity. Convenience sampling, used for in-person recruitment of survey participants, could lead to bias if prehospital providers working day shifts systematically differ from other staff. Moreover, the low response rates from the YAS mailing list, and variable survey completion, could result in further selection bias. Although focus groups included a full range of prehospital and hospital roles, there was relative under-representation of trauma desk personnel and TU ED physicians. On-line focus groups were used to allow inclusion of distant participants from diverse locations, and to accommodate busy and irregular shift patterns. However, there may be drawbacks from this approach including less engaged discussions, reduced group member dynamics and the inability to observe body language.

This study was conducted > 6 months following adoption of the MATTS tool, allowing time for it to become ingrained into practice, and allow a realistic appraisal of practice. YAS and WMAS are representative of other NHS ambulance services and findings should therefore be generalisable throughout the UK. Implementation of the new triage tool, without a detailed training package, reflects usual practice, and results should therefore apply to the introduction and use of other prehospital decision tools in the future.

Conclusions

The new MATTS triage tool was received favourably and appears to perform well operationally. Selective application, triage tool use as a guideline subject to clinical judgement, and flexible ED pre-alert discussions, likely improve overall triage performance but limit the potential for change in outcomes from introducing new triage tools. Improved training and senior clinical decision support may therefore be more important than triage tool content in influencing under- and over-triage rates.

Chapter 12 The cost-effectiveness of major trauma triage using the Major Trauma Triage Study specific tool: a decision-analytic economic evaluation

Introduction

There is currently wide variation in major trauma triage tools used across ambulance service in the NHS.[214] While this could appropriately reflect local circumstances, including transport times and MTC capacity, the variability may contribute to heterogeneous costs outcomes. The MATTS tool was developed to optimise triage for English trauma networks, prioritising a relatively high specificity to sensitivity trade-off, and targeting patients with the potential to benefit from expedited MTC care. Following implementation, it is important to examine the costs incurred and expected benefits, compared to triage using other tools. This economic evaluation therefore aimed to establish the cost-effectiveness of major trauma triage and tools in an English NHS setting. Specific objectives were to examine the costs and consequences of major trauma triage following implementation of the MATTS triage tool, compared to previously used tools; investigate theoretical cost-effectiveness of different triage tools; explore uncertainty in these results; and evaluate the cost and value of undertaking further research by estimating the expected value of perfect information (EVPI) and expected value of partial perfect information (EVPPI).

Methods

Overview and decision problem

The optimal prehospital triage strategy for injured patients presenting to English ambulance services is uncertain. This study compared the cost-effectiveness of plausible triage strategies in the English NHS, including using the newly developed MATTS triage tool.[215] An economic evaluation was performed using an adapted version of the previously reported MATTS Phase 1 patient-level decision tree model (see *Chapter 4*).[43] Study procedures followed guidelines from NICE, including cost–utility analysis, a lifetime horizon and an NHS and a personal social services perspective.[113] Analyses were pre-specified and reported according to the CHEERS Statement.[114]

Population and setting

The model setting was a hypothetical English regional trauma network, with non-specialist TUs and a single specialist MTC served by one ambulance service. Only patients injured in a TU catchment area were included, as patients within the MTC catchment area would receive specialist care regardless of the triage tool used.[19] Possible triage pathways were therefore direct conveyance to the local TU, with subsequent management at the TU or secondary transfer to the MTC, or bypass with prolonged transportation to the distant MTC. Injured patients self-presenting to hospitals were excluded, as major trauma triage tools would not be used for these cases.

The modelled patient population was simulated using data from a prospective cohort study which included injured adults presenting to EMS in the Netherlands.[115] Patient attributes comprised age, sex, ISS, GCS and injury type (blunt/penetrating). Means, standard deviations and covariances between all parameters were defined and simulated patients sampled using correlated draws from these distributions. The model population was stratified into elderly (65 or above) and non-elderly adults (16–64 years), to reflect expected differential triage performance and benefit of MTC care across these age groups. Children were not considered, as major trauma is rare in this age group, different triage tools may be used, there is limited evidence for triage accuracy, and costs and consequences of serious injury could substantially differ.[46,62,63]

Comparators

In the primary analysis, the accuracy of prehospital triage decisions was examined. The sensitivity and specificity of triage outcomes, defined as the first hospital an injured patient was conveyed to, either a specialist MTC or

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non-specialist local hospital, were compared between ambulance services using different major trauma triage tools. Triage accuracy was evaluated regardless of compliance to the theoretical triage tool result, pre-alert status, or subsequent secondary transfers. This definition for triage decisions was used to mirror the primary purpose of major trauma triage (i.e. identify patients for expedited MTC care) and for concordance with available evidence on MTC effectiveness.[28] In a secondary analysis, the theoretical sensitivity and specificity of competing triage tools was compared. Triage outcomes were consequently defined according to the indicated triage tool results determined from objectively apparent information, regardless of compliance, observed pre-alert status, or actual hospital destination. The reference standard used to categorise patients as potentially benefitting from MTC care was an ISS ≥ 16. This was chosen to align with available cost-effectiveness evidence, to allow comparison with previous economic evaluations, and as NICE uses ISS to define major trauma.[28,151]

Data informing the accuracy of triage decisions and triage tool accuracy were obtained from secondary analyses of the MATTS Phase 2 case–cohort and MATTS Phase 3 cohort studies, reported in detail in *Chapters 8* and *9*. Briefly, in Phase 2, a case–cohort study was conducted between November 2019 and February 2020, evaluating the performance of triage decisions in four English regional trauma networks, each served by separate ambulance service and using a different triage tool: London (LAS pre-2020), South West (SWAS pre-2020), West Midlands (WMAS pre-MATTS) and YAS (pre-MATTS).[216,217] Subsequently in Phase 3, a cohort study examined performance of the newly implemented MATTS triage tool in six trauma networks within YAS (YAS MATTS) and WMAS (WMAS MATTS) between November 2021 and May 2022.[218] Data for each triage strategy and tool were extracted for patients injured closest to a non-MTC and bootstrapping used to generate a correlated distribution around sensitivity and specificity. For theoretical triage tool performance, all sensitivities and specificities were correlated in one bootstrapping procedure. Using the percentile method, 95% confidence limits were calculated.

In total, six comparators were evaluated in the primary analysis, comprising actual triage decisions using the following triage tools: LAS pre-2020, SWAS pre-2020, WMAS pre-MATTS, YAS pre-MATTS, YAS MATTS and WMAS MATTS. Overall, five comparators were evaluated for theoretical performance analysis, comprising the following triage tools: SWAS pre-2020, MATTS specific, WMAS pre-MATTS, YAS pre-MATTS, LAS pre-2020. The competing triage strategies in the primary and secondary analysis, and the data sources for accuracy estimates, are detailed in *Appendix 10*, *Table 85* and *Figure 42*.

Model structure

A similar patient-level decision tree model to that used in the MATTS Phase 1 cost-effectiveness evaluation was implemented (see *Chapter 4*), as presented in *Figure 6*. A patient-level simulation was chosen to account for the heterogeneity of injured patients and to include correlation between triage decisions, injury severity and survival.[219] After entering the model, hospital destination for individual patients was determined according to the sensitivity and specificity of the modelled triage strategy or tool. Patients initially conveyed to a TU could undergo subsequent secondary transfer to the MTC, dependent on injury severity. The probability of short-term 30-day survival was then determined by a validated outcome prediction model. For patients with major trauma who did not receive MTC care, the probability of survival was reduced using a relative risk of death to reflect higher mortality associated with a lack of specialist care. All patients treated in the MTC gained an equal survival benefit, regardless of whether they were bypassed or underwent secondary transfer; however, transferred patients incurred additional transfer-related costs. For patients surviving to 30 days post injury, subsequent risk of fatality up to 1 year post discharge was estimated from published data, with a relative risk of death applied to increase mortality in patients with ISS ≥ 16 that did not receive MTC care. A discrete event simulation then estimated life expectancy using general population mortality with hazard ratios applied to reflect the increased risk of death for patients who sustained major trauma. Longer-term survival beyond 1 year was not affected by receiving MTC care. Utility values were applied to surviving patients, weighting years of life accrued to calculate QALYs.[220] Costs and QALYs were measured at each decision tree node for individual patients and then summed across the entire modelled population to provide totals for each comparator. The model was coded in R version 4.3.0 and a fully executable open source version of the model is available.[221]

Model data

Where possible, data for model parameterisation were updated from the Phase 1 MATTS model after further literature searches. The final choice was determined by internal validity, applicability to the decision problem and conformity with

NICE modelling recommendations.[113] The final model parameters are detailed in *Appendix 10*, *Table 86*. As described above, the data source for the simulated model population was a published Dutch adult cohort of injured patients, and the accuracy of competing triage strategies and triage tools were derived from MATTS Phase 2 case–cohort and Phase 3 cohort data. The probability of secondary transfer for patients initially taken to a non-specialist local hospital was obtained from a recent analysis by the TARN, the national trauma registry for England.[222]

Patient survival was assessed at three time points. Short-term survival up to 30 days post injury was calculated using the latest iteration of the validated TARN mortality prediction model.[112] The effect of MTC care for patients with major trauma was implemented using published relative risks of death associated with specialist care reported in two large cohort studies: Maughan *et al.*[45] for patients aged 65 or over; and Newgard *et al.* for patients aged 16–64 years.[118] For patients surviving beyond 30 days, estimates from risk of death up to 1 year were obtained from published values reported in large cohort studies from the USA.[45,119,120] Population lifetables for the UK were then used to estimate the long-term survival of patients beyond 1 year.[227] Mortality rates for patients were increased compared to the general population using hazard ratios reported in longitudinal follow-up studies of injury survivors.[44,122] Health-related quality of life and utilities for calculation of QALYs were obtained from a recent prospective cohort study of injured patients in the Netherlands. The EuroQol-5 Dimensions, three-level version (EQ-5D-3L) questionnaire was used at several time points, with recall of pre-injury utility, and the EuroQol-5 Dimensions (EQ-5D) responses converted into a utility score using the Dutch EQ-5D-3L tariff.[224] These were applied multiplicatively to the age–gender-matched utilities of the UK general population.[124]

Ambulance and hospital costs for the care of injured patients were assigned according to NHS reference costs.[125] Notably, there is a tiered 'best practice tariff' for care of major trauma patients, in MTCs, varying by ISS strata of 9–15 and ≥ 16. The cost of healthcare resource use between ambulance call out and discharge, stratified by injury severity, was informed by two UK-based cost studies for patients with major trauma.[127] Costs between hospital discharge and 6 months post injury were obtained from a report on the cost-effectiveness of implementing MTCs in England.[225] Data for costs after 6 months were based on a Canadian study,[128] demonstrating that patients will have higher than average lifetime costs compared to the general population, and reference costs incurred by the NHS for treating the general population by age and gender.[130] There were no differences in the cost of administering different triage tools to patients. All costs were reported in 2021–2 prices. When needed, prices from previous years were inflated using the hospital and community health services pay and prices index and NHS Cost Inflation Index pay and prices inflation indices.[228]

Cost-effectiveness analyses

The primary analysis examined the accuracy of actual triage decisions in terms of hospital destination, with the theoretical sensitivity and specificity of competing triage tools evaluated in a secondary analysis. A full incremental analysis of total costs and QALYs was undertaken to calculate the ICERs.[229] Future costs and QALYs were discounted at 3.5% per annum. After ordering comparators by effectiveness, incremental costs and QALYs were consecutively compared to the next least effective intervention. Options producing fewer QALYs at a higher cost (dominated), or that had a higher ICER than a more effective comparator (extendedly dominated), were removed from consideration. The MAICER is the amount of money that the decision-maker is willing to pay to gain 1 additional QALY. The usual threshold for decision-making at NICE is usually considered to be £20,000 per QALY, but may increase to £30,000 in special circumstances, as detailed in NICE guidelines.[113,230] ICERs were compared with these MAICERs to indicate the most cost-effective comparator.

In line with NICE's methods guide, the base-case model was run with all parameters set to their mean values (deterministic analysis), with a probabilistic analysis also conducted to account for uncertainty in estimates of model inputs.[133] The model was repeatedly run on different samples of parameters from their assigned statistical distributions using Monte Carlo simulation.[229] Mean ICERs were calculated from the average expected costs and effects over all model runs and compared with cost-effectiveness thresholds to inform adoption decisions. If findings significantly differed, the probabilistic results were defined a priori as taking primacy.

A cost-effectiveness acceptability curve (CEAC), plotting a relevant range of MAICER values against the probability that each intervention was the most cost-effective, was additionally graphed to summarise the uncertainty of PSA results.[231] The CEAC is derived from the joint density of individual incremental costs and incremental effects calculated

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for competing treatment options during a PSA, and shows the proportion of model runs for which each strategy is cost-effective over a range of potential WTP thresholds. The probability of being most cost-effective corresponds to the proportion of the joint density of incremental costs and effects that result in the highest net monetary benefit at a given MAICER.

The stability of base-case model results was assessed, in relation to the number of simulated patients and number of PSA runs required to produce model convergence.[134] The number of simulated patients was determined by visually analysing the stability of cost and QALYs estimates with respect to the number of patients run through the model. The number of PSA runs was determined by ensuring that the 95% CI around the ICER calculated from mean costs and mean QALYs did not contain the usual NICE decision-making thresholds of £20,000 or £30,000 per QALY gained. In addition to the base case, several additional scenario analyses were also conducted to explore the influence of different assumptions for utility values, MTC effectiveness, short-term survival and removing obviously dominated comparators, as detailed in *Appendix 10*, *Table 87*.

Expected value of information analysis

A value of information analysis was conducted for the base-case model to examine if further research into the cost-effectiveness of triage strategies is an efficient use of resources from the healthcare system perspective,[232,233] and determine the overall gain associated with: removing all uncertainty from the decision problem (EVPI); removing all uncertainty from a subset of parameters (EVPPI); and if these values were sufficiently large, the expected value of conducting future research assuming finite sized trials (expected value of sample information, EVSI).

EVPI for individual patients was calculated directly from the model PSA output using standard formulas. EVPPI analyses were performed using a non-parametric regression approach implemented in the Sheffield Accelerated Value of Information online application.[234,235] Assumptions on major trauma incidence (20,000 patients per year in England and Wales), discount rates (3.5%), health technology lifespan (10 years) and MAICER (£20,000 per QALY gained) were then used to compute population-level statistics. Five groups of parameters, reflecting targets for potential future research designs, were considered in EVPPI analyses: probability of receiving MTC care; mortality; MTC effectiveness; utilities; and costs.

Results

Empirically, 100,000 simulated patients and 1000 PSA runs were shown to provide base-case model convergence. Results from the PSA appreciably differed from the deterministic results, and in accordance with NICE recommendations and the a priori plan, further analyses were therefore conducted using the probabilistic model.

Table 22 summarises the results of the base-case analysis. Compared to triage decisions in SWAS using their pre-2020 tool, triage decisions in WMAS and YAS using their pre-MATTS triage tools demonstrated ICERs of £21,093 and £28,127 per QALY gained, respectively. Given a NICE threshold of £20,000 per QALY, the base-case analysis indicates that low-sensitivity/high-specificity triage decisions observed in SWAS were cost-effective. However, there were only very small differences in incremental costs and QALYs across competing triage strategies in the base-case model. The actual differences in costs and benefits between all comparators was under £149 and 0.006 QALYs (equivalent to under 1.8 days in perfect health for a patient), respectively. The base-case CEAC is presented in *Figure 27*, demonstrating considerable uncertainty around which option that is likely to be cost-effective.

In most scenario analyses, triage decisions using the SWAS pre-2020 triage tool were cost-effective assuming a threshold ICER of £20,000 per QALY gained, whereas triage decisions using the YAS pre-MATTS tool were cost-effective at £30,000 per QALY gained. The only scenarios where this systematically changed was in the contingency that patients with ISS 9 and 15 benefited from MTC care. In these scenarios, triage decisions in LAS using their pre-2020 tool could be cost-effective as MTC benefit for less seriously injured patients increased. *Appendix 10*, *Table 88* summarises the results of the scenario analyses.

The theoretical performance of triage tools was examined in a secondary analysis as detailed in *Table 23*. Compared to the SWAS pre-2020 tool, the MATTS specific tool demonstrated an ICER of £21,163 per QALY gained, with the

TABLE 22 The results of the Phase 3 base-case analysis examining actual triage decisions in terms of hospital destination

Strategy	QALYs	Costs (£)	Incremental QALYs	Incremental costs (£)	ICER (£ per QALY gained)
Deterministic					
SWAS (pre-2020)	12.538	£35,753	–	–	
YAS (MATTS)	12.542	£35,838	–	–	Dominated by WMAS (pre-MATTS)
WMAS (pre-MATTS)	12.542	£35,831	–	–	Extendedly dominated by YAS (pre-MATTS)
WMAS (MATTS)	12.542	£35,843	–	–	Dominated by YAS (pre-MATTS)
YAS (pre-MATTS)	12.543	£35,838	0.005	£86	£17,445
LAS (pre-2021)	12.543	£35,899	0.000	£60	£952,115
Probabilistic analysis results					
SWAS (pre-2020)	12.547	£36,700	–	–	–
YAS (MATTS)	12.551	£36,785	–	–	Dominated by WMAS (pre-MATTS)
WMAS (pre-MATTS)	12.551	£36,779	0.004	£79	£21,093
WMAS (MATTS)	12.551	£36,791	–	–	Extendedly dominated by YAS (pre-MATTS)
LAS (pre-2021)	12.553	£36,849	–	–	Dominated by YAS (pre-MATTS)
YAS (pre-MATTS)	12.553	£36,840	0.002	£61	£28,127

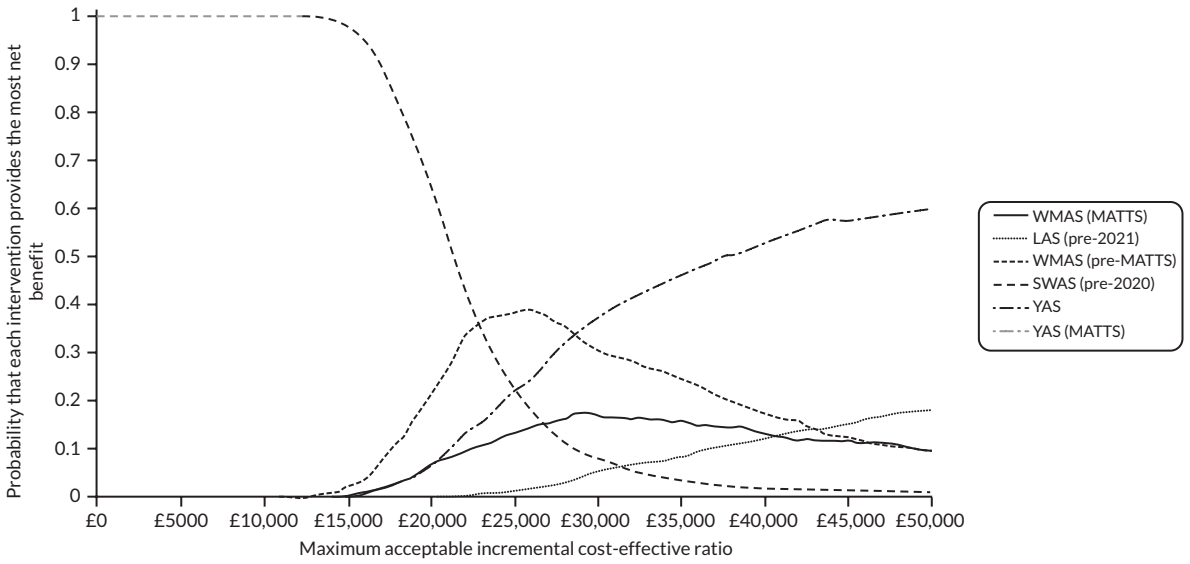


FIGURE 27 The base-case CEAC.

TABLE 23 Results of the secondary analysis examining theoretical triage tool results (regardless of hospital destination)

Triage tool	QALYs	Costs (£)	Incremental QALYs	Incremental costs (£)	ICER (£ per QALY gained)
SWAS pre-2020	12.539	£36,318	–	–	–
MATTS specific	12.541	£36,356	0.002	£38	£21,163
WMAS pre-MATTS	12.544	£36,433	–	–	Extendedly dominated by LAS pre-2020
YAS pre-MATTS	12.544	£36,453	–	–	Extendedly dominated by LAS pre-2020
LAS pre-2020	12.546	£36,489	0.005	£133	£29,123

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LAS pre-2020 tool demonstrating an ICER £29,123 per QALY. The WMAS and YAS pre-MATTS tools were extendedly dominated (i.e. there could be a random chance of using the MATTS and LAS pre-2020 triage tools that would result in a cheaper and more effective outcome).

The value of reducing all uncertainty in the model parameters was £5.21 per person with suspected major trauma. Over a 10-year time span with an incidence of 20,000 people per year this equates to a population EVPI of £1M. The EVPPI results indicated that the biggest drivers of uncertainty were model parameters that determine the probability that a patient dies, with a population EVPPI of £708,883 (68.1% of overall EVPI). However, much of this value was from the subset of parameters that determine the effectiveness of MTC care in preventing deaths, with the population EVPPI of just these parameters being £542,958. Given these relatively low population values for EVPI and EVPPI, EVSI was not performed as per the a priori plan. Values of information analysis results are summarised in *Appendix 10*, *Table 89*.

Discussion

Summary of results

For actual triage decisions in terms of hospital destination, using the higher-specificity SWAS pre-2020 triage tool appeared to provide the most cost-effective strategy. Its base-case ICER was just above the usual NICE threshold of £20,000 per QALY, and this remained true in most scenario analyses. However, a trade-off was apparent, with the higher-sensitivity YAS pre-2020 strategy favoured at a higher WTP threshold of £30,000 per QALY. Overall, there were minimal differences between the costs and benefits of triage decisions overall, reflecting similar accuracy across different ambulance services regardless of the triage tool used. When the theoretical performance of triage tools was examined, higher specificity was favoured, with the SWAS pre-2020 and MATTS specific tools appearing cost-effective at MAICERs below £21,163 and £29,123, respectively. The value of information was relatively low at a MAICER of £20,000 per QALY gained, with the health economic value of reducing the sampling uncertainty in all model parameters being £1.0M.

Interpretation

Overall, relatively lower sensitivity and higher specificity were cost-effective for both actual triage decisions and theoretical tool performance at the usual NICE decision-making threshold of £20,000 per QALY in the base-case analyses. This is primarily caused by MTC care incurring costs, but no additional survival benefit, for bypassed patients without major trauma. The prevalence of major trauma is low in injured patients presenting to ambulance services, resulting in a low positive predictive value and increased numbers of false-positive cases unless specificity is high. Importantly, this contradicts guidelines from the ACS-COT recommending that sensitivity is prioritised at the expense of specificity.[32] Higher-sensitivity triage would only be favoured in the contingency that less severely injured patients (ISS 9–15) received a significant survival benefit from bypassing to a MTC.

Despite the studied English ambulance services using a range of different triage tools,[214] it appeared that conveyance decisions for injured patients were broadly similar. Consequently, minimal differences in costs and benefits were apparent between comparators. Taken together with the sampling and structural uncertainty inherent in the modelling, it is therefore not possible to identify a best individual triage strategy. Qualitative work has suggested that triage tools are used selectively, and clinical judgement is often applied.[52,141236] Consequently, there may be limited scope for tools to influence triage outcomes, as prehospital clinicians will over-rule indicated triage results to produce similar overall accuracy, regardless of the tool used. The MATTS specific tool demonstrated cost-effective theoretical performance compared to plausible NICE WTP thresholds between £20,000 and £30,000, and implementation across the NHS could provide benefits of standardisation and better alignment of theoretical and actual triage outcomes.

Overall, the expected value of information analysis suggested that only a relatively small amount of £1M should be invested in future research investigating major trauma triage, with EVPPI indicating that reducing uncertainty in estimates of MTC effectiveness would provide the most value of money at up to £547,653. Therefore, at face value, any future study would likely need to be of an observational design and performed cheaply for it to be economical. However, the value of information estimates only includes reductions in second-order parameter uncertainty (i.e. the

probability distribution estimated from statistical models), with structural uncertainty (e.g. systematic error in effectiveness estimates for MTC effectiveness) unaccounted for. Given the high risk of bias inherent in the current evidence base regarding MTC effectiveness, EVPI and EVVPI results should therefore be interpreted with caution.

The economic model was specifically structured to reflect the NHS setting and should have external validity to UK trauma networks. British evidence was used where possible to inform model parameters, including the TARN prediction model, UK population life tables, NHS reference values, and secondary transfer rates informed by English data. However, similar to the previous model, it was not possible to parameterise the model entirely with UK data. The simulated population was based on a Dutch cohort, which should be broadly comparable to injured patients presenting to UK ambulance services. The Dutch tariff EQ-5D-derived utilities will diverge slightly from UK values, but these differences have been shown to have made minimal difference in previous economic evaluations.[237] MTC effectiveness estimates were based on US evidence from the USA, but appear consistent with English case-mix adjusted odds of death reported in an evaluation of trauma network implementation.[2]

Comparison to previous literature

The previous MATTS Phase 1 economic evaluation modelled the optimal triage tool trade-off between triage sensitivity and specificity.[43] This economic model (updated in the current study) demonstrated a very similar profile of relatively lower sensitivity and higher specificity to produce cost-effective triage. Other studies have been conducted in the US setting and are not directly comparable to the English context.[44-46] However, these economic evaluations have reported qualitatively similar findings that relatively higher specificity compared to sensitivity is favoured for cost-effectiveness. This was particularly the case in elderly patients, where following the high-sensitivity field triage target recommended by ACS-COT has been shown to result in an exceptionally high ICER of $1,236,295 per QALY.[45]

Limitations

This economic evaluation followed best practice recommendations and brought together the strongest available evidence to inform decision-making on major trauma triage in England. However, there are several potential issues. Firstly, the foremost limitation is that although a head-to-head comparison of multiple triage strategies was conducted, accuracy was based on separate observational studies conducted during different time periods. Secular trends, regression to the mean, and selection or information bias from differences in study recruitment and data collection are all possible. Given the very small differences in costs and QALYs, results should therefore be treated with caution. Secondly, major trauma triage is likely to show spectrum effects,[47] with accuracy varying according to injury mechanism and severity. Average sensitivity and specificity of triage decisions and tools were used, and we did not account for correlation between accuracy and patient characteristics beyond age. Thirdly, ISS may not represent the most appropriate reference standard for major trauma, as it does not necessarily account for injury acuity, need for specialist care, or requirement for time-critical treatments. Although alternative reference standards have been proposed,[161] estimates of the effectiveness of care at MTCs for these alternative definitions are lacking, precluding their use in this economic model. Fourthly, there are no recent studies estimating the cost of treating patients in the UK; given the heterogeneity in care for patients with major trauma, such studies are needed to fully estimate costs for economic analyses. Fifthly, parameter estimates were often imprecise leading to second-order sampling uncertainty. Finally, assumptions for the effectiveness of MTC care are based on non-randomised studies at risk of confounding and other biases inherent in observational studies.

Conclusions

The accuracy of prehospital triage decisions is similar regardless of the triage tool used, leading to very similar costs and benefits across comparators. Taken together with the potential parameter and structural uncertainty, results should be interpreted with caution, and it is not possible to identify a clearly superior triage tool based on real-life triage performance. However, in common with previous research, relatively higher-specificity triage was favoured, and the new MATTS tool offered cost-effective theoretical performance. Implementation of this tool across the NHS could provide benefits of standardisation and better alignment of theoretical and actual triage outcomes.

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Chapter 13 Implications for policy, practice and future research

Summary of results

The main findings of the MATTS project were as follows:

- There are many existing major trauma triage tools with marked variation in structure, included variables, and their under-/over-triage trade-off focus.
- A simple 'stepped' triage tool structure is valued.
- Triage tools are not routinely applied, and clinical judgement is often used.
- Existing triage tools have limited diagnostic accuracy, particularly in elderly patients.
- Relatively higher-specificity triage tools are more cost-effective.
- The expert-derived MATTS triage tool, targeting relatively higher specificity, provided the optimum achievable balance between under- and over-triage.
- Real-life triage decisions following implementation of the MATTS triage tool achieved sensitivity of 51%, specificity of 94%, negative predictive value of 99%, and positive predictive value of 15%.
- Although sensitivity and specificity of triage decisions varied across subgroups of different ages and injury mechanism, negative predictive value remained high (98–99%).
- The MATTS triage tool was viewed favourably by stakeholders and was perceived to perform well operationally.
- Triage accuracy was similar before and after implementation of the MATTS triage tool, with prehospital triage decisions diverging from the indicated theoretical result in a significant minority of cases.
- Theoretical triage tool performance of the MATTS triage tool aligned more closely with real-life triage decisions.
- The MATTS tool offers cost-effective theoretical triage tool performance.
- Real-life triage decisions were very similar regardless of the triage tool used, resulting in very similar costs and benefits.

Implications for policy and practice

The MATTS triage tool is evidence based, specifically designed for NHS trauma networks, targets patients who can benefit from early MTC care, optimises under-/over-triage, and appears to have cost-effective theoretical performance at typical NHS WTP thresholds. Its stepped 'checklist' format, supporting information, and exclusion criteria were valued by ambulance service and hospital clinicians. Clinical judgement and senior decision support were also welcomed and possibly improved accuracy. Triage performance was as expected following implementation, with high negative predictive values (98–99%) across all subgroups of patients. No adverse events were recorded. The MATTS tool therefore directly addresses the NICE major trauma service delivery research recommendation for a national triage tool and implementation could potentially *'lead to improved patient outcomes and reduced costs'*.[28]

Each English ambulance service currently uses a different major trauma triage tool, varying in the number of steps, included variables, thresholds, incorporation of clinical judgement, provision of senior decision support, and relative focus on sensitivity or specificity. These were categorised into three groups in the Phase 1 document analysis (see *Chapter 2*): 'specific and prescriptive', 'sensitive and non-prescriptive' and intermediate tools. The MATTS triage tool would be classified between the intermediate and specific groups. The similarity of content to some existing NHS triage tools (e.g. SWAS), and an existing precedent for clinical judgement and senior clinical support (e.g. WMAS), indicates that the MATTS tool represents *'evolution not revolution'*, which could facilitate national implementation. Education and training of ambulance service clinicians in triage tool use with inclusion in undergraduate training curriculums, JRCALC guidance and professional development programmes could be important to aid successful deployment.

Conversely, it was apparent that tools are not used routinely, and unstructured clinical acumen often determines triage decisions. Consequently, the accuracy of triage decisions did not materially differ following introduction of the MATTS

triage tool, despite superior theoretical tool performance. This appeared to arise from clinical judgement operating in opposite directions with different tools to produce the same overall outcome. In this context, national implementation of the MATTS tool might have a limited impact on trauma network flows and patient outcomes. However, there are several factors that would support its wider implementation. Theoretical diagnostic accuracy was better, suggesting improved triage performance in cases where the triage tool is used by inexperienced staff or in uncertain cases. Agreement between theoretical triage tool results and actual triage decisions was higher following introduction of the MATTS tool, suggesting greater acceptability and consistency. Other intangible benefits could include increased simplicity from fewer variables, defined exclusion criteria, supporting variable definitions, and conformity of decision-making within trauma networks served by multiple ambulance services.

English trauma networks are designed as 'inclusive' systems, where *'all health-care facilities within a region are involved in the care of injured patients according to their capabilities and resources'*. The relative focus on specificity with the MATTS tool could potentially mean that some TUs in networks using 'sensitive and non-prescriptive' tools would manage an increased number of seriously injured patients following national adoption. Conversely, there could be an expected reduction in the numbers of false-positive pre-alerts and bypasses to the network MTC, which may be very pertinent given overwhelming current pressures on EDs.[238] The MATTS tool performed differentially across age groups and mechanisms of injury, with comparatively more under-triage in elderly and low-energy transfer mechanisms. These cases appeared to be lower acuity with less indication for time-critical resuscitative and operative interventions (< 1% of the observed under-triaged patients), offering the opportunity for later secondary transfer if needed. Increased investment in TUs, with further development of health care of the elderly and rehabilitation services, might therefore be beneficial to support any changes in patient flow within trauma networks.

Implications for future research

The value of a triage tool is not fully captured by its accuracy, but rather through the ultimate health outcomes resulting from its use. This is particularly important given the uncertainties around triage tool application and MTC benefit in certain subgroups, for example elderly patients. Furthermore, triage tools do not operate in isolation, and there is a complex prehospital–hospital interface that influences the timing, place and level of trauma care. Randomised trials of diagnostic tests are typically considered the best way to evaluate the effects or impact of interventions.[239] Although challenging to perform, particularly in the prehospital environment and complex trauma network setting, a stepped wedge trial of a new triage tool has been proposed in the Netherlands, although no information on study progress is available after its registration in 2018.[240] A similar cluster randomised trial of the MATTS tool examining its impact on mortality and disability would provide definitive evidence on its utility. However, the expected value of information analysis suggested that only £1 million should be invested in future research. A more expedient alternative, providing effectiveness estimates at lower cost but at increased risk of bias, would be a natural experiment following staged implementation of the MATTS tool, with completion of an observational controlled before-and-after study.

The NICE major trauma service delivery guidelines and HTA commissioning brief requested a single unified triage tool for use in all ages.[28] While triage using the MATTS tool appeared satisfactory in elderly patients, performance in children was uncertain. Further research in the paediatric subgroup could provide a more precise estimate of triage tool accuracy, determine optimal vital sign thresholds, and may identify novel triage variables for younger patients. However, the incidence of injured children and major trauma presenting to ambulance services is very low, suggesting that research may not be cost-effective and could be a lower strategic priority. Moreover, the existing profusion of prehospital clinical decision rules was identified as a major barrier to the use of triage tools, supporting a more parsimonious single tool approach.

The acute care research landscape has evolved significantly since the MATTS project was commissioned in 2018, with a rapid increase in the popularity of data science, artificial intelligence and machine learning.[241] Advances in computing power and development of sophisticated classification algorithms offer the promise of highly accurate machine learning models. The protocol for the GOAT study, developing a gradient boosting decision-tree algorithm to identify patients in need of specialised trauma care during Dutch field triage, was published in 2019, but no results have been published to date.[242] However, there have been very few successful deployments of artificial intelligence in emergency

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medicine settings so far, and there are numerous reasons why artificial intelligence may not be a panacea for major trauma triage.[241] Firstly, there is a low signal-to-noise ratio in the prehospital assessment of injured patients, inevitably resulting in substantial irreducible modelling error. Secondly, training complex algorithms is very data intensive.[243] Many modelling features are not easily available from prehospital medical records, labels are dependent on TARN case ascertainment, and complete-case matching is challenged by the absence of personal identifiers. The costs of developing a robust and large-scale data set severely limits the scope for model development. Thirdly, ambulance service clinicians clearly indicated that simplicity was very important in the prehospital realm. Even straightforward triage tools are infrequently used, challenging the introduction of more complex models. Fourthly, it is apparent that pre-alert calls constitute a negotiation between ambulance and MTC clinicians. 'Black box' machine learning algorithms do not have the transparency of simple triage tools, potentially acting as a barrier to these interactions.[244] Finally, clinical judgement is highly valued and systematic reviews have shown that statistically derived diagnostic prediction models rarely outperform experienced clinical acumen in emergency settings.[35,72,183,245] Unless machine learning applications were clearly demonstrated to outperform gestalt, it is unlikely their predictions would be trusted and used.

Despite a plethora of existing triage tools, it has been noted that *'under-triage remains a vexing problem for even the most highly developed trauma systems'*.[246] Non-invasive physiological monitoring (e.g. end-tidal CO_2), point-of-care testing (e.g. lactate, ultrasound), advanced technologies (e.g. telemedicine) and novel triage criteria (e.g. abdominal signs) may warrant further investigation as innovative triage criteria. However, these variables are generally not specific for major trauma, and it is possible that further triage tool refinement to improve sensitivity is not possible without an unacceptable increase in over-triage. Other research areas that could inform future major trauma triage include establishing the effectiveness of trauma desk decision support, examining and improving the pre-alert process, further exploring triage tool use across groups of ambulance service clinicians with differing experience and training, and definitively determining the effectiveness of clinical judgement. The expected value of information analysis demonstrated that research into the effectiveness of MTC care could potentially provide value for money and defining which frail patients have the potential to gain benefit from early MTC care could be particularly cost-effective.

Equality, diversity and inclusion

The MATTS project was conducted across eight regional trauma networks in four ambulance services, comprising a broad range of socioeconomic and demographic settings. Inclusion of consecutive patients with broad inclusion criteria should therefore have resulted in a representative and inclusive study population. Ages ranged from 0 years to > 100 years, and 52% of the studied patients were female. Data were not available on race, but the source population included areas with majority Black and Asian ethnicity. The absence of racial information, preventing interpretation of findings in minority populations, may be important as major trauma triage could be influenced by ethnicity, for example measurement of peripheral oxygen saturations may differ in Black and Asian patients. Evidence on the influence of ethnicity on outcomes following major trauma is mixed, and it was not possible to investigate disparities in MTC access following implementation of the MATTS triage tool.

Patient and public involvement

Patient and public involvement was included at all stages of the MATTS project from inception to dissemination, ensuring that the research was conducted 'with, rather than 'for' patients, and was acceptable, relevant and understandable. PPI made important contributions to the following stages of the project:

- Identification and development of the research question: Co-investigator JS led a James Lind Alliance Priority Setting Partnership which established this topic in the top 10 priorities for Emergency Medicine research.
- Proposal development: The research proposal was developed in partnership with a service-user co-applicant with personal experience of major trauma, a second lay representative, and was reviewed in terms of feasibility and relevance by the Sheffield Emergency Care Forum and After Injury PPI panels. Through meetings with the chief investigator, they contributed to the draft proposal and *plain language summary*. Feedback from these service users led to several important design changes, for example exploring the acceptability of long family travel times to distant

MTCs. Following the success of the outline proposal, further consultation with PPI collaborators reviewed the commissioning board's feedback. They strongly supported a national evaluation of triage tool implementation and were keen that the acceptability of any triage strategy was explored with patients from a range of settings.

- Study delivery: A service-user advisory group was convened, working to agreed terms of reference, for collaboration throughout the project. This group was consulted on all aspects of study conduct and helped with specific tasks such as developing questionnaires. Two service-user co-applicants were essential members of the Project Management Group, providing important lay input into all operational decisions. Two independent patient experts were also included in the steering committee, identified from our PPI panel. The training needs of all patient representatives were assessed during study set-up and appropriate training and support provided. Honoraria and reimbursement of expenses were provided in line with NIHR best practice recommendations.
- Reference standard and triage tool development: Following expert consensus development of the MATTS reference standard, separate focus groups were conducted with the Sheffield Emergency Care Forum and Birmingham Injuries PPI groups. PPI feedback was important in including frailty score rather than age in the MATTS reference standard. These panels also review the expert-derived MATTS triage tools to endure its acceptability to public and patient stakeholders.
- Review of study outputs. PPI representatives reviewed the study results, conclusions, practice implications and recommendations for further research. They provided a lay perspective and confirmed the project findings were aligned with needs, preferences and values of patients, relatives, and the public.
- Dissemination: Plain English study progress reports were provided to patient advocacy groups, local PPI panels and the service-user advisory group throughout the project. Service-user co-applicants contributed to writing of scientific publications and the MATTS HTA report, particularly the *Plain language summary*.

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Patient data statement

This work uses data provided by patients and collected by the NHS as part of their care and support. Using patient data is vital to improve health and care for everyone. There is huge potential to make better use of information from people's patient records, to understand more about disease, develop new treatments, monitor safety and plan NHS services. Patient data should be kept safe and secure, to protect everyone's privacy, and it is important that there are safeguards to make sure that they are stored and used responsibly. Everyone should be able to find out about how patient data are used. #datasaveslives You can find out more about the background to this citation here: https://understandingpatientdata.org.uk/data-citation

Data-sharing statement

All data requests should be submitted to the corresponding author for consideration. Access to anonymised data may be granted following review. Any queries should be addressed to the corresponding author.

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Ethics statement

Ethical approval was provided by Yorkshire and The Humber – Bradford Leeds Research Ethics Committee (Reference: 19/YH/0197) on 28 June 2019.

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Disclosure of interests

Full disclosure of interests: Completed ICMJE forms for all authors, including all related interests, are available in the toolkit on the NIHR Journals Library report publication page at https://doi.org/10.3310/ALPE8857.

Primary conflicts of interest: Gavin D Perkins is Emeritus NIHR Senior Investigator and former member of the NIHR HTA Programme Funding Committee (General). Abdullah Pandor is a member of the NIHR HTA Programme Funding Committee (General). Fiona Lecky is research director for TARN, former member of the NIHR HTA European Economic and Social Committee (EESC) Panel, former member of the NIHR HTA Programme Post-Funding Committee, and former member of the NICE head injury guideline committee. Cindy Cooper is a former member of the NIHR Clinical Trials Unit Standing Advisory Committee.

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Publications

The following publications have arisen from the MATTS project to date:

Fuller G, Keating S, Turner J, Miller J, Holt C, Smith JE, Lecky F. Injured patients who would benefit from expedited major trauma centre care: a consensus-based definition for the United Kingdom. *Br Paramed J* 2021;**6**:7–14.

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Pandor A, Fuller G, Essat M, Sabir L, Holt C, Buckley Woods H, Chatha H. Individual risk factors predictive of major trauma in pre-hospital injured older patients: a systematic review. *Br Paramed J* 2022;**6**:26–40.

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An Economic Evaluation of Triage Tools for Patients with Suspected Severe Injuries in England (www.researchsquare.com/article/rs-504608/v1)

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Appendix 1 Phase 1 systematic review supplementary methodological details and results

TABLE 24 Literature search strategy for the systematic review of prehospital triage tools for identifying major trauma in elderly injured patients: MEDLINE

Database searched:	Ovid MEDLINE Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE Daily, Ovid MEDLINE and Versions
Platform or provider used:	Ovid SP
Date of coverage:	1946–February 2019
Search undertaken:	February 2019

1	exp Ambulances/
2	(ambulance$ or mobile intensive care unit$ or micu or mobile intensive care ambulance$ or mica$ or paramedic* or para-medic* or emergency medical technician*).ti,ab.
3	(before hospital or pre-hospital or pre hospital or prehospital or out-of-hospital or out of hospital or emergency medical service*).ti,ab.
4	(prior adj5 hospital).ti,ab.
5	*Emergency Medical Services/ or trauma center/
6	Ambulatory Care Facilities/
7	Emergency Medical Technicians/
8	or/1-7
9	exp “Wounds and Injuries”/
10	trauma*.mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
11	9 or 10
12	Triage/
13	(triage or undertriage or overtriage or under-triage or over-triage).ti,ab.
14	12 or 13
15	predict:.mp. or scor:.tw. or observ:.mp.
16	(validation or validate).tw.
17	predict:.tw. or validat:.mp. or develop.tw.
18	(sensitivity or specificity or injury severity score or risk assess* or risk predict* or risk stratif*).mp.
19	exp *Risk/ or exp Models, Statistical/ or exp Risk Assessment/ or *Postoperative Complications/ or *Risk Factors/ or “Outcome Assessment (Health Care) ”/ or *Trauma Severity Indices/ or *Severity of Illness Index/ or *Injury Severity Score/ or *Prognosis/ or *Risk Factors/
20	(Risk model* or prognostic model* or prediction model* or predictive model* or risk assessment model* or prediction score* or algorithm* or matrix or matrices or assessment tool* or prediction rule* or decision rule* or risk score*).mp.
21	15 or 16 or 17 or 18 or 19 or 20
22	8 and 11 and 14 and 21

TABLE 25 Literature search strategy for the systematic review of prehospital triage tools for identifying major trauma in elderly injured patients: EMBASE

Databases searched:	EMBASE
Platform or provider used:	Ovid SP
Date of coverage:	1974–February 2019
Search undertaken:	February 2019

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1 exp Ambulance/
2 (ambulance$ or mobile intensive care unit$ or micu or mobile intensive care ambulance$ or mica$ or paramedic* or para-medic* or emergency medical technician*).ti,ab.
3 (before hospital or pre-hospital or pre hospital or prehospital or out-of-hospital or out of hospital or emergency medical service*).ti,ab.
4 (prior adj5 hospital).ti,ab.
5 *emergency health service/
6 Ambulatory Care/
7 rescue personnel/ or paramedical profession/ or paramedical personnel/
8 or/1-7
9 exp injury/
10 trauma*.mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword, floating subheading word, candidate term word]
11 9 or 10
12 (triage or undertriage or overtriage or under-triage or over-triage).ti,ab.
13 predict:.mp. or scor:.tw. or observ:.mp.
14 (validation or validate).tw.
15 predict:.tw. or validat:.mp. or develop.tw.
16 (sensitivity or specificity or injury severity score or risk assess* or risk predict* or risk stratif*).mp.
17 exp *Risk/ or exp Statistical model/ or exp Risk Assessment/ or *Postoperative Complication/ or *Risk Factor/ or Outcome Assessment/ or *"Severity of illness Index"/ or *disease severity/ or *injury scale/ or *Prognosis/
18 (Risk model* or prognostic model* or prediction model* or predictive model* or risk assessment model* or prediction score* or algorithm* or matrix or matrices or assessment tool* or prediction rule* or decision rule* or risk score*).mp.
19 13 or 14 or 15 or 16 or 17 or 18
20 8 and 11 and 12 and 19

TABLE 26 Literature search strategy for the systematic review of prehospital triage tools for identifying major trauma in elderly injured patients: CINAHL

Databases searched:	CINAHL
Platform or provider used:	EBSCO*host*
Date of coverage:	1981–February 2019
Search undertaken:	February 2019

S1 (MH "Ambulances")
S2 TI ((ambulance* or mobile intensive care unit* or micu or mobile intensive care ambulance* or mica* or paramedic* or para-medic* or emergency medical technician*)) OR AB ((ambulance* or mobile intensive care unit* or micu or mobile intensive care ambulance* or mica* or paramedic* or para-medic* or emergency medical technician*))
S3 TI ((before hospital or pre-hospital or pre hospital or prehospital or out-of-hospital or out of hospital or emergency medical service*)) OR AB ((before hospital or pre-hospital or pre hospital or prehospital or out-of-hospital or out of hospital or emergency medical service*))
S4 TI (prior N5 hospital) OR AB (prior N5 hospital)
S5 (MM "Emergency Medical Services")
S6 (MH "Trauma Centers")
S7 (MH "Ambulatory Care Facilities")
S8 (MH "Emergency Medical Technicians")
S9 S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8

S10 (MH "Wounds and Injuries+")
S11 TI trauma* OR AB trauma*
S12 S10 OR S11
S13 (MH "Triage")
S14 TI ((triage or undertriage or overtriage or under-triage or over-triage)) OR AB ((triage or undertriage or overtriage or under-triage or over-triage))
S15 S13 OR S14
S16 TX predict* or scor* or observ*
S17 TX (validation or validate) OR TX (predict* or validat* or develop*) OR TX (sensitivity or specificity or injury severity score or risk assess* or risk predict* or risk stratif*)
S18 (MH "Models, Statistical")
S19 (MH "Risk Assessment")
S20 (MM "Postoperative Complications")
S21 (MM "Risk Factors")
S22 (MH "Outcomes (Health Care) ")
S23 (MM "Trauma Severity Indices")
S24 (MM "Severity of Illness Indices")
S25 (MM "Prognosis")
S26 S18 OR S19 OR S20 OR S21 OR S22 OR S23 OR S24 OR S25
S27 TI ((Risk model* or prognostic model* or prediction model* or predictive model* or risk assessment model* or prediction score* or algorithm* or matrix or matrices or assessment tool* or prediction rule* or decision rule*

TABLE 27 Quality Assessment of Diagnostic Accuracy Studies-2 quality assessment summary for studies included in the systematic review

	Risk of bias				Applicability concerns		
Author, year	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Brown, 2015[85]	HIGH	UNCLEAR	LOW	UNCLEAR	HIGH	LOW	LOW
Cox, 2014[86]	LOW	HIGH	HIGH	UNCLEAR	HIGH	LOW	HIGH
Ichwan, 2015[87]	HIGH	UNCLEAR	UNCLEAR	HIGH	HIGH	LOW	LOW
Jones, 2017[88]	UNCLEAR	UNCLEAR	UNCLEAR	UNCLEAR	HIGH	LOW	HIGH
Lavoie, 2010[89]	LOW	HIGH	HIGH	UNCLEAR	HIGH	LOW	LOW
Newgard, 2013[91]	LOW	HIGH	UNCLEAR	UNCLEAR	LOW	LOW	LOW
Newgard, 2014[93]	LOW	HIGH	UNCLEAR	UNCLEAR	HIGH	LOW	LOW
Newgard, 2016[90]	LOW	HIGH	UNCLEAR	UNCLEAR	LOW	LOW	LOW
Newgard, 2019[92]	UNCLEAR	UNCLEAR	UNCLEAR	HIGH	LOW	LOW	LOW
Phillips, 1996[95]	UNCLEAR	HIGH	LOW	HIGH	LOW	LOW	LOW
Scheetz, 2007[98]	LOW	HIGH	LOW	UNCLEAR	HIGH	HIGH	LOW
Scheetz, 2003[96]	HIGH	LOW	UNCLEAR	UNCLEAR	HIGH	UNCLEAR	LOW
Scheetz, 2011[97]	HIGH	LOW	LOW	UNCLEAR	HIGH	LOW	HIGH
Voskens, 2018[99]	HIGH	LOW	LOW	LOW	LOW	LOW	LOW
Nishijima, 2017[94]	HIGH	(A) UNCLEAR[a] (B) LOW[a]	UNCLEAR	UNCLEAR	HIGH	(A) LOW[a] (B) LOW[a]	HIGH

a Index test assessment of (A) triage tool accuracy (B) real-life triage tool performance.

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or risk score*)) OR AB ((Risk model* or prognostic model* or prediction model* or predictive model* or risk assessment model* or prediction score* or algorithm* or matrix or matrices or assessment tool* or prediction rule* or decision rule* or risk score*))

S28 S16 OR S17 OR S26 OR S27

S29 S9 AND S12 AND S15 AND S28

Appendix 2 Phase 1 economic evaluation additional methodological information and supplementary results

TABLE 28 A summary of the simulated characteristics of the patients included in the economic model

Characteristic	Mean	SD/*n*/*N*	Source
Age	46.8	21.3	Patients with complete age, gender, ISS, GCS and trauma type data in Van Rein *et al.*[115]
Percentage male	58.3%	2887/4720	
ISS	5.2	7.2	
Percentage with an ISS ≥ 16	9.1%	428/4720	
GCS	14.4	1.9	
Percentage with blunt trauma	98.2%	4637/4720	

TABLE 29 Summary of the parameters used in the Phase 1 economic model

Parameter	Value	Source
Clinical parameters		
Probability of patients having a transfer from a local hospital to a MTC if		
They were a true positive (ISS ≥ 16 and tool positive)	26.6%	Newgard *et al.*[44]
They were a false negative (ISS ≥ 16 and tool negative)	32.5%	
They were a true negative (ISS < 16 and tool negative)	4.3%	
They were a false positive (ISS < 16 and tool positive)	7.4%	
Probability of death within 30 days	Risk equation	TARN[117]
Relative risk of death within 30 days of hospitalisation for patients with an ISS ≥ 16 who were treated at a local hospital	1.25	Newgard *et al.*[118]
Relative risk of death within 30 days of hospitalisation for patients with an ISS < 16 who were treated at a local hospital	1	Assumption
Probability of death between 30 days post injury and 1 year post injury for patients with an ISS ≥ 16	3.6%	MacKenzie *et al.*[119]
Relative risk of death between 30 days and 1 year post hospitalisation for patients with an ISS ≥ 16 who were treated at an local hospital	1.64	
Probability of death between 30 days post injury and 1 year post injury for patients with an ISS < 16	1.7%	Davidson *et al.*[120]
Probability of death after 1 year	Age and gender dependent	ONS[121]
Hazard ratio for the risk of death if someone has a suspected major trauma case with		
An ISS of < 16	1.38	Newgard *et al.*[44]
An ISS of ≥ 16	5.19	Cameron *et al.*[122]

continued

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TABLE 29 Summary of the parameters used in the Phase 1 economic model (*continued*)

Parameter	Value	Source
Utility parameters		
Utility for patients with		
An ISS of 16 or more	0.65	Ahmed *et al.*[123]
An ISS of 15 or less	0.65	
General population utility		
Constant	0.9508566	Ara and Brazier[124]
Age	−0.0002587	
Age squared	−0.0000332	
Male (1 = male, 0 = otherwise)	0.0212126	
Calculations		
Age- and gender-matched general population utility for the Ahmed *et al.* population	0.824	Calculated. Mean age was 61 years and 59.1% of the analysis population was male in Ahmed *et al.*[123]
Utility multipliers, relative to the utility in the general population, for patients with		
An ISS of 16 or more	0.789	Calculated
An ISS between 15 and 9	0.789	Calculated
An ISS of under 9	1	Assumption that these patients would have a utility equal to that of the general population
Cost parameters		
Admission costs – base case		
Transfers between local hospitals and MTCs	£252	Assumed to be one additional ambulance call out. NHS improvement.[125] Currency code ASS02.
MTC admission, if ISS is 16 or over	£2819	NHS improvement[125]
MTC admission, if ISS is < 16 and over 8	£1466	
Treatment of a patient with blunt trauma and an ISS in the range of		
ISS ≤ 9	£6198	Christensen *et al.*[126]
9 < ISS ≤ 16	£8989	
16 < ISS ≤ 25	£14,205	
ISS > 25	£21,173	
Treatment of a patient with penetrating trauma and an ISS in the range of		
ISS ≤ 9	£6501	Christensen *et al.*[127]
9 < ISS ≤ 15	£6035	
15 < ISS ≤ 24	£9453	
24 < ISS ≤ 34	£12,347	
ISS > 34	£16,438	

TABLE 29 Summary of the parameters used in the Phase 1 economic model (*continued*)

Parameter	Value	Source
Post discharge costs		
Cost between discharge and 6 months post treatment	£1766	John Nichol, personal communication
Relative increase in lifetime treatment costs for patients with an ISS ≥ 16 compared to the general population	1.45	Cameron *et al.*[128] Delgado *et al.*[129]
Relative increase in lifetime treatment costs for patients with an ISS < 16 compared to the general population	1.25	Cameron *et al.*[128] Delgado *et al.*[129]
Yearly costs of NHS treatment	Age and gender dependent	Asaria[130]

ONS, Office for National Statistics.

TABLE 30 The results of the scenario analyses

Scenario	Cost-effective tool at £20,000 per QALY gained	Cost-effective tool at £30,000 per QALY gained
Base case	28.4% Sens, 88.6% Spec	87.5% Sens, 62.8% Spec
Scenario analyses		
TARN 2015 survival equation with every patient's CCI being missing	28.4% Sens, 88.6% Spec	87.5% Sens, 62.8% Spec
MTC benefit for people with and ISS in the range 16 > ISS ≥ 9		
MTCs have 25% benefit ▪ RR of death prior to discharge = 1.07 ▪ RR of death discharge and 1 year = 1.16	28.4% Sens, 88.6% Spec	99.8% Sens, 2.5% Spec
MTCs have 50% benefit ▪ RR of death prior to discharge = 1.13 ▪ RR of death discharge to 1 year = 1.32	28.4% Sens, 88.6% Spec	99.8% Sens, 2.5% Spec
MTCs have 75% benefit ▪ RR of death prior to discharge = 1.19 ▪ RR of death discharge to 1 year = 1.48	99.8% Sens, 2.5% Spec	99.8% Sens, 2.5% Spec

RR, relative risk; Sens, sensitivity; Spec, specificity.

TABLE 31 Most cost-effective triage tools in the threshold analyses on the cost of MTC care in England

MAICER = £20,000 per QALY gained

Costs of MTC care for injured patients with 16 > ISS ≥ 9

Costs of MTC care for injured patients with ISS ≥ 16	£1541 (2020–1 tariff levels)	£1466 (100%)	£1099.50 (75%)	£733 (50%)	£366.50 (25%)
£2961 (2020–1 tariff levels)	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	57.0% Sens 80.0% Spec
£2819 (100%)	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	57.0% Sens 80.0% Spec
£2114.25 (75%)	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	57.0% Sens 80.0% Spec
£1409.50 (50%)	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	57.0% Sens 80.0% Spec	87.5% Sens 62.8% Spec
£704.75 (25%)	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	28.4% Sens 88.6% Spec	87.5% Sens 62.8% Spec	90.4% Sens 58.4% Spec

continued

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TABLE 31 Most cost-effective triage tools in the threshold analyses on the cost of MTC care in England (*continued*)

MAICER = £30,000 per QALY gained

Costs of MTC care for injured patients with 16 > ISS ≥ 9

Costs of MTC care for injured patients with ISS ≥ 16	£1541 (2020–1 tariff levels)	£1466 (100%)	£1099.50 (75%)	£733 (50%)	£366.50 (25%)
£1541 (2020–1 tariff levels)	87.5% Sens 62.8% Spec	87.5% Sens 62.8% Spec	87.5% Sens 62.8% Spec	90.4% Sens 58.4% Spec	87.5% Sens 62.8% Spec
£2819 (100%)	87.5% Sens 62.8% Spec	87.5% Sens 62.8% Spec	87.5% Sens 62.8% Spec	87.5% Sens 62.8% Spec	87.5% Sens 62.8% Spec
£2114.25 (75%)	87.5% Sens 62.8% Spec	87.5% Sens 62.8% Spec	87.5% Sens 62.8% Spec	90.4% Sens 58.4% Spec	90.4% Sens 58.4% Spec
£1409.50 (50%)	90.4% Sens 58.4% Spec	87.5% Sens 62.8% Spec	90.4% Sens 58.4% Spec	90.4% Sens 58.4% Spec	90.4% Sens 58.4% Spec
£704.75 (25%)	90.4% Sens 58.4% Spec	90.4% Sens 58.4% Spec	90.4% Sens 58.4% Spec	90.4% Sens 58.4% Spec	99.8% Sens 2.5% Spec

Sens, sensitivity; Spec, specificity.

Appendix 3 Phase 1 qualitative study supplementary results

TABLE 32 Illustrative text responses on triage criteria for each survey question

Question	Illustrative text responses
Q1. Contributors to over triage?	
Mechanism of injury Specific injuries	*'Vehicles are much safer for restrained passengers in new vehicles'* *'High speed RTC'* *'In my experience, mechanism is a poor correlation'* *'Suspected pelvic #, distal open upper limb injuries'* *'Penetrating chest or abdo trauma without significant wound findings and normal observations'*
Q2. Contributors to under triage?	
Older age/specific mechanisms Comorbidities	*'Fall from standing in over 65's (clinical staff tend not to regard this as "fall")'* *'Elderly patients over 65yrs, and with fall from own height'* *'Fall down stairs'* *'Elderly patients on warfarin/NOAC's'* *'Other risk factors, pharmacology, complex pt's* *'Frailty, dementia'*
Q3. Modification to physiological triage criteria?	
Age-specific thresholds Additional variables Glasgow Coma Score	*'Physiological triggers should be age dependent or referenced against known baselines for individuals'* *'Would suggest amended physiological parameters for the elderly and paediatrics'* *'No GCS in elderly, small drop indicative of serious issue'* *'HR, BP depending on age in adults, in elderly normal BP is low'* *'Sats level, instead add in O_2 requirements'* *'Tachycardia in the elderly – 90 bpm or above'* *'GCS; I would remove the total score and include a Motor Score of 4 or less as a trigger instead'* *'Raise GCS parameters from 13 to 14 in paediatric and elderly patients'* *'Any decrease in GCS'*
Q4. Which patient subgroups benefit from MTC care?	
Specific significant injuries Older age Multiple injuries	*'SCI, Head/neck penetrating, chest penetration, high speed MVA and child passenger'* *'Chest wall injuries where MTC has expertise in interventional analgesia/rib fixation'* *'Open fracture (defined as exposed bone NOT long bone fracture)'* *'pts with severe single system injury e.g. open fracture, flail chest, neurosurgical head injury'* *'The elderly would benefit but are often under triaged'* *'Elderly chest injuries'* *'TBI, polytrauma, maxfax, spine with neurology'* *'Polytrauma requiring multispecialty input & prolonged rehab'* *'Pts with polytrauma i.e. 3 systems with AIS > 3'*
Q5. Which patient subgroups do not benefit from MTC care?	
Hypoxic injuries Frailty Palliative	*'Hanging/drowning – these are hypoxic injuries not trauma'* *'Frail elderly non operative BUT we must ensure that the holistic care provided at the TU is same standard as MTC'* *'Cachexic frailty with likely unsalvageable injury'* *'Frail/elderly pts where surgical intervention would be futile'* *'Children who are usually observed'* *'Those deemed end of life with advanced frailty'* *'Very frail elderly patients dragged miles from their families to delay inevitable death by a couple of weeks'* *'Frail elderly patients who are for EoL care'*
Other themes	
Clinical judgement	*'Should enhanced care teams (i.e. PHEM Dr/para teams) use same tool or have more "license"'*
Geography	*'Geography is a big issue'.* *'Over-triage in a large network like ours will make workload for ambulance service greater & inconvenience families & patients more than in smaller networks'.* *'We try to keep families (for example involved in RTC's) together (even when only 1 member needs MTC care)'*

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TABLE 33 Major trauma triage themes and subthemes

Subtheme	Issues	Illustrative responses
Theme 1: Context – the setting and circumstances in which major trauma networks operate will strongly influence triage decisions.		
Population	• Influence of demographic changes, particularly ageing population • Different injury profiles across age groups • Under triage of 'silver trauma'	• *'The population's got older so if you look at the brain injury studies in the 80s the median age was 23 man it's now 55 .... Yet the trauma tools still imagine that this is a, is a young person's game'*
Secular trends	• Societal changes influencing incidence and nature of injury and major trauma • Improvements in vehicle safety	• *'I feel rolling a car is no longer such a big deal, falling downstairs is a very big deal'* • 'Age cut-offs of 55 meaningless today'
Setting	• Variation in geography and organisation of trauma networks • Trauma specialties spread across different hospitals within networks • Inconsistent hospital capabilities • Wide diversity of transport times to MTCs	• *'Geography is a big issue. Over-triage in a large network like ours will make workload for ambulance service greater & inconvenience families & patients more than in smaller networks'* • *'Hospital [X] scan up to 21 stone, we have had to send patients before to hospital [X] to use the bigger scanners'*
Human factors	• Impact of workload • Possibility for human error • Clinical short cuts • Using triage tools to retrospectively validate clinical decisions	• *'Most governance clangers that occur happen at the end of shift time'* • *'The other influencing factor is the location of base station compared to the major trauma centre'* • *'Respiratory rate it's always 16, blood pressure is always 120 80 and GCS is always 3 or 15'* • *'It's just confirmatory, in the same way that your drug guidelines are: you vaguely know what they say and you're checking them to double check that you're correct'*
Expertise	• Level of education • Importance of ongoing professional training • Impact of experience and clinical gestalt	• *'Paramedics are getting younger, straight out of University, straight onto the road with unfortunately not much on-going education'* • *'You have to recognise that the people using this tool range from people who've spent eight weeks in a training school, to people who have been a paramedic for twenty years'*
Theme 2: Positive aspects – current major trauma triage (including triage tools and trauma network systems) performs well overall.		
Pathways	• Well-organised systems and care pathways • Good teamwork • Robust clinical governance	• *'You're not putting all the pressure on an inexperienced roadside person to get it right all the time'* • *'We've not had many secondary transfers out and therefore to me something's working . . . its working'*
Prehospital: hospital interface	• Clinical support available from senior ambulance clinicians, for example trauma desk • Pre-alert calls to EDs	• *'The benefit comes in of having someone on the other end of a phone who's sitting on the trauma desk who sees more of these trauma cases per day and can differentiate more quickly than you can'*
Triage tool	• Effective and accurate for high-acuity major trauma • Simple, structured, stepped format	• *'It's used as a structured thing by paramedics and, and that gets it right quite a lot of the time'*
Theme 3: Areas for improvement – aspects of major trauma triage that aren't working well or could be improved.		
Pathways	• Variation in provision of specialties relevant to major trauma across different MTCs	• *'Things like your plastics, your maxfax that's not necessarily part of the major trauma pathway'* • *'That's, part of the problem with the tool in some ways is that we go everything has to go to a MTC, or a MTU'*
Prehospital: hospital interface	• Conflicting senior advice, for example trauma desk	• *'So we've got two clinicians now, one in front of the patient, one over a telephone using exactly the same triage tool, which doesn't make sense'*

TABLE 33 Major trauma triage themes and subthemes (*continued*)

Subtheme	Issues	Illustrative responses
Triage tool	• Ambiguous variable definitions • Under-triage of elderly (although benefit of MTC care uncertain) • Some mechanisms traditionally perceived as high risk now less important • Flexibility and clinical judgement are valued	• *'Most of the triage tools is that there's a heavy mix of ambiguity and pointless specificity'* • *'It's so woolly and open ended, doesn't define, doesn't predict'* • *'It doesn't need to be bent metal to be major trauma'* • *'The more you nail it down the more problems you have'* • *'There should be less detail and less specific and allow more for just general sort of clinician discretion'* • *'Gut feeling, nine times out of ten, it's cos you look at a patient and you go you look like you're dying'* • *'Should enhanced care teams (i.e. PHEM Dr/para teams) use same tool or have more "license"?'*

TABLE 34 Main areas of discordant opinion regarding major trauma triage tools

View	Opposing view	Illustrative responses
Tool should be applied to all injured patients.	Tool is only helpful in certain cases or to retrospectively validate clinical decisions.	• *'Calling it a major trauma triage tool is the wrong thing to do in the first place, it's the phraseology affecting how people interact with it'* • *'The first one is when I'm already at a major trauma centre and I need to justify why I'm there. The second is when I have a patient who I'm quite confident is fine but I think the local ED is going to kick up a fuss. The third one is when my gut feeling is that they need to be in a major trauma centre and I'm just trying to find something to make it fit'*
It is a rule in tool for MTC care	It is a rule out tool for TU care	• *'You don't want the big SICK to go elsewhere'* • *'It's to help us to decide how appropriate is it to allow somebody who doesn't look so injured to go to a DGH'*
Certain variables should be added/ removed	Other variables should be added/ removed	• *'Separate physiological parameters for older patients please', 'Keep vital signs cut offs'* • *'Keep "ejection from car" very likely polytrauma', 'take out 'intrusion into vehicle, and take out 'fatalities in the same vehicle', 'Add 'falls down stairs'* • *'Take out GCS, only use motor component (> 4)'* • *'Take out "pelvic binder" as automatic trigger', 'Penetrating trauma but take out limbs', 'Put paralysis rather than spinal trauma'*
Needs to be a single universal tool	Need separate 'silver' and paediatric major trauma tools.	• *'Add clinical frailty score – age cut-offs of 55 meaningless today'* • *'Separate "silver trauma" triage tool is needed'* • *'It is capturing all of those and they're all going to the right place. So it's filling its current remit'* • *'Children aren't mini-adults'*
Needs to be a simple paper format	Needs to be an electronic	• *'It's used as a structured thing by paramedics and, and that gets it right quite a lot of the time'* • *'simplicity actually more helpful than the complexity that's gone in there'* • *'Make it electronic/App based'* • *'Replace tool with an SOP pull out'*
Remote decision support is helpful	Remote decision support is unhelpful	• *'We've got clinicians, with patients in front of them, then we've got someone on the other end of the phone telling them, no that's not correct, do this instead'* • *'So, we've got two clinicians now, one in front of the patient, one over a telephone using exactly the same triage tool, which doesn't make sense'* • *'I'm one of the newly qualified ones and yeah, it's useful. When you ring the trauma desk, they'll ask the questions, potentially say things that we might have missed, or may not have missed, but they'll also take into account what our opinions are as well'* • *'The benefit comes in of having someone on the other end of a phone who's sitting on the trauma desk who sees more of these trauma cases per day and can differentiate more quickly than you can'*

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Appendix 4 Phase 1 reference standard supplementary information

TABLE 35 Expert panel details

	Name	Specialty	Location
1	Jason Smith	Emergency medicine, MTC	Plymouth
2	Tim Coats	Emergency medicine, MTC	Leicester
3	Fiona Lecky	TARN research director, Emergency Medicine MTC	Manchester
4	Kay Stenton	Emergency medicine, non-MTC	Rotherham
5	Bill Bailey	Emergency medicine, non-MTC	Chesterfield
6	Adel Helmy	Neurosurgery, MTC	Cambridge
7	Stuart Harrison	Neurosurgery, MTC	Stoke
8	John Edwards	Thoracic surgery, MTC	Sheffield
9	Stuart Reid	Major trauma, Trauma network lead	Sheffield
10	Jeff Garner	General surgery, non-MTC	Rotherham
11	Mike Dennison	Orthopaedics, MTC	Sheffield
12	Ian Carmichael	Orthopaedics, non-MTC	Rotherham
13	Edward Mills	Orthopaedics, MTC	Sheffield
14	Johnathan May	Orthopaedics, non-MTC	Chesterfield
15	Jonathan Jones	Trauma network lead	Leeds
16	Gary Mills	Intensive Care, MTC	Sheffield
17	Johno Breeze	Maxillo-facial surgery, MTC	Birmingham

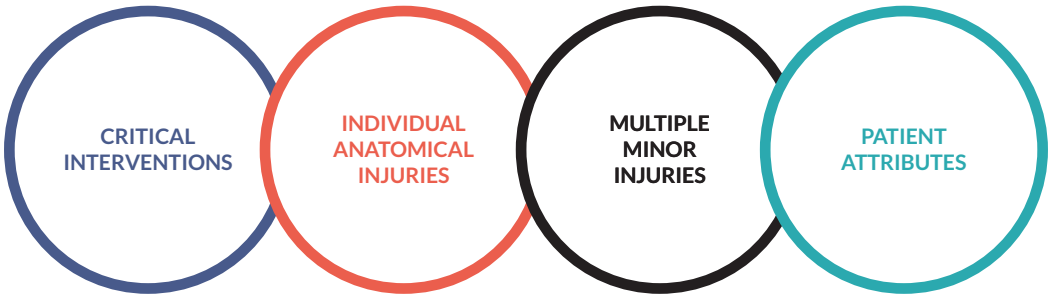


FIGURE 28 Schematic diagram of UK consensus definition of injury benefiting from MTC care.

TABLE 36 Existing reference standards for major trauma

	Category of reference standard			
	Anatomical	**Resource**	**Prognosis**	**Composite**
Examples	• ISS • New ISS • Abbreviated injury scale • Swiss highly specialised medicine regulations	• US consensus definitions • Vassallo definition	• Revised trauma score • TRISS • TARN prediction model • New Revised trauma score • MGAP • Emergency Trauma Score • A Severity Characterisation of Trauma (ASCOT) • ICD-based ISS (ICISS) • Trauma Mortality Prediction Model • Polytrauma score • Acute Trauma Index • CRAMS • PHI • Triage Revised Trauma Score (T-RTS) • Physiologic Severity Score (PSS) • MGAP • Modified Rapid Emergency Medicine Score (mREMS) • Kampala Trauma Score (KTS) • Berlin polytrauma criteria	• Current MATTS reference standard • German trauma society criteria • Ad hoc composite measures, for example combination of ISS, intensive care unit admission, and any non-orthopaedic surgery within 24 hours
Advantages for defining need for expedited MTC care	Theoretical: • Simple • Objective Operational: • Readily available for research purposes from trauma registries	Theoretical: • Captures patients with low ISS who need urgent trauma interventions • Reflects critical determinants of benefits of MTC care Operational: • Readily available for research purposes from trauma registries	Theoretical: • Objective • Presents mortality risk range/threshold Operational: • Information for calculation available from trauma registries	Theoretical: • Minimising the disadvantages of single domain reference standards Operational: • Information for calculation available from trauma registries

continued

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TABLE 36 Existing reference standards for major trauma (*continued*)

	Category of reference standard			
	Anatomical	**Resource**	**Prognosis**	**Composite**
Disadvantages for defining need for expedited MTC care	Theoretical: • Some apparently less severe injuries benefit from urgent MTC interventions. • Modifiers of injury severity excluded, for example comorbidities • Injury severity not fully captured, for example GCS score in TBI • Futility excluded (except AIS 6 un-survivable injuries) • Patient values excluded	Theoretical: • Some serious injuries benefiting from MTC care may not need resource-based interventions • Patient values excluded	Theoretical: • Significance of individual injuries excluded • Resource use excluded • Futility excluded • Patient values excluded	Theoretical: • Might compound the disadvantages of single domain reference standard
	Operational: • Influenced by degree of investigation	Operational: • Subject to variability in medical decision making and hospital expertise • Potential confounding effect from concomitant acute medical events	Operational: • Often complex • Generally poor predictive performance • Often un-validated	Operational: • Increased complexity

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; TRISS, trauma and injury severity score.

Appendix 5 Phase 1 triage tool development supplementary information

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TABLE 37 Delphi survey participants

	Medical Director/Clinical Lead/Representative			Member			
Name	MTC/ Network	NHS Ambulance Service	Air Ambulance Service	NHS Major Trauma Clinical Reference Group	RCEM Major Trauma Committee	Other affiliations	Clinical background
Alastair Wilson			East Anglian				Emergency medicine consultant
Andy Eynon				■			Neurocritical care consultant
Anil Hormis				■			Anaesthesia consultant
Anna Crossley				■			Registered nurse
Bas Sen	MTC						Emergency medicine consultant
Benjamin Walton	MTC						Anaesthesia consultant
Bob Winter		East Midlands	Lincolnshire and Nottinghamshire	■			Critical care consultant
Caroline Leech					■		Emergency medicine consultant
Charles Deakin			Hampshire and Isle of Wight				Anaesthesia/critical care consultant
Chris Fitzsimmons	MTN				■		Paediatric emergency medicine consultant
Chris Martin		East of England					Critical care paramedic
Chris Moran				■		National Clinical Director for MT	Orthopaedic consultant
Darren Walter			North West				Emergency medicine consultant
Dave Bramley	MTN		Great North				Emergency medicine consultant
David Ratcliffe		North West					General practitioner
Fiona Lecky					■		Emergency medicine consultant
Fionna Moore				■			Emergency medicine consultant
Heather Jarman	MTC				■		Registered Nurse
James Wenman		South Western					Paramedic
Jeremy Henning				■			Critical care consultant
John Black		South Central					Emergency medicine consultant
John Martin				■			Paramedic

TABLE 37 Delphi survey participants (*continued*)

Name	Medical Director/Clinical Lead/Representative			Member		Other affiliations	Clinical background
	MTC/ Network	NHS Ambulance Service	Air Ambulance Service	NHS Major Trauma Clinical Reference Group	RCEM Major Trauma Committee		
John Stephenson			Lincolnshire and Nottinghamshire				Emergency medicine consultant
Jonathan Jones	MTN				■		Emergency medicine consultant
Jonathan Whelan		Wales					Anaesthetic consultant
Keith Porter	MTC						Trauma surgery consultant
Kyee Han		North East					Emergency medicine consultant
Magnus Nelson	MTC					Ambulance Service Medical Advisor	Magnus Nelson
Mark Jadav	MTN						Emergency medicine consultant
Mark Millins		Yorkshire					Paramedic
Martin Berry						College of Paramedics	Paramedic
Martin Smith	MTN						Emergency medicine consultant
Matthew Wyse			The Air Ambulance Service	■			Anaesthetic consultant
Michael Jenkins	MTC						Vascular surgery consultant
Miriam Duffy	MTC			■			Physiotherapist
Naomi Davis	MTC			■			Orthopaedics consultant
Nick Crombie			Midlands				Anaesthetic consultant
Nik Kanakaris	MTC						Orthopaedics consultant
Paul Fell		North East				College of Paramedics	Paramedic
Phil Hyde			Dorset and Somerset				Paediatric critical care consultant
Phil Moss					■		Emergency medicine consultant
Phillip Godfrey	MTC						Anaesthetic consultant
Robert Crouch				■			Registered nurse

continued

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TABLE 37 Delphi survey participants (*continued*)

Name	Medical Director/Clinical Lead/Representative			Member		Other affiliations	Clinical background
	MTC/ Network	NHS Ambulance Service	Air Ambulance Service	NHS Major Trauma Clinical Reference Group	RCEM Major Trauma Committee		
Rod Mackenzie	MTC			■			Emergency medicine consultant
Scott Adams	MTC						Orthopaedics consultant
Simon Hughes	MTC						Anaesthetic consultant
Simon Lewis	MTN		Magpas				Emergency medicine consultant
Stephen Garvey			Cornwall				Anaesthetic consultant
Steve Riddle			Wiltshire				Paramedic
Stuart Durham	MTC						Emergency medicine consultant
Tim Nutbeam			Devon				Emergency medicine consultant
Tom Hurst	MTC				■		Critical care consultant
Tony Kehoe	MTC				■	MTN Governance Lead	Emergency medicine consultant

MTN, major trauma network.

TABLE 38 Consensus meeting participants

Name	Specialism	Affiliation
Dr Nicola Batrick	Emergency Medicine (MTC)	St Mary's Hospital, London
Mr Mark Faulkner	Ambulance Service	London Ambulance Service
Professor Steve Goodacre (Chair)	Emergency Medicine (MTC)	Sheffield Teaching Hospitals, University of Sheffield
Dr Nathan Howes	Emergency Medicine (MTC), Pre-Hospital Emergency Medicine	Cambridge University Hospitals, Magpas Air Ambulance
Dr Rob Jones	Emergency Medicine (TU)	Barnsley District General Hospital
Dr Anthony Kehoe	Emergency Medicine (MTC)	University Hospitals Plymouth
Dr Allie Klein	Emergency Medicine (TU)	University Hospital of Derby
Mr Josh Miller	Ambulancee Service	West Midlands Ambulance Service
Dr Chris Press	Anaesthesia (MTC), pre-hospital physician	Sheffield Teaching Hospitals
Dr Stuart Reid	Emergency Medicine (MTC), pre-hospital physician	Sheffield Teaching Hospitals
Mr Simon Standen	Ambulance Service	Yorkshire Ambulance Service
Mr Paul Younger	Ambulance Service	North East Ambulance Service, College of Paramedics

TABLE 39 Variables, categories and domains present in English ambulance service triage tools

Physiological criteria										
Trust	**EEAST**	**EMAS**	**LAS**	**NEAS**	**NWAS**	**SCAS**	**SECAS**	**SWAS**	**WMAS**	**YAS**
Resp. rate < 10 or > 29	Sustained	✓	✓	✓	✓	✓	✓	Sustained	✓	✓
Systolic BP < 90 mmHg	Sustained	Sustained	Sustained	Sustained	Sustained	✓	Sustained	Sustained	2 readings	Sustained
Absent radials	✓			Sustained		✓		✓		
GCS total		< 14	< 14	< 14	< 13		< 14		< 14	< 14
GCS Motor	< 5					< 5		< 5		
Other		Lucid interval								
Any met?	MTC									

EEAST, EMAS, SCAS, SWAS and YAS advise application of JRCALC abnormal paediatric values for children.

Anatomical criteria (1/2)										
Trust	**EEAST**	**EMAS**	**LAS**	**NEAS**	**NWAS**	**SCAS**	**SECAS**	**SWAS**	**WMAS**	**YAS**
Chest injury+		Altered physiology	Altered physiology	Hypoxia			Altered physiology			Altered physiology
Open PTX	✓					✓		✓		
Flail	✓			✓	✓	✓		✓		
Suspected pelvic #	Major	✓	✓	+ Obvious deformity/ instability		Major	✓	✓	✓	✓
> 1 Long bone #s	Proximal	✓			Proximal	Proximal		Proximal	✓	

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TABLE 39 Variables, categories and domains present in English ambulance service triage tools (*continued*)

Anatomical criteria (1/2)										
Trust	**EEAST**	**EMAS**	**LAS**	**NEAS**	**NWAS**	**SCAS**	**SECAS**	**SWAS**	**WMAS**	**YAS**
Crushed/ de-gloved limb	✓				Extremity	✓		✓	Extremity	
Mangled limb	✓		Proximal to ankle/ wrist		Extremity	✓		✓	Extremity	
Amputated limb	✓	Proximal to ankle/ wrist	Proximal to ankle/ wrist	Proximal to ankle/ wrist	Proximal to ankle/ wrist	✓	Proximal to ankle/ wrist	✓	Proximal to ankle/ wrist	Proximal to ankle/ wrist
Suspected open/ depressed skull #	✓	✓	✓			✓	✓	✓	✓	✓
Spinal trauma+		Abnormal neurology	Abnormal neurology	Abnormal neurology		Motor deficit	Abnormal neurology	Motor deficit		Abnormal neurology
Neurological deficit					Sensory/ motor				Sensory/ motor	
Any met?	MTC									

EMAS, SECAS and YAS also use: Time-critical (e.g. Burns > 20%). EMAS also use: Haemorrhage requiring CAT/haemostatic dressing. LAS also use: Open lower limb fracture proximal to ankle.

Anatomical criteria (2/2)										
Trust	**EEAST**	**EMAS**	**LAS**	**NEAS**	**NWAS**	**SCAS**	**SECAS**	**SWAS**	**WMAS**	**YAS**
Penetrating injury										
Head				Proximal to elbow/knee	Head, neck, trunk, proximal to elbow/ knee					
Neck		✓	Below head and above knees, NOT arms				✓		✓	✓
Chest		✓					✓		✓	✓
Abdomen		✓					✓		✓	✓
Back		✓					✓			✓
Groin		✓					✓			✓
Thigh							✓			
Arm				(Upper)	(Upper)		✓			
Burns										
Body surface area		> 20%	> 30%	≥ 15%	Severe burns		> 20%			> 20%
Facial		+ Trauma	Complete skin loss lower ½ face	✓			✓			+ Trauma
Circumferential		+ Trauma	✓	✓			✓			+ Trauma
Hand				✓						
Inhalational				✓						
Any met?	MTC									

NEAS use ≥ 10% Body surface area burns in children.

TABLE 39 Variables, categories and domains present in English ambulance service triage tools (*continued*)

Mechanistic criteria										
Trust	**EEAST**	**EMAS**	**LAS**	**NEAS**	**NWAS**	**SCAS**	**SECAS**	**SWAS**	**WMAS**	**YAS**
Fall > 2 storeys		Or > 20 feet	Or > 20 feet	✓	Or > 5 m		Or > 20 feet		Or > 6 m	Or > 20 feet
Occupant fatality in same:		Compart-ment	Compart-ment	Vehicle	Compart-ment		Compart-ment		Compart-ment	Compart-ment
Pedestrian/ cyclist vs. vehicle		Thrown/run over with significant impact		✓					Thrown/run over with significant impact	
Ejection		At speed		✓	Complete/ partial				Complete/ partial	
Entrapment		Under vehicle	Under vehicle/large object	Pro-longed	✓		Under vehicle		✓	Under vehicle
Bull's-eye window/a post damage		✓	From impact of individual outside vehicle				✓			✓
Any met?		Consider MTC/advice	MTC	Apply tool[a]	Advice		Advice		Advice	Consider MTC

a NEAS use listed criteria as examples of when the rest of the tool should be applied, in addition to the following mechanisms: high-speed RTC, motorcycle collision, crush, assault with weapon, and blast.

Note
WMAS also use: intrusion > 30 cm @ patient site, and motorcycle collision > 20 mph.
WMAS use fall > 3 m/2 × height in children.

Special circumstances										
Trust	**EEAST**	**EMAS**	**LAS**	**NEAS**	**NWAS**	**SCAS**	**SECAS**	**SWAS**	**WMAS**	**YAS**
> 55 years old		✓	✓	> 65 years old	≥ 65 years old		✓		✓	✓
Children		Compensating							< 8 years old	
Pregnancy > 20/40		✓	✓	✓	✓		✓		✓	✓
Bleeding disorder		✓	✓	✓			✓		✓	✓
Anticoag			✓				✓		✓	
Morbidly obese		✓	✓				✓			✓
Other		20% burns or circumferential (without trauma)			Significant comorbid-ities				20% burns or circumferential, dialysis, time-critical extremity injury	
Any met?		Consider MTC/ advice	Advice[a]	MTC[b]	Advice[a]		Advice[a]		Advice	Consider MTC

a LAS, NWAS and SECAS: also seek advice, if clinical concern, but triage-negative.
b NEAS: AND high clinical concern.

continued

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TABLE 39 Variables, categories and domains present in English ambulance service triage tools (*continued*)

TU bypass guidance										
Trust	**EEAST**	**EMAS**	**LAS**	**NEAS**	**NWAS**	**SCAS**	**SECAS**	**SWAS**	**WMAS**	**YAS**
If MTC more than										
45 minutes	Of scene arrival	✓		✓	✓	✓	✓	✓		✓
Then:	TU	TU		TU	TU	TU	Advice	TU		TU
If unable to manage										
A	✓	Compro-mise	✓	✓	✓	✓	Obstruction/ imminent compromise	✓		Compro-mise
B	✓				✓					
C	✓	Major haemor-rhage			Catastrophic haemor-rhage	Catastrophic haemor-rhage	Imminent cardiac arrest	Catastrophic haemor-rhage		
Then:	TU	Consider TU	Consider TU	TU	TU	TU	Clinical advice[a]	TU		Consider TU

a SECAS: also for clinical deterioration.

Note
SCAS and SWAS advise nearest ED if cardiac arrest imminent.

TABLE 40 Novel variables from Delphi round 1

Domain	Category	Variable
Physiology	Blood pressure	Shock index (HR/SBP)
	Level of consciousness	AVPU score P or less
		AVPU score P or less, with evidence of head injury
Anatomical injury	Chest injury	Multiple rib fractures
	Spinal injury	Evidence of spinal cord injury
	Long bone injury	Open fracture of the femur
		Open long bone fractures
		Open long bone fractures with extensive soft-tissue laceration (≥ 10 cm)
	Limb/extremity injury	Open mid- and hindfoot fractures
Mechanism of injury	Falls	Fall down full flight of stairs
Special circumstance	Intoxication	Intoxicated with alcohol or drugs
	Patient preference	Patient request to be taken to a MTC

AVPU, Alert Verbal Pain Unresponsive scale; HR, heart rate; SBP, systolic blood pressure.e

TABLE 41 Results for Delphi round 4 selecting implementation categories and criteria

Implementation category	Level of agreement	Most appropriate descriptor	Level of appropriateness
For all injured adults, who TRIGGER the triage tool			
Prompt consideration of Enhanced Care Team Support	**78%**	Prompt:	
		Discuss with Enhanced Care Team	2.4
		Request/activate Enhanced Care Team	2.2
		Consider requesting/activating Enhanced Care Team	2.2
		Consider discussing with Enhanced Care Team	1.9
Include consideration of Immediate Clinical Risk	**81%**	Immediate Clinical Risk criteria:	
		Difficulty maintaining airway	3.2
		Imminent cardiac arrest	3.1
		Difficulty controlling haemorrhage	2.9
		Difficulty maintaining oxygenation	2.8
		Action, if any Immediate Clinical Risk criteria triggered:	
		Triage to nearest TU	2.8
		Request/activate Enhanced Care Team	2.6
		Seek clinical advice	2.4
		Consider requesting/activating Enhanced Care Team	2.2
Include a Time to MTC ED Arrival Threshold	**78%**	Action, if time threshold exceeded:	
Within 60 minutes' journey	81%	Seek clinical advice	2.6
Within 90 minutes of 999 call	16%	Consider helicopter to facilitate direct transport to MTC	2.6
Within 45 minutes' journey	3%	Request/activate Enhanced Care Team	2.4
		Consider requesting/activating Enhanced Care Team	2.4
		Triage to nearest TU	2.3
For injured adults, who DO NOT TRIGGER the triage tool			
	Level of Agreement	Most Appropriate Descriptor	Level of Appropriateness
Include Clinical Concern of the Healthcare Professional on Scene	**72%**	Action:	
		Seek clinical advice	3.0
		Consider triage to MTC	2.4
		Consider clinical advice	2.2
		Triage to MTC	1.8

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TABLE 42 Exploratory expert consensus sensitive and balanced triage tools

Sensitive triage tool	Balanced triage tool	Specific triage tool
Physiology • Respiratory rate < 10, > 24 • Shock index > 0.9; or SBP < 110 in elderly • New GCS ≤ 14	Physiology • Sustained respiratory rate < 10, > 29 • Sustained shock index > 1; or SBP < 90 (< 110 in > 65 years) • Sustained new GCS ≤ 13 (elderly ≤ 14)*	Physiology • Sustained respiratory rate < 10 or > 29 • Sustained systolic BP < 90 • New best GCS motor score ≤ 4*
Anatomical injuries • Chest injury with tachycardia, oxygen requirement, or low oxygen saturations (< 94%) • Chest wall instability, deformity or surgical emphysema • ≥ 2 long bone fractures • Open fracture proximal to mid-foot/wrist • Amputation or mangled extremity proximal to ankle or wrist • De-gloving injury proximal to mid-foot/wrist • Penetrating injury proximal to elbows/knees (i.e. penetrating injury except lower arms and lower legs). • Suspected open, depressed or CSF leak skull fracture • Spinal injury with abnormal neurology • Arterial bleeding requiring control with tourniquet • Suspected pelvis fracture	Anatomical injuries • Chest injury with tachycardia, oxygen requirement, or low oxygen saturations (< 94%) • ≥ 2 long bone fractures • Open fracture proximal to mid-foot/wrist • Amputation or mangled extremity proximal to ankle or wrist • De-gloving injury proximal to mid-foot/wrist • Penetrating injury proximal to elbows/knees • Definite open, depressed or CSF leak skull fracture • Spinal injury with abnormal neurology • Arterial bleeding requiring control with tourniquet • Suspected pelvis fracture	Anatomical injuries • Chest injury with oxygen requirement/low oxygen saturations (< 94%) • ≥ 2 proximal long bone fractures • Open fracture proximal to mid-foot/wrist • Amputation or mangled extremity proximal to ankle or wrist • Penetrating injury to neck, chest, axilla, abdomen, back or groin • Definite open, depressed or CSF leak skull fracture • Spinal injury with paralysis • Suspected major pelvis fracture
Mechanism • Fall down a full flight of stairs • Fall > 20 feet/2 floors • Pedestrian/cyclist vs. train/bus/tram/lorry		

TABLE 43 MATTS triage tool variable definitions

Variable	Definition
Sustained vital signs	Repeated physiological observations with similar values
GCS motor score of 4 or less	Best obtainable GCS motor response of withdrawing from pain or worse, that is not responding to motor commands and not localising to pain
Chest injury with new oxygen requirement	Significant chest injury such as chest wall deformity/instability, flail segment, crepitus, surgical emphysema, suspected open or closed pneumothorax, suspected haemothorax, severe pain requiring morphine AND new oxygen requirement: new drop in saturations on room air to < 94% (< 88% if chronic obstructive pulmonary disease)
Major pelvis fracture	Mechanism of injury and clinical findings are suggestive of a pelvic fracture AND any of clinical signs of shock, pelvis deformity/instability, severe pelvic pain, pelvis injury with PU/PR/PV bleeding, or scrotal haematoma
Penetrating injury to head, neck, chest, axilla, abdomen, back, gluteal region, or groin	Non-trivial penetrating injury with suspected visceral or vascular injury
Open or depressed skull fracture	Open skull fracture = clearly visualised skull fracture or intracranial contents; not extensive scalp wound or visualised skull alone. Depressed skull fracture = obvious skull deformity or palpable discrepancy in skull contour; not boggy swelling alone.

TABLE 43 MATTS triage tool variable definitions (*continued*)

Variable	Definition
Spinal injury with paralysis	Paraplegia, tetraplegia, or limb paralysis; not isolated paraesthesia
> 1 proximal long bone fractures	Two or more fractures of shafts of humerus or femur. Excludes: fractured neck of humerus, fractured neck of femur; shoulder, elbow, and knee injuries.
Amputation or mangled extremity proximal to ankle or wrist	Traumatic limb amputation at level of wrist/ankle, or more proximally. Excludes partial hand, partial foot, finger, thumb, or toe amputations. Severe soft-tissue damage to limbs with or without fractures. Excludes hand/fingers/thumb and foot/toes soft-tissue injuries.
Open fracture proximal to forefoot/wrist	Open fractures of upper or lower limb proximal to wrist/forefoot, with: bone protruding out of skin, greater than credit card sized skin defect, or highly contaminated. Excludes wrist, hand, fingers, forefoot, toes. If isolated open fracture, consider triage to TU with ortho-plastic capability according to local pathways.
Step 3 clinical judgement	Clinical judgement is valued and important. Evaluate history, vital signs, examination findings, mechanism of injury, and patient characteristics (age, medications, comorbidities). Examples of scenarios in which to carefully evaluate for major trauma include: • High falls, for example > 2 m, or full flight of stairs • High-energy RTC, for example entrapment, ejection, A-post deformity, death in same vehicle compartment, high speed motorcycle crash > 30 mph • Pedestrian/bicyclist vs. vehicle/object with significant impact, for example > 30 mph Obtain senior clinical advice according to local pathways (e.g. trauma desk, critical care desk, senior paramedic, enhanced care team, HEMS, prehospital medical team, or MTC) if: • Major trauma is suspected based on clinical findings and mechanism of injury, but steps 1 and 2 are negative. • Triage category is not felt to reflect patient need (i.e. triage tool triggered, but major trauma not suspected, or patient would not benefit from MTC care) Transport to MTC with pre-alert if suspicion for major trauma confirmed by senior clinical support.

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Appendix 6 Phase 2 validation study supplementary information

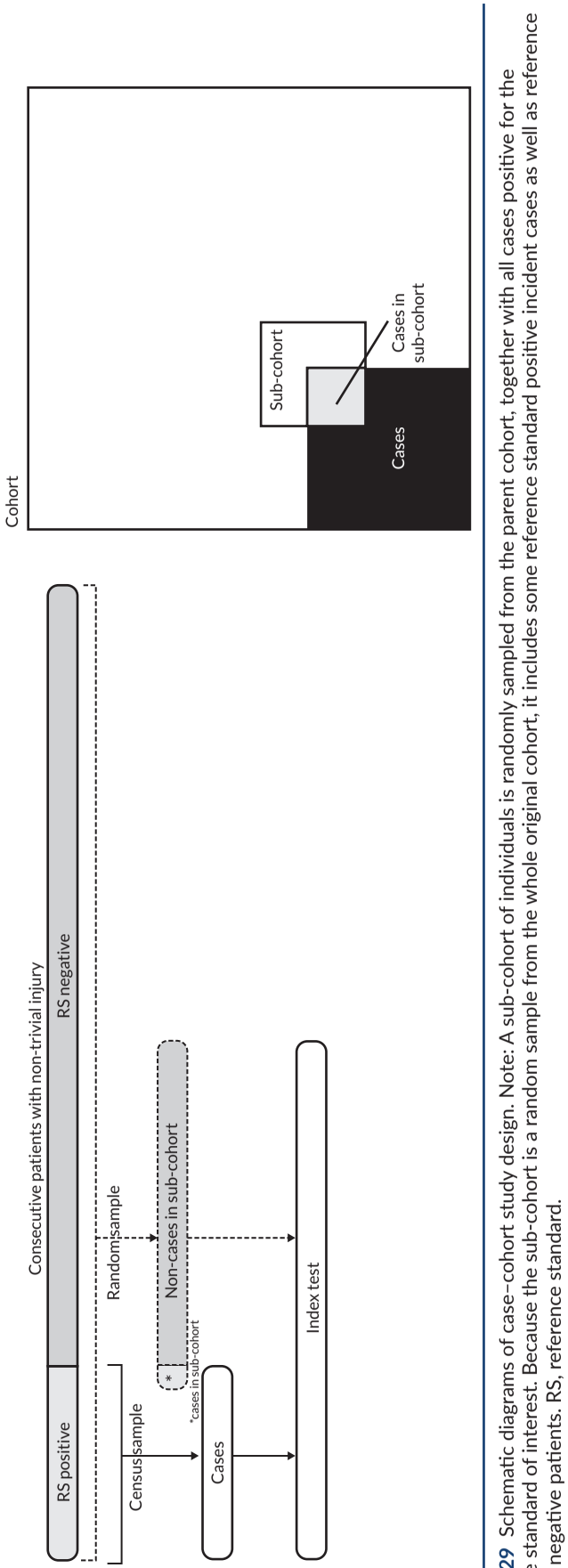


FIGURE 29 Schematic diagrams of case–cohort study design. Note: A sub-cohort of individuals is randomly sampled from the parent cohort, together with all cases positive for the reference standard of interest. Because the sub-cohort is a random sample from the whole original cohort, it includes some reference standard positive incident cases as well as reference standard negative patients. RS, reference standard.

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FIGURE 30 Participating trauma networks. Note: Bristol Royal Infirmary (TU) and Bristol Children's Hospital (MTC) are obscured by Southmead Hospital. Similarly, St James Hospital (TU) is obscured by Leeds General Infirmary. LGI, Leeds General Infirmary; QEB, Queen Elizabeth's Hospital Birmingham; SMDH, Southmead Hospital; SM, St Mary's Hospital.

TABLE 44 Included trauma networks and hospitals

Trust	Hospital	Designation – adults	Designation – children
Severn Network			
North Bristol NHS Trust	Southmead Hospital	MTC	N/A
University Hospitals Bristol NHS Foundation Trust	Bristol Royal Hospital for Children	N/A	MTC
University Hospitals Bristol NHS Foundation Trust	Bristol Royal Infirmary	TU	N/A
Royal United Hospitals Bath NHS Foundation Trust	Royal United Hospital Bath	TU	TU
Somerset NHS Foundation Trust	Yeovil Hospital	TU	TU
Somerset NHS Foundation Trust	Musgrove Park Hospital	TU	TU
Great Western Hospitals NHS Foundation Trust	Great Western Hospital (Swindon)	TU	TU
Gloucestershire Hospitals NHS Foundation Trust	Gloucestershire Royal Hospital	TU	TU
University Hospitals Bristol NHS Foundation Trust	Western General Hospital	LEH	LEH
Gloucestershire Hospitals NHS Foundation Trust	Cheltenham General Hospital	LEH	LEH
North West London Network			
Imperial College Healthcare NHS Trust	St Mary's Hospital	MTC	MTC
Hillingdon Hospitals NHS Foundation Trust	Hillingdon Hospital	TU	TU
Chelsea and Westminster Hospital NHS Foundation Trust	Chelsea and Westminster Hospital	TU	TU
Chelsea and Westminster Hospital NHS Foundation Trust	West Middlesex University Hospital	TU	TU
London North West University Healthcare NHS Trust	Ealing Hospital	TU	TU
London North West University Healthcare NHS Trust	Northwick Park Hospital	TU	TU
West Hertfordshire Teaching Hospitals NHS Trust	Watford General Hospital	TU	TU
West Yorkshire Network			
Leeds Teaching Hospitals NHS Trust	Leeds General Infirmary	MTC	MTC
Leeds Teaching Hospitals NHS Trust	St James University Hospital	TU	TU
Airedale NHS Foundation Trust	Airedale General Hospital	TU	TU
Bradford Teaching Hospitals NHS Foundation Trust	Bradford Royal Infirmary	TU	TU
Calderdale and Huddersfield NHS Foundation Trust	Calderdale Royal Hospital	TU	TU
Mid Yorkshire Hospitals NHS Trust	Dewsbury and District Hospital	LEH	LEH
Harrogate and District NHS Foundation Trust	Harrogate District Hospital	TU	TU
Calderdale and Huddersfield NHS Foundation Trust	Huddersfield Royal Infirmary	TU	TU
Mid Yorkshire Hospitals NHS Trust	Pinderfields General Hospital	TU	TU
Birmingham Network			
University Hospitals Birmingham NHS Foundation Trust	Queen Elizabeth Birmingham	MTC	N/A
Birmingham Women's and Children's NHS Foundation Trust	Birmingham Children's Hospital	N/A	MTC
University Hospitals Birmingham NHS Foundation Trust	Heartlands Hospital	TU	TU
Sandwell and West Birmingham Hospitals NHS Trust	Birmingham City Hospital	LEH	LEH
University Hospitals Birmingham NHS Foundation Trust	Good Hope Hospital	LEH	LEH

continued

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TABLE 44 Included trauma networks and hospitals (*continued*)

Trust	Hospital	Designation – adults	Designation – children
Wye Valley NHS Trust	Hereford General Hospital	TU	TU
Royal Wolverhampton NHS Trust.	New Cross Hospital	TU	TU
The Dudley Group NHS Foundation Trust	Russells Hall Hospital	TU	TU
Sandwell and West Birmingham Hospitals NHS Trust	Sandwell District General Hospital	TU	TU
Walsall Healthcare NHS Trust	Walsall Manor Hospital	TU	TU
Worcestershire Acute Hospitals NHS Trust	Worcestershire Royal Hospital	TU	TU
Worcestershire Acute Hospitals NHS Trust	Alexandria Hospital	LEH	LEH

N/A, not applicable.

TABLE 45 Characteristics of trauma networks included in Phase 2

Characteristic	West Yorkshire	Birmingham	Severn	North-West London
Population	2.38 million	2.95 million	2.3 million	0.59 million
Population density	1172/km^2	3276/km^2	1291/km^2	7600/km^2
Urban population	90%	99%	69%	98%
Over 65 seconds	17%	15.6%	19.6%	12.3%
White ethnicity	77%	61.4%	88.6%	50.9%
Life expectancy	80 years	80 years	82 years	80 years
Unemployment	2.9%	6.7%	2.5%	4.3%
Ambulance service	Yorkshire Ambulance Service	West Midlands Ambulance Service	South-West Ambulance Service	London Ambulance Service
Trauma desk	Yes	Yes	Yes	Yes
Critical care paramedics	Yes	Yes	Yes	Yes
Air ambulance	Yes	Yes	Yes	Yes
Trauma network model	Inclusive	Inclusive	Inclusive	Inclusive

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TABLE 46 Phase 2 case–cohort study inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Presented with non-trivial injury: selected WI code, major trauma pre-alert, trauma-specific intervention.	Conveyed to non-participating hospital
Attended by participating ambulance service.	Conveyed by non-participating ambulance service
	Not conveyed to hospital
Major trauma triage tool would plausibly be used.	Non-ambulance presentation
Presented during 4 months study period.	Death in field
Any age.	Secondary transfer
Direct conveyance from scene to a hospital in included trauma network.	Presentation out of study dates
Conveyed by participating ambulance service.	Trivial injury presentation
Injured within defined geographical area, with corresponding ambulance service and trauma network catchments area.	Non-acute injury presentation (> 72 hours)
	Medical presentation
	Isolated hypoxic injury (hanging, drowning)
	Isolated burns
	Triage tool exclusions: traumatic cardiac arrest, unstable airway, breathing, or circulation/divert to TU

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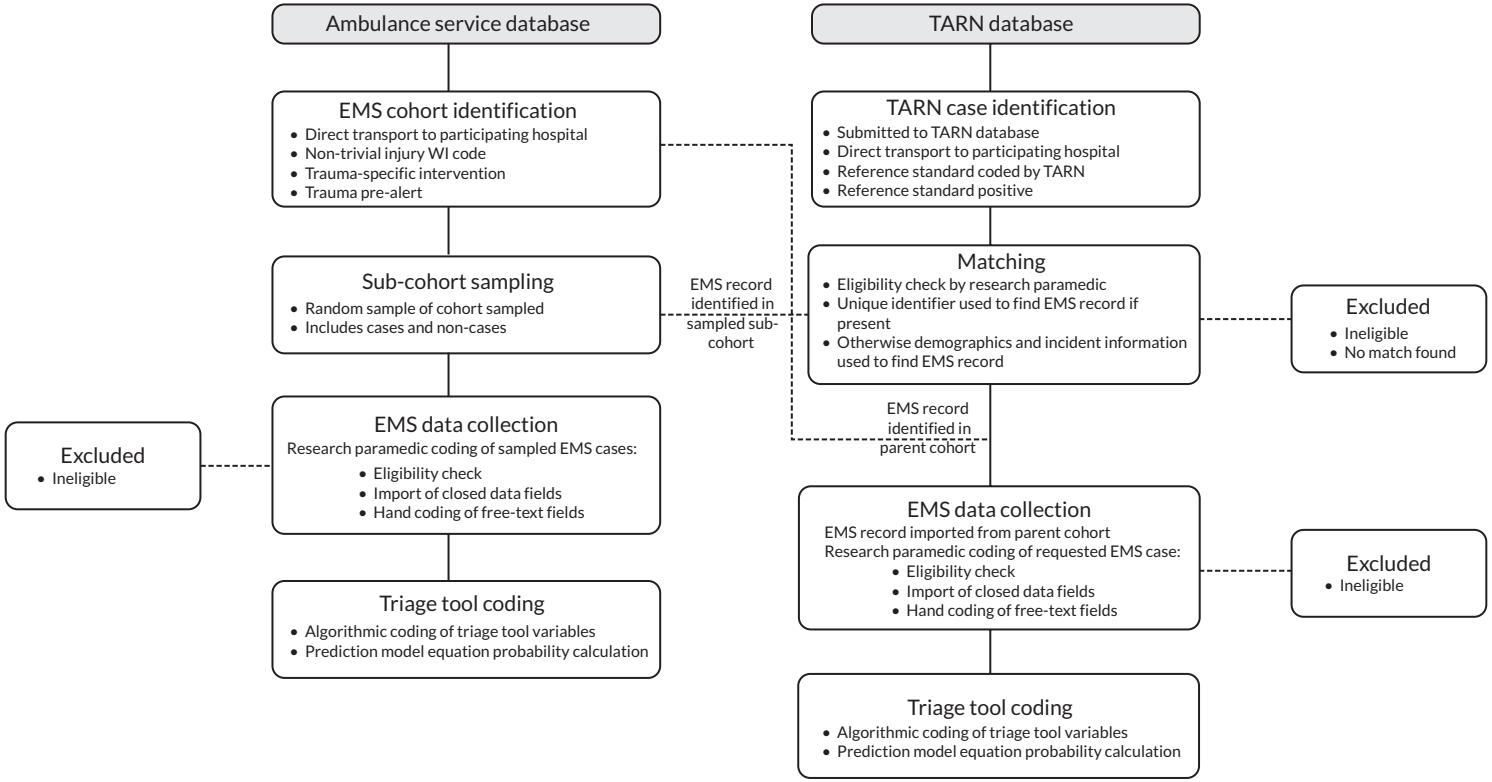


FIGURE 31 Data flows for derivation of the Phase 2 case–cohort study sample.

Trauma Audit and Research Network data collection procedures

Trauma Audit and Research Network is the English national trauma registry database and collects information on patients with major injuries presenting to all trauma receiving hospitals in England. Patients are included in the TARN database if they sustain injury resulting in any of the following: hospital admission for > 72 hours; critical care or high dependency unit admission; transfer for specialist care; or death. Patients with simple isolated injuries (e.g. radius fracture), pubic rami or femoral neck fractures and aged over 65, prehospital deaths, or diagnosed as dead on emergency department arrival with no further management instigated, are excluded. The TARN registry therefore aims to include all patients requiring significant treatment for non-trivial injuries sustained from meaningful trauma. Notably, MTCs, but not TUs, receive payment for case submissions to TARN as part of a national reimbursement tariff per major trauma cases.

Admissible patients are identified by data co-ordinators in member hospitals. TARN standards of practice recommend that ED information technology systems and hospital patient administration systems are checked regularly to identify eligible patients based on recorded clinical information, diagnostic codes and discharge dates. To capture secondary transfers, screening of intensive care units, and orthopaedic, plastic surgery, paediatrics and other trauma specialty admissions is dictated. Individual hospitals may also employ additional ad hoc procedures for case recognition. Cases potentially eligible for TARN inclusion are subsequently confirmed by examination of clinical case notes.

Trauma Audit and Research Network data collectors in member hospitals collate demographic, injury, treatment, investigation and outcome data for eligible patients. Data are gathered from all relevant patient records including ambulance records, radiology reports, post-mortem reports, hospital notes, trauma sheets, operative notes, discharge summaries and clinical information technology systems. Information is submitted to the trauma registry by a web-based electronic Data Collection and Reporting system. Autogenerated unique submission numbers, field limiters, range limiters, drop lists and radio buttons are utilised to reduce input errors. Completion of a core data set including details of patient demographics, incident information, EMS identifiers, attendants, key observations, important clinical interventions injury descriptions and outcome is mandatory. An extended data set is accessible including information on clinical assessment, transfers and specific treatments in the field, ED, ward and critical care.

Independent, trained, TARN injury coders centrally grade individual injuries for each case according to AIS (2008 revision) criteria based on clinical, radiological and post-mortem information, and a subsequent ISS is assigned.[176] Only definite injuries are considered, with possible, probable or suspected injuries excluded. All submissions are checked centrally for consistency with TARN inclusion criteria and completeness of the core dataset. Additional information may be requested from hospitals prior to final approval of each submission.

Major trauma cases may undergo inter-hospital transfer during their patient journey and separate submissions for individual patients from separate hospitals are automatically linked using incident date, care locations, date of birth, age, gender and patient name. Potential transfer matches are manually checked and linked by central TARN data validators who ensure that key fields such as demographics, prehospital details and injuries are consistent. Multiple submissions are linked to form a single unique case.

A TARN procedures manual provides standards of practice, defines data fields, and provides guidance on electronic data entry. All data collectors in member hospitals receive initial and refresher training including an overview of TARN structures, reporting facilities, trauma outcome process statistics, and how to enter data into the web-based collection system. Case ascertainment in member hospitals is checked against Hospital Episode Statistics data and is physically audited every 5 years by examination of hospital records.[189] Hospitals undergo additional audit every 2–5 years examining coding, data ranges and inconsistencies. Quality assurance is also performed on central AIS coding with a 1% sample of cases extracted and re-coded each month to test reproducibility.

Each submitted case from participating hospitals during the study period was coded centrally by TARN data analysts according to primary and secondary reference standard criteria. Eligibility against inclusion and exclusion criteria was confirmed manually by research paramedics. Submission of cases to TARN may be delayed due to operational issues, coronial investigations, or post-mortems. A final data transfer of TARN cases meeting reference standard criteria was therefore performed 10 months after the end of the study period to maximise case ascertainment.

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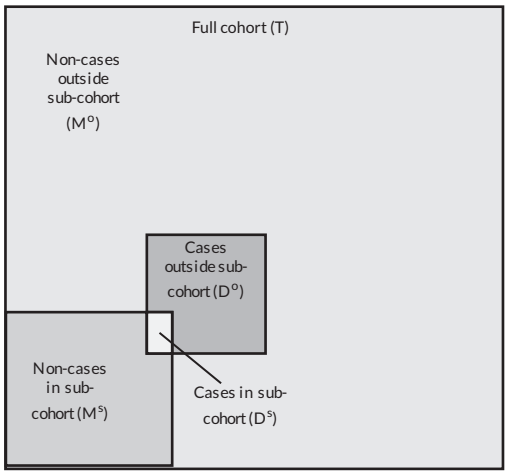
TABLE 47 Summary of analyses

Number	Population	Index test	Reference standard
Main analysis			
1.	• Case–cohort patients ≥ 16 years • Meeting inclusion criteria • Complete data	• All adult triage tools	• Primary MATTS reference standard • ISS ≥ 16 • MATTS reference standard excluding open fractures • Urgent interventions
Subgroup analyses – age			
2.	Children • Case–cohort patients < 16 years • Meeting inclusion criteria • Complete data	• Paediatric tools • Adult tools from participating ambulance services with paediatric modifications • MATTS expert tools	• Primary MATTS reference standard • ISS ≥ 16 • MATTS reference standard excluding open fractures • Urgent interventions
3.	Elderly • Case–cohort patients ≥ 65 years • Meeting inclusion criteria • Complete data	• All elderly tools • All adult tools	• Primary MATTS reference standard • ISS≥ 16 • MATTS reference standard excluding open fractures • Urgent interventions
4.	Adults • Case–cohort patients 16–64 years • Meeting inclusion criteria • Complete data	• All adult tools	• Primary MATTS reference standard • ISS ≥ 16 • MATTS reference standard excluding open fractures • Urgent interventions
Subgroup analyses – injury characteristics[a]			
5.	Mode of injury • Case–cohort patients ≥ 16 years • Penetrating vs. blunt • Meeting inclusion criteria • Complete data	• All adult tools	• Primary MATTS reference standard
6.	Mechanism of injury • Case–cohort patients ≥ 16 years • Higher energy injury vs. low level falls • Meeting inclusion criteria • Complete data	• All adult tools	• Primary MATTS reference standard
Sensitivity analyses			
7.	Study selection • Case–cohort patients ≥ 16 years • Meeting inclusion criteria • Inclusion of cases with acute non-trivial injury events with non-selected WI codes • Complete data	• All adult tools	• Primary MATTS reference standard
8.	Missing data • Case–cohort patients ≥ 16 years • Meeting inclusion criteria • Deterministic imputation of missing data under 'best' and 'worst' case 'missing not at random' assumption • Multiple imputation of missing data under missing at random assumption	• All adult tools	• Primary MATTS reference standard

TABLE 47 Summary of analyses (*continued*)

Number	Population	Index test	Reference standard
Ancillary analysis			
9.	• Case–cohort patients • Overall, adults, age deciles • Meeting inclusion criteria • Complete data	• Real-life triage decisions – MTC pre-alert • Real-life triage decisions – MTC vs. TU • Theoretical triage tool results	• Primary MATTS reference standard • ISS ≥ 16 • MATTS reference standard excluding open fractures • Urgent interventions

a Subgroup analyses for mechanism of injury not performed in paediatric and elderly subgroup due to low sample size and/or low prevalence of penetrating and high-energy trauma.



	In sub-cohort?		
	Outside	Inside	Total
Non-case	M^o	M^s	M
Case	D^o	D^s	D
Total	T^o	T^s	T

Sampling fraction (p) = $\frac{T^s}{T}$

Sampling fraction cases (P_D) = $\frac{D^o + D^s}{D}$

Sampling fraction non-cases (P_M) = $\frac{M^s}{M}$=1

Borgan II analysis weights (w) used to give inference for the full cohort:
- Cases: w = 1
- Non-cases: w = $1/P_M$

[Non-cases are up/weighted so that each sampled non-case represents $1/P_M$ non-case in the full cohort, e.g. ,P_M = 5% then $1/P_M$ = 20]

FIGURE 32 Case–cohort sampling fractions and analysis weights calculation.

TABLE 48 Summary of protocol modifications and post hoc analyses in the Phase 2 case–cohort study

Modification	Details	Rationale
Protocol modification	Additional calculation of predictive values and LRs.	• To provide additional information to evaluate triage tool performance
Protocol modification	Non-calculation of Younden's index.	• Unrealistic ratio of misclassification costs (1 – prevalence) not relevant to decision problem
Post hoc analysis	Additional decision curve analysis	• Provides relevant and objective misclassification cost to evaluate triage tool performance
Post hoc subgroup analyses	Additional subgroup analyses examining different injury characteristics.	• To provide additional information to evaluate triage tool performance • Requested by study oversight committees
Post hoc sensitivity analysis	Best-case, worst-case, and multiple imputation missing data analyses.	• To explore the potential influence of selection bias from complete-case analyses
Post hoc sensitivity analysis	Scenario analysis including reference standard positive cases with non-selected WI codes.	• To explore the potential influence of selection bias from incomplete-case ascertainment

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TABLE 49 Prevalence of reference standards for complete-case analyses

Reference standard	Sub-cohort cases (*n* =)	Sub-cohort size (*n* =)	Unweighted prevalence (95% CI)	All cases (*n* =)	Weighted prevalence (95% CI)
All ages					
Primary					
▪ MATTS	55	1853	2.9% (2.3 to 3.9)	959	2.4% (2.2 to 2.5)
Secondary					
▪ MATTS not open	47	1853	2.5% (1.9 to 3.4)	885	2.2% (2.0 to 2.3)
▪ ISS > 15	39	1853	2.1% (1.5 to 2.9)	832	2.0% (1.9 to 2.2)
▪ Urgent intervention	16	1853	0.9% (0.5 to 1.4)	296	0.7% (0.6 to 0.8)
Children < 16 years					
Primary					
▪ MATTS	1	120	0.8% (0.01 to 5.8)	31	1.1% (0.8 to 1.7)
Secondary					
▪ MATTS not open	1	120	0.8% (0.01 to 5.8)	29	1.1% (0.7 to 1.6)
▪ ISS > 15	0	120	N/A	24	0.9% (0.6 to 1.4)
▪ Urgent intervention	1	120	0.8% (0.01 to 5.8)	11	0.4% (0.2 to 0.8)
Adults 16–64 years					
Primary					
▪ MATTS	34	678	5.0% (3.6 to 6.9)	491	3.5% (3.1 to 3.9)
Secondary					
▪ MATTS not open	29	678	4.3% (3.0 to 6.1)	451	3.2% (2.8 to 3.6)
▪ ISS > 15	20	678	3.0% (1.9 to 4.5)	344	2.4% (2.1 to 2.8)
▪ Urgent intervention	11	678	1.6% (0.9 to 2.9)	214	1.5% (1.3 to 1.8)
Elderly ≥ 65 years					
Primary					
▪ MATTS	20	1055	1.9% (1.2 to 2.9)	437	1.8% (1.6 to 2.0)
Secondary					
▪ MATTS not open	17	1055	1.6% (1.0 to 2.6)	405	1.7% (1.5 to 1.9)
▪ ISS > 15	19	1055	1.8% (1.2 to 2.8)	464	1.9% (1.7 to 2.1)
▪ Urgent intervention	4	1055	0.4% (0.1 to 1.0)	71	0.3% (0.2 to 0.4)

N/A, not applicable.

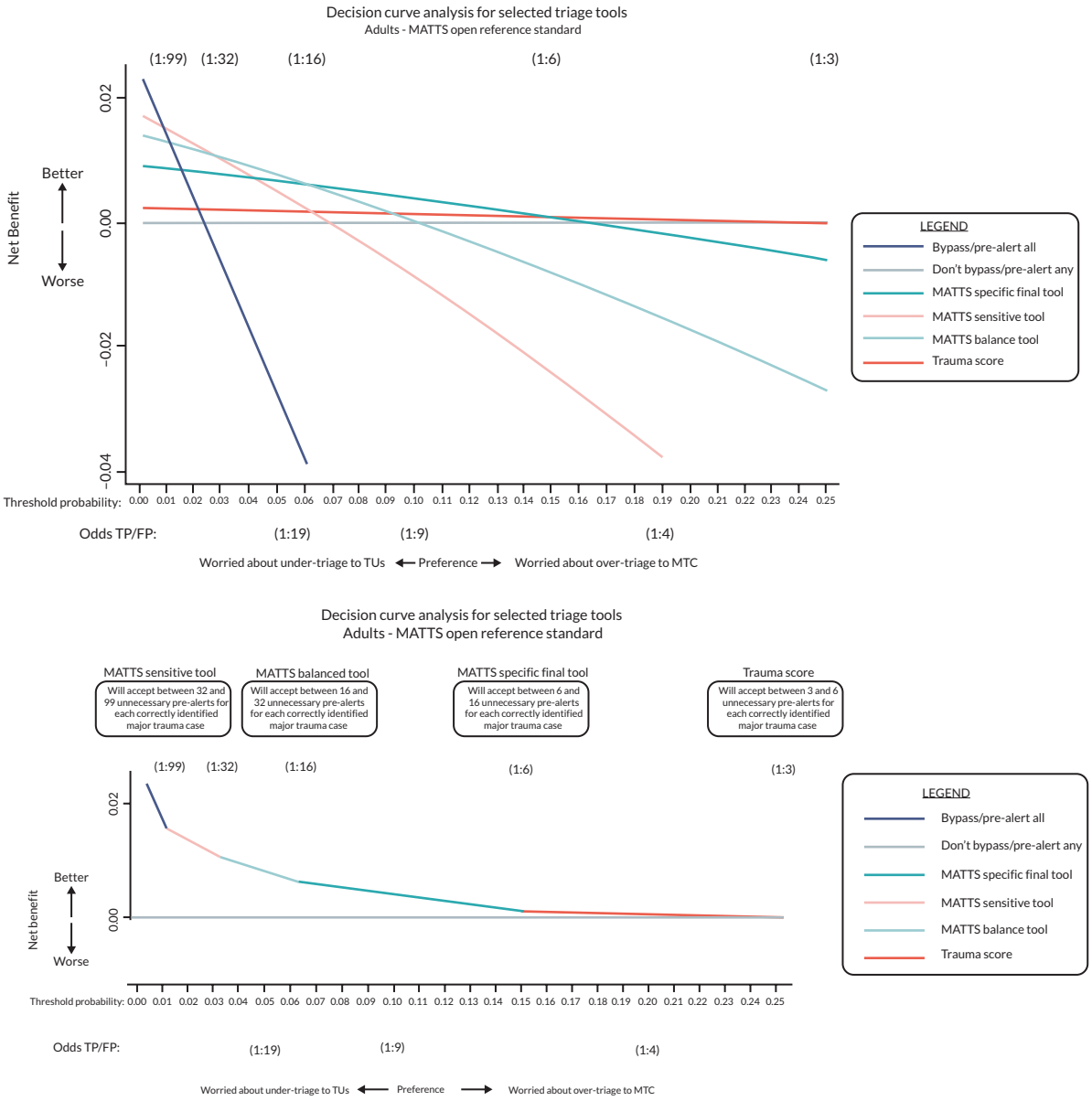


FIGURE 33 Decision curve analysis curves for Pareto optimal triage tools evaluated in adult patients against the primary reference standard. Top panel shows full decision curve. Bottom panel shows the frontier of optimal triage tools at different threshold probabilities.

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TABLE 50 Diagnostic accuracy metrics for selected adult triage tools evaluated against the secondary ISS ≥ 16 reference standard in patients aged over 16 years

Tool number	Tool name	*n*	Sensitivity	LCL	UCL	Specificity	LCL	UCL	Accuracy	TP	FP	TN	FN	PPV	NPV	Positive LR	Negative LR
1	CRAMS	2502	0.35	0.32	0.39	0.94	0.92	0.95	0.75	285	110	1584	523	0.11	0.99	5.43	0.69
2	Dutch	2502	0.26	0.23	0.29	0.93	0.92	0.94	0.71	208	117	1577	600	0.08	0.98	3.73	0.80
3	Florida	2502	0.41	0.37	0.44	0.86	0.84	0.87	0.71	329	242	1452	479	0.06	0.99	2.85	0.69
4	LAS (current)	2502	0.42	0.38	0.45	0.89	0.88	0.91	0.74	338	182	1512	470	0.08	0.99	3.89	0.65
5	LAS (old)	2502	0.54	0.50	0.57	0.85	0.84	0.87	0.75	434	246	1448	374	0.08	0.99	3.70	0.54
6	MATTS balanced	2502	0.54	0.51	0.58	0.86	0.85	0.88	0.76	438	229	1465	370	0.08	0.99	4.01	0.53
7	MATTS sensitive	2502	0.68	0.65	0.71	0.75	0.73	0.77	0.73	548	419	1275	260	0.06	0.99	2.74	0.43
8	MATTS specific	2502	0.31	0.28	0.34	0.95	0.94	0.96	0.74	251	88	1606	557	0.12	0.98	5.98	0.73
9	MGAP	2502	0.36	0.32	0.39	0.85	0.83	0.87	0.69	289	253	1441	519	0.05	0.98	2.40	0.76
10	North Carolina	2502	0.41	0.38	0.45	0.89	0.88	0.91	0.74	333	186	1508	475	0.08	0.99	3.75	0.66
11	Oregon	2502	0.39	0.35	0.42	0.91	0.90	0.93	0.74	312	149	1545	496	0.09	0.99	4.39	0.67
12	PHI	2502	0.17	0.14	0.19	0.96	0.95	0.97	0.71	136	66	1628	672	0.09	0.98	4.32	0.87
13	RTST	2502	0.34	0.30	0.37	0.93	0.92	0.94	0.74	272	122	1572	536	0.10	0.98	4.67	0.72
14	SWAS	2502	0.29	0.26	0.32	0.95	0.94	0.96	0.74	232	85	1609	576	0.12	0.98	5.72	0.75
15	Trauma Score	2502	0.11	0.09	0.13	0.99	0.99	1.00	0.71	88	15	1679	720	0.23	0.98	12.30	0.90
16	Trauma Scorecard	2502	0.34	0.31	0.37	0.92	0.91	0.93	0.73	276	133	1561	532	0.09	0.98	4.35	0.72
17	TTR	2502	0.21	0.18	0.24	0.96	0.95	0.97	0.72	169	69	1625	639	0.11	0.98	5.14	0.82
18	US Field Triage	2502	0.43	0.40	0.46	0.88	0.86	0.89	0.73	347	211	1483	461	0.07	0.99	3.45	0.65
19	Victoria	2502	0.57	0.53	0.60	0.75	0.72	0.77	0.69	457	431	1263	351	0.05	0.99	2.22	0.58
20	Vittel	2502	0.43	0.40	0.47	0.87	0.86	0.89	0.73	349	217	1477	459	0.07	0.99	3.37	0.65
21	WMAS	2502	0.44	0.41	0.47	0.88	0.86	0.89	0.73	355	211	1483	453	0.07	0.99	3.53	0.64
22	YAS	2502	0.53	0.50	0.57	0.86	0.84	0.87	0.75	431	243	1451	377	0.08	0.99	3.72	0.55

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

TABLE 51 Diagnostic accuracy metrics for selected adult triage tools evaluated against the secondary MATTS reference standard omitting open fractures in patients aged over 16 years

Tool number	Tool name	*n*	Sensitivity	LCL	UCL	Specificity	LCL	UCL	Accuracy	TP	FP	TN	FN	PPV	NPV	Positive LR	Negative LR
1	CRAMS	2543	0.36	0.33	0.39	0.94	0.92	0.95	0.76	307	108	1579	549	0.12	0.98	5.60	0.69
2	Dutch	2543	0.28	0.25	0.31	0.93	0.92	0.94	0.77	241	114	1573	615	0.09	0.98	4.17	0.77
3	Florida	2543	0.42	0.39	0.46	0.86	0.84	0.87	0.75	362	240	1447	494	0.07	0.98	2.97	0.67
4	LAS (current)	2543	0.45	0.41	0.48	0.89	0.88	0.91	0.67	383	179	1508	473	0.09	0.99	4.22	0.62
5	LAS (old)	2543	0.57	0.54	0.60	0.86	0.84	0.87	0.73	488	242	1445	368	0.09	0.99	3.97	0.50
6	MATTS balanced	2543	0.59	0.55	0.62	0.87	0.85	0.88	0.74	503	223	1464	353	0.10	0.99	4.45	0.48
7	MATTS sensitive	2543	0.74	0.71	0.77	0.76	0.74	0.78	0.74	631	412	1275	225	0.07	0.99	3.02	0.35
8	MATTS specific	2543	0.37	0.33	0.40	0.95	0.94	0.96	0.74	314	84	1603	542	0.15	0.98	7.37	0.67
9	MGAP	2543	0.32	0.29	0.35	0.85	0.83	0.87	0.71	275	255	1432	581	0.04	0.98	2.13	0.80
10	North Carolina	2543	0.43	0.40	0.47	0.89	0.88	0.91	0.73	370	182	1505	486	0.09	0.99	4.01	0.64
11	Oregon	2543	0.40	0.36	0.43	0.91	0.90	0.93	0.71	340	146	1541	516	0.10	0.99	4.59	0.66
12	PHI	2543	0.19	0.16	0.22	0.96	0.95	0.97	0.75	163	66	1621	693	0.10	0.98	4.87	0.84
13	RTST	2543	0.33	0.30	0.36	0.93	0.92	0.94	0.75	281	121	1566	575	0.10	0.98	4.58	0.72
14	SWAS	2543	0.31	0.28	0.34	0.95	0.94	0.96	0.74	267	83	1604	589	0.13	0.98	6.34	0.72
15	Trauma Score	2543	0.11	0.09	0.13	0.99	0.99	1.00	0.74	92	14	1673	764	0.26	0.98	12.95	0.90
16	Trauma Scorecard	2543	0.36	0.33	0.39	0.92	0.91	0.94	0.74	306	131	1556	550	0.10	0.98	4.60	0.70
17	TTR	2543	0.22	0.19	0.25	0.96	0.95	0.97	0.74	188	66	1621	668	0.12	0.98	5.61	0.81
18	US Field Triage	2543	0.45	0.42	0.48	0.88	0.86	0.89	0.70	386	207	1480	470	0.08	0.99	3.68	0.63
19	Victoria	2543	0.60	0.56	0.63	0.75	0.73	0.77	0.69	511	426	1261	345	0.05	0.99	2.36	0.54
20	Vittel	2543	0.46	0.43	0.49	0.87	0.86	0.89	0.73	394	212	1475	462	0.08	0.99	3.66	0.62
21	WMAS	2543	0.47	0.44	0.51	0.88	0.86	0.89	0.70	404	207	1480	452	0.08	0.99	3.85	0.60
22	YAS	2543	0.55	0.52	0.58	0.86	0.84	0.87	0.73	470	239	1448	386	0.08	0.99	3.88	0.53

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

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TABLE 52 Diagnostic accuracy metrics for selected adult triage tools evaluated against the secondary urgent interventions reference standard in patients aged over 16 years

Tool number	Tool name	*n*	Sensitivity	LCL	UCL	Specificity	LCL	UCL	Accuracy	TP	FP	TN	FN	PPV	NPV	Positive LR	Negative LR
1	CRAMS	2003	0.55	0.50	0.61	0.93	0.92	0.95	0.88	158	113	1605	127	0.06	1.00	8.43	0.48
2	Dutch	2003	0.55	0.49	0.61	0.93	0.92	0.94	0.88	157	119	1599	128	0.06	1.00	7.95	0.48
3	Florida	2003	0.71	0.65	0.76	0.86	0.84	0.87	0.84	201	245	1473	84	0.04	1.00	4.95	0.34
4	LAS (current)	2003	0.71	0.66	0.76	0.89	0.88	0.91	0.87	202	184	1534	83	0.05	1.00	6.62	0.33
5	LAS (old)	2003	0.77	0.72	0.82	0.85	0.84	0.87	0.84	220	254	1464	65	0.04	1.00	5.22	0.27
6	MATTS balanced	2003	0.79	0.74	0.84	0.86	0.85	0.88	0.85	225	234	1484	60	0.04	1.00	5.80	0.24
7	MATTS sensitive	2003	0.90	0.86	0.93	0.75	0.73	0.77	0.77	256	431	1287	29	0.03	1.00	3.58	0.14
8	MATTS specific	2003	0.64	0.58	0.69	0.95	0.94	0.96	0.90	182	89	1629	103	0.09	1.00	12.33	0.38
9	MGAP	2003	0.44	0.38	0.50	0.85	0.83	0.87	0.79	125	259	1459	160	0.02	0.99	2.91	0.66
10	North Carolina	2003	0.70	0.64	0.75	0.89	0.87	0.90	0.86	199	190	1528	86	0.05	1.00	6.31	0.34
11	Oregon	2003	0.65	0.59	0.70	0.91	0.90	0.93	0.87	184	151	1567	101	0.06	1.00	7.35	0.39
12	PHI	2003	0.40	0.34	0.46	0.96	0.95	0.97	0.88	114	67	1651	171	0.07	1.00	10.26	0.62
13	RTST	2003	0.53	0.47	0.59	0.93	0.91	0.94	0.87	151	125	1593	134	0.05	1.00	7.28	0.51
14	SWAS	2003	0.58	0.53	0.64	0.95	0.94	0.96	0.90	166	90	1628	119	0.08	1.00	11.12	0.44
15	Trauma Score	2003	0.27	0.22	0.33	0.99	0.99	1.00	0.89	78	14	1704	207	0.23	0.99	33.59	0.73
16	Trauma Scorecard	2003	0.61	0.55	0.66	0.92	0.91	0.93	0.88	173	136	1582	112	0.06	1.00	7.67	0.43
17	TTR	2003	0.47	0.41	0.53	0.96	0.95	0.97	0.89	134	68	1650	151	0.09	1.00	11.88	0.55
18	US Field Triage	2003	0.70	0.65	0.75	0.87	0.86	0.89	0.85	200	216	1502	85	0.04	1.00	5.58	0.34
19	Victoria	2003	0.82	0.77	0.86	0.74	0.72	0.76	0.75	233	441	1277	52	0.02	1.00	3.19	0.25
20	Vittel	2003	0.73	0.68	0.78	0.87	0.85	0.89	0.85	208	223	1495	77	0.04	1.00	5.62	0.31
21	WMAS	2003	0.74	0.69	0.79	0.87	0.86	0.89	0.85	210	217	1501	75	0.04	1.00	5.83	0.30
22	YAS	2003	0.72	0.67	0.77	0.85	0.84	0.87	0.84	206	251	1467	79	0.04	1.00	4.95	0.33

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

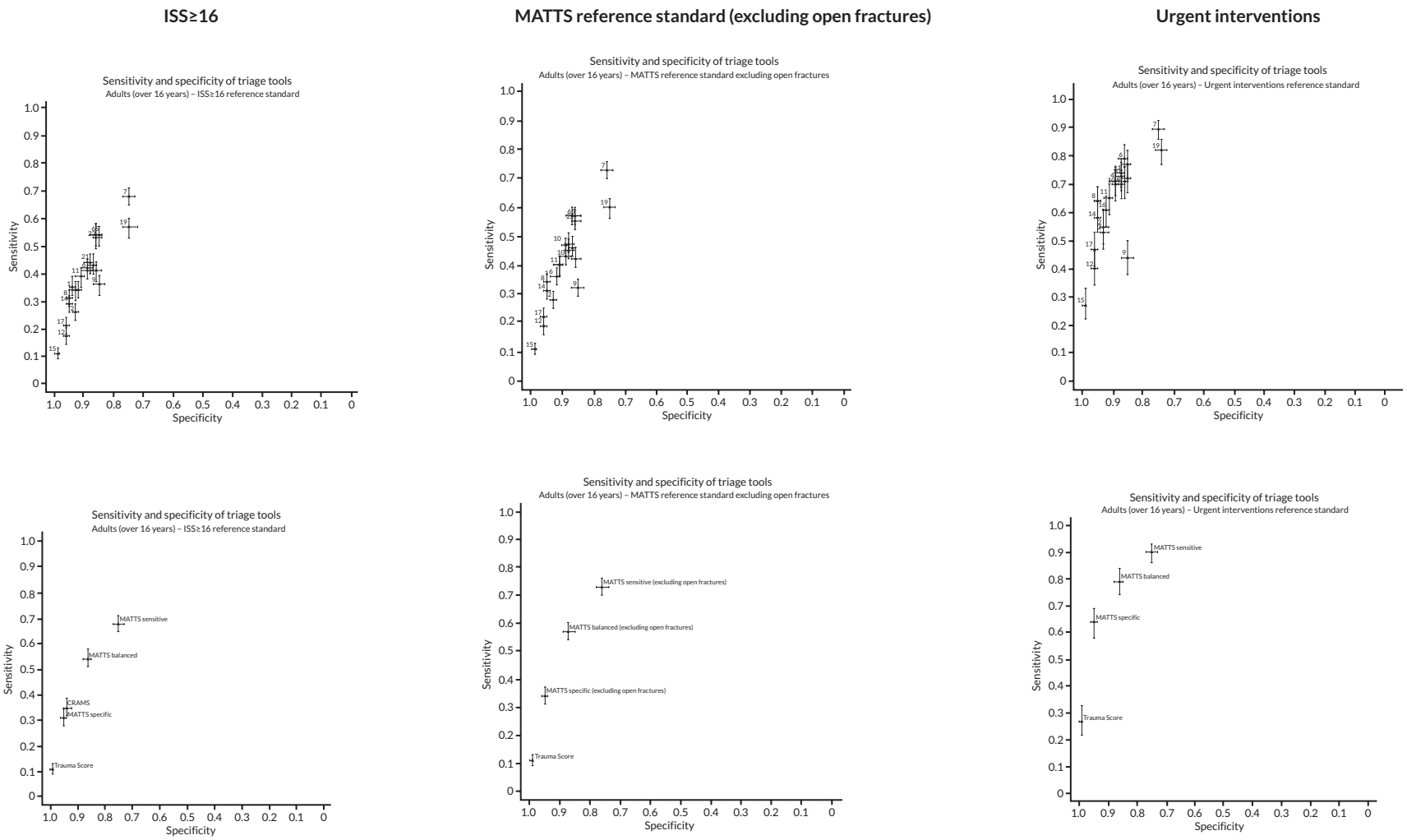


FIGURE 34 Sensitivity–specificity plot for triage tools evaluated against secondary reference standard in patients ≥ 16 years. Upper panel shows all triage tools. Lower panel shows maximum realisable ROC curve/Pareto front of optimal tools, excluding tools with worse accuracy.

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TABLE 53 Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years sustaining blunt trauma

Tool number	Tool name	*n*	Sensitivity	LCL	UCL	Specificity	LCL	UCL	Accuracy	TP	FP	TN	FN	PPV	NPV	Positive LR	Negative LR
1	CRAMS	2514	0.31	0.28	0.34	0.94	0.93	0.95	0.72	267	93	1548	606	0.12	0.98	5.40	0.74
2	Dutch	2514	0.23	0.21	0.26	0.94	0.93	0.95	0.70	205	95	1546	668	0.09	0.98	4.06	0.81
3	Florida	2514	0.38	0.34	0.41	0.87	0.85	0.89	0.70	328	214	1427	545	0.07	0.98	2.88	0.72
4	LAS (current)	2514	0.42	0.39	0.45	0.91	0.89	0.92	0.74	367	151	1490	506	0.10	0.98	4.57	0.64
5	LAS (old)	2514	0.54	0.50	0.57	0.87	0.85	0.88	0.75	469	219	1422	404	0.09	0.99	4.03	0.53
6	MATTS balanced	2514	0.56	0.52	0.59	0.88	0.86	0.90	0.77	487	196	1445	386	0.10	0.99	4.67	0.50
7	MATTS sensitive	2514	0.71	0.68	0.74	0.77	0.75	0.79	0.75	619	381	1260	254	0.07	0.99	3.05	0.38
8	MATTS specific	2514	0.34	0.31	0.37	0.96	0.95	0.97	0.75	298	63	1578	575	0.18	0.98	8.89	0.69
9	MGAP	2514	0.31	0.28	0.34	0.85	0.83	0.87	0.66	272	245	1396	601	0.05	0.98	2.09	0.81
10	North Carolina	2514	0.38	0.35	0.41	0.91	0.89	0.92	0.72	332	153	1488	541	0.09	0.98	4.08	0.68
11	Oregon	2514	0.34	0.31	0.38	0.93	0.91	0.94	0.72	301	120	1521	572	0.11	0.98	4.72	0.71
12	PHI	2514	0.14	0.12	0.17	0.97	0.96	0.98	0.68	124	53	1588	749	0.09	0.98	4.40	0.89
13	RTST	2514	0.30	0.27	0.33	0.93	0.92	0.94	0.71	263	116	1525	610	0.10	0.98	4.26	0.75
14	SWAS	2514	0.32	0.29	0.35	0.95	0.94	0.96	0.73	279	76	1565	594	0.15	0.98	6.90	0.71
15	Trauma Score	2514	0.10	0.08	0.11	0.99	0.99	1.00	0.68	83	14	1627	790	0.24	0.98	11.14	0.91
16	Trauma Scorecard	2514	0.31	0.28	0.34	0.93	0.92	0.95	0.72	269	109	1532	604	0.10	0.98	4.64	0.74
17	TTR	2514	0.17	0.14	0.19	0.97	0.97	0.98	0.69	145	44	1597	728	0.13	0.98	6.20	0.86
18	US Field Triage	2514	0.40	0.37	0.43	0.89	0.88	0.91	0.72	350	178	1463	523	0.08	0.98	3.70	0.67
19	Victoria	2514	0.58	0.55	0.61	0.77	0.74	0.79	0.70	508	385	1256	365	0.05	0.99	2.48	0.55
20	Vittel	2514	0.42	0.39	0.45	0.89	0.88	0.91	0.73	366	178	1463	507	0.08	0.98	3.87	0.65
21	WMAS	2514	0.43	0.40	0.46	0.89	0.88	0.91	0.73	374	180	1461	499	0.09	0.98	3.91	0.64
22	YAS	2514	0.49	0.46	0.52	0.87	0.85	0.88	0.74	427	219	1422	446	0.08	0.99	3.67	0.59

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

TABLE 54 Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years sustaining penetrating trauma

Tool number	Tool name	*n*	Sensitivity	LCL	UCL	Specificity	LCL	UCL	Accuracy	TP	FP	TN	FN	PPV	NPV	Positive LR	Negative LR
1	CRAMS	93	0.78	0.67	0.89	0.63	0.48	0.78	0.72	43	14	24	12	0.15	0.97	2.09	0.36
2	Dutch	93	0.84	0.74	0.93	0.53	0.37	0.69	0.71	46	18	20	9	0.12	0.97	1.75	0.32
3	Florida	93	0.93	0.86	1.00	0.34	0.19	0.49	0.69	51	25	13	4	0.10	0.98	1.41	0.23
4	LAS (current)	93	0.85	0.76	0.95	0.34	0.19	0.49	0.65	47	25	13	8	0.10	0.97	1.30	0.44
5	LAS (old)	93	0.89	0.81	0.97	0.50	0.34	0.66	0.73	49	19	19	6	0.13	0.98	1.77	0.23
6	MATTS balanced	93	0.93	0.86	1.00	0.39	0.24	0.55	0.71	51	23	15	4	0.11	0.98	1.53	0.20
7	MATTS sensitive	93	0.96	0.91	1.01	0.32	0.17	0.46	0.70	53	26	12	2	0.11	0.99	1.41	0.14
8	MATTS specific	93	0.87	0.78	0.96	0.53	0.37	0.69	0.73	48	18	20	7	0.14	0.98	1.83	0.26
9	MGAP	93	0.31	0.19	0.43	0.79	0.66	0.92	0.51	17	8	30	38	0.13	0.93	1.43	0.88
10	North Carolina	93	0.96	0.91	1.01	0.26	0.12	0.40	0.68	53	28	10	2	0.11	0.99	1.31	0.17
11	Oregon	93	0.89	0.81	0.97	0.32	0.17	0.46	0.66	49	26	12	6	0.10	0.97	1.30	0.36
12	PHI	93	0.80	0.69	0.91	0.66	0.51	0.81	0.74	44	13	25	11	0.16	0.97	2.30	0.31
13	RTST	93	0.47	0.34	0.60	0.87	0.76	0.98	0.63	26	5	33	29	0.41	0.95	3.36	0.61
14	SWAS	93	0.38	0.25	0.51	0.89	0.80	0.99	0.59	21	4	34	34	0.31	0.95	3.33	0.70
15	Trauma Score	93	0.16	0.07	0.26	1.00	1.00	1.00	0.51	9	0	38	46	1.00	0.93	13.23	0.84
16	Trauma Scorecard	93	0.89	0.81	0.97	0.42	0.26	0.58	0.70	49	22	16	6	0.11	0.98	1.53	0.27
17	TTR	93	0.87	0.78	0.96	0.42	0.26	0.58	0.69	48	22	16	7	0.11	0.97	1.50	0.32
18	US Field Triage	93	0.93	0.86	1.00	0.26	0.12	0.40	0.66	51	28	10	4	0.10	0.98	1.26	0.30
19	Victoria	93	0.93	0.86	1.00	0.03	−0.02	0.08	0.56	51	37	1	4	0.08	0.90	0.96	2.09
20	Vittel	93	0.93	0.86	1.00	0.13	0.02	0.24	0.60	51	33	5	4	0.09	0.96	1.07	0.57
21	WMAS	93	0.93	0.86	1.00	0.34	0.19	0.49	0.69	51	25	13	4	0.12	0.98	1.41	0.23
22	YAS	93	0.89	0.81	0.97	0.50	0.34	0.66	0.73	49	19	19	6	0.13	0.98	1.77	0.23

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

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TABLE 55 Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years sustaining higher-energy trauma

Tool number	Tool name	n	Sensitivity	LCL	UCL	Specificity	LCL	UCL	Accuracy	TP	FP	TN	FN	PPV	NPV	Positive LR	Negative LR
1	CRAMS	906	0.41	0.37	0.45	0.90	0.87	0.93	0.59	232	33	307	334	0.26	0.95	4.22	0.65
2	Dutch	906	0.34	0.30	0.38	0.85	0.81	0.89	0.53	193	51	289	373	0.16	0.94	2.27	0.78
3	Florida	906	0.49	0.45	0.54	0.77	0.73	0.82	0.60	280	77	263	286	0.16	0.95	2.18	0.65
4	LAS (current)	906	0.52	0.48	0.56	0.80	0.76	0.85	0.63	296	67	273	270	0.19	0.96	2.65	0.59
5	LAS (old)	906	0.66	0.62	0.70	0.74	0.69	0.79	0.69	374	88	252	192	0.17	0.96	2.55	0.46
6	MATTS balanced	906	0.66	0.62	0.70	0.76	0.71	0.80	0.70	375	83	257	191	0.18	0.97	2.71	0.45
7	MATTS sensitive	906	0.82	0.79	0.85	0.61	0.56	0.66	0.74	464	132	208	102	0.14	0.98	2.11	0.30
8	MATTS specific	906	0.46	0.42	0.50	0.89	0.85	0.92	0.62	260	38	302	306	0.26	0.95	4.11	0.61
9	MGAP	906	0.31	0.27	0.35	0.93	0.90	0.95	0.54	176	25	315	390	0.25	0.94	4.23	0.74
10	North Carolina	906	0.52	0.48	0.56	0.78	0.74	0.82	0.62	295	75	265	271	0.17	0.95	2.36	0.61
11	Oregon	906	0.46	0.42	0.51	0.83	0.79	0.87	0.60	263	57	283	303	0.20	0.95	2.77	0.64
12	PHI	906	0.24	0.21	0.28	0.91	0.89	0.94	0.49	137	29	311	429	0.19	0.94	2.84	0.83
13	RTST	906	0.37	0.33	0.41	0.90	0.87	0.93	0.57	209	33	307	357	0.25	0.95	3.80	0.70
14	SWAS	906	0.40	0.36	0.44	0.92	0.90	0.95	0.59	224	26	314	342	0.30	0.95	5.18	0.65
15	Trauma Score	906	0.12	0.10	0.15	0.99	0.99	1.00	0.45	70	2	338	496	0.69	0.93	21.03	0.88
16	Trauma Scorecard	906	0.43	0.39	0.47	0.84	0.80	0.87	0.58	244	56	284	322	0.18	0.95	2.62	0.68
17	TTR	906	0.27	0.23	0.30	0.91	0.87	0.94	0.51	151	32	308	415	0.20	0.94	2.84	0.81
18	US Field Triage	906	0.52	0.48	0.56	0.78	0.73	0.82	0.62	296	76	264	270	0.17	0.95	2.34	0.61
19	Victoria	906	0.73	0.69	0.77	0.57	0.52	0.62	0.67	413	146	194	153	0.12	0.96	1.70	0.47
20	Vittel	906	0.56	0.52	0.60	0.77	0.73	0.82	0.64	319	78	262	247	0.17	0.96	2.46	0.57
21	WMAS	906	0.55	0.50	0.59	0.78	0.74	0.83	0.63	309	74	266	257	0.17	0.96	2.51	0.58
22	YAS	906	0.61	0.57	0.65	0.74	0.69	0.79	0.66	343	88	252	223	0.16	0.96	2.34	0.53

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

TABLE 56 Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years sustaining non-trivial injury from ground-level falls

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	PPV	NPV	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
1	CRAMS	1701	78	74	1265	284	0.22	0.17	0.26	0.94	0.93	0.96	0.05	0.99	3.90	2.90	5.24	0.83	0.66	1.04
2	Dutch	1701	58	62	1277	304	0.16	0.12	0.20	0.95	0.94	0.96	0.04	0.99	3.46	2.47	4.86	0.88	0.69	1.13
3	Florida	1701	99	162	1177	263	0.27	0.23	0.32	0.88	0.86	0.90	0.03	0.99	2.26	1.81	2.82	0.83	0.71	0.97
4	LAS (current)	1701	118	109	1230	244	0.33	0.28	0.37	0.92	0.90	0.93	0.05	0.99	4.00	3.17	5.06	0.73	0.60	0.89
5	LAS (old)	1701	144	150	1189	218	0.40	0.35	0.45	0.89	0.87	0.90	0.04	0.99	3.55	2.92	4.32	0.68	0.57	0.81
6	MATTS balanced	1701	163	136	1203	199	0.45	0.40	0.50	0.90	0.88	0.91	0.05	0.99	4.43	3.64	5.39	0.61	0.51	0.74
7	MATTS sensitive	1701	208	275	1064	154	0.57	0.52	0.63	0.79	0.77	0.82	0.03	0.99	2.80	2.44	3.21	0.54	0.46	0.63
8	MATTS specific	1701	86	43	1296	276	0.24	0.19	0.28	0.97	0.96	0.98	0.08	0.99	7.40	5.23	10.47	0.79	0.58	1.06
9	MGAP	1701	113	228	1111	249	0.31	0.26	0.36	0.83	0.81	0.85	0.02	0.99	1.83	1.51	2.22	0.83	0.72	0.95
10	North Carolina	1701	90	106	1233	272	0.25	0.20	0.29	0.92	0.91	0.94	0.04	0.99	3.14	2.43	4.06	0.82	0.67	0.99
11	Oregon	1701	87	89	1250	275	0.24	0.20	0.28	0.93	0.92	0.95	0.04	0.99	3.62	2.76	4.74	0.81	0.66	1.00
12	PHI	1701	31	37	1302	331	0.09	0.06	0.11	0.97	0.96	0.98	0.04	0.99	3.10	1.95	4.92	0.94	0.68	1.29
13	RTST	1701	80	88	1251	282	0.22	0.18	0.26	0.93	0.92	0.95	0.04	0.99	3.36	2.54	4.45	0.83	0.68	1.03
14	SWAS	1701	76	54	1285	286	0.21	0.17	0.25	0.96	0.95	0.97	0.06	0.99	5.21	3.75	7.23	0.82	0.63	1.07
15	Trauma Score	1701	22	12	1327	340	0.06	0.04	0.09	0.99	0.99	1.00	0.09	0.99	6.78	3.39	13.57	0.95	0.54	1.67
16	Trauma Scorecard	1701	74	75	1264	288	0.20	0.16	0.25	0.94	0.93	0.96	0.04	0.99	3.65	2.71	4.92	0.84	0.67	1.06
17	TTR	1701	42	34	1305	320	0.12	0.08	0.15	0.97	0.97	0.98	0.05	0.99	4.57	2.95	7.07	0.91	0.65	1.27
18	US Field Triage	1701	105	130	1209	257	0.29	0.24	0.34	0.90	0.89	0.92	0.04	0.99	2.99	2.37	3.76	0.79	0.66	0.94
19	Victoria	1701	146	276	1063	216	0.40	0.35	0.45	0.79	0.77	0.82	0.02	0.99	1.96	1.66	2.30	0.75	0.66	0.86
20	Vittel	1701	98	133	1206	264	0.27	0.22	0.32	0.90	0.88	0.92	0.03	0.99	2.73	2.16	3.44	0.81	0.68	0.96
21	WMAS	1701	116	131	1208	246	0.32	0.27	0.37	0.90	0.89	0.92	0.04	0.99	3.28	2.63	4.09	0.75	0.63	0.90
22	YAS	1701	133	150	1189	229	0.37	0.32	0.42	0.89	0.87	0.90	0.04	0.99	3.28	2.68	4.02	0.71	0.60	0.84

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

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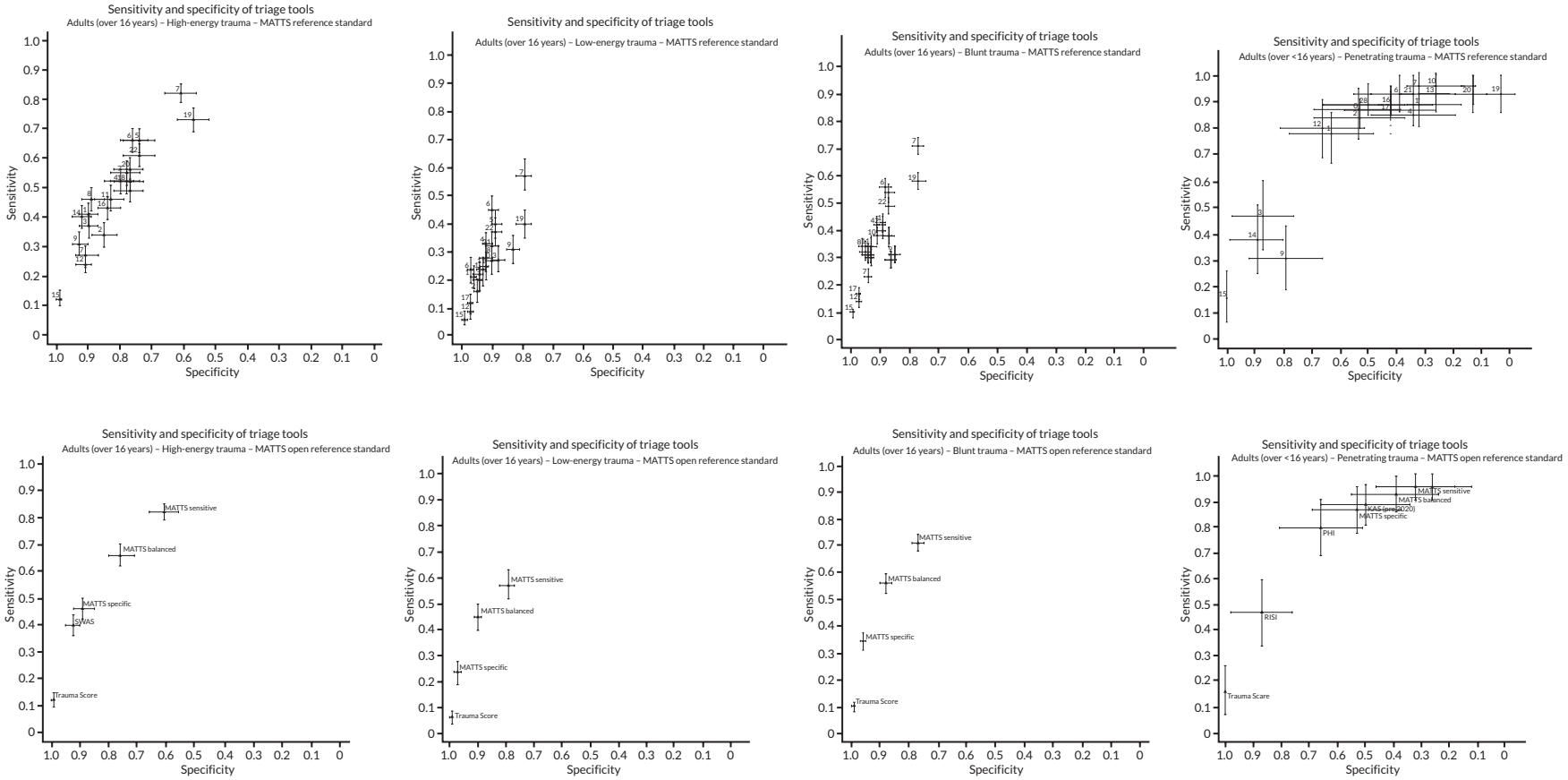


FIGURE 35 Sensitivity–specificity plot for triage tools evaluated against the MATTS reference standard in patients ≥ 16 years across injury subgroups. Upper panel shows all triage tools. Lower panel shows maximum realisable ROC curve of optimal tools, excluding tools with worse accuracy. See table for tool numbers.

TABLE 57 Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged under 16 years

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
6	MATTS balanced	150	23	39	80	8	0.74	0.59	0.90	0.67	0.59	0.76	2.26	1.63	3.15	0.38	0.20	0.74
7	MATTS sensitive	150	29	72	47	2	0.94	0.85	1.02	0.39	0.31	0.48	1.55	1.30	1.84	0.16	0.04	0.63
8	MATTS specific	150	18	25	94	13	0.58	0.41	0.75	0.79	0.72	0.86	2.76	1.75	4.37	0.53	0.31	0.91
14	SWAS	150	19	55	64	12	0.61	0.44	0.78	0.54	0.45	0.63	1.33	0.94	1.86	0.72	0.44	1.17
21	WMAS	150	18	19	100	13	0.58	0.41	0.75	0.84	0.77	0.91	3.64	2.19	6.05	0.50	0.28	0.90
22	YAS	150	25	45	74	6	0.81	0.67	0.95	0.62	0.53	0.71	2.13	1.60	2.84	0.31	0.15	0.66
26	LAS (pre 2020 children)	150	24	60	59	7	0.77	0.63	0.92	0.50	0.41	0.59	1.54	1.18	1.99	0.46	0.23	0.90
27	NWAS (children)	150	28	69	50	3	0.90	0.80	1.01	0.42	0.33	0.51	1.56	1.29	1.89	0.23	0.08	0.68
28	Pediatric checklist	150	18	13	106	13	0.58	0.41	0.75	0.89	0.83	0.95	5.32	2.93	9.63	0.47	0.24	0.91

LCL, lower 95% confidence limit; PPV, positive predictive value; UCL, upper 95% confidence limit.

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TABLE 58 Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged between 16 and 64 years

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	PPV	NPV	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
1	CRAMS	1135	198	44	600	293	0.40	0.36	0.45	0.93	0.91	0.95	0.19	0.98	5.90	4.35	8.01	0.64	0.48	0.86
2	Dutch	1135	179	76	568	312	0.36	0.32	0.41	0.88	0.86	0.91	0.11	0.97	3.09	2.43	3.93	0.72	0.58	0.90
3	Florida	1135	251	119	525	240	0.51	0.47	0.56	0.82	0.79	0.85	0.10	0.98	2.77	2.30	3.32	0.60	0.50	0.72
4	LAS (current)	1135	278	90	554	213	0.57	0.52	0.61	0.86	0.83	0.89	0.13	0.98	4.05	3.29	4.98	0.50	0.41	0.63
5	LAS (old)	1135	326	114	530	165	0.66	0.62	0.71	0.82	0.79	0.85	0.12	0.99	3.75	3.14	4.48	0.41	0.33	0.50
6	MATTS balanced	1135	319	101	543	172	0.65	0.61	0.69	0.84	0.82	0.87	0.13	0.99	4.14	3.42	5.01	0.42	0.33	0.52
7	MATTS sensitive	1135	400	208	436	91	0.81	0.78	0.85	0.68	0.64	0.71	0.08	0.99	2.52	2.24	2.84	0.27	0.22	0.34
8	MATTS specific	1135	234	48	596	257	0.48	0.43	0.52	0.93	0.91	0.95	0.19	0.98	6.39	4.80	8.52	0.57	0.43	0.75
9	MGAP	1135	125	31	613	366	0.25	0.22	0.29	0.95	0.94	0.97	0.18	0.97	5.29	3.63	7.70	0.78	0.55	1.11
10	North Carolina	1135	267	88	556	224	0.54	0.50	0.59	0.86	0.84	0.89	0.13	0.98	3.98	3.22	4.91	0.53	0.43	0.66
11	Oregon	1135	241	68	576	250	0.49	0.45	0.54	0.89	0.87	0.92	0.16	0.98	4.65	3.65	5.92	0.57	0.45	0.72
12	PHI	1135	121	28	616	370	0.25	0.21	0.28	0.96	0.94	0.97	0.17	0.97	5.67	3.82	8.40	0.79	0.55	1.14
13	RTST	1135	193	47	597	298	0.39	0.35	0.44	0.93	0.91	0.95	0.19	0.98	5.39	4.00	7.24	0.65	0.49	0.87
14	SWAS	1135	203	39	605	288	0.41	0.37	0.46	0.94	0.92	0.96	0.20	0.98	6.83	4.95	9.42	0.62	0.46	0.85
15	Trauma Score	1135	65	7	637	426	0.13	0.10	0.16	0.99	0.98	1.00	0.32	0.97	12.18	5.63	26.32	0.88	0.42	1.83
16	Trauma Scorecard	1135	225	66	578	266	0.46	0.41	0.50	0.90	0.87	0.92	0.15	0.98	4.47	3.49	5.73	0.60	0.47	0.77
17	TTR	1135	145	39	605	346	0.30	0.25	0.34	0.94	0.92	0.96	0.17	0.97	4.88	3.49	6.81	0.75	0.55	1.02
18	US Field Triage	1135	269	98	546	222	0.55	0.50	0.59	0.85	0.82	0.88	0.12	0.98	3.60	2.95	4.39	0.53	0.43	0.66
19	Victoria	1135	343	183	461	148	0.70	0.66	0.74	0.72	0.68	0.75	0.08	0.98	2.46	2.15	2.82	0.42	0.35	0.51
20	Vittel	1135	281	88	556	210	0.57	0.53	0.62	0.86	0.84	0.89	0.14	0.98	4.19	3.40	5.16	0.50	0.40	0.62
21	WMAS	1135	279	96	548	212	0.57	0.52	0.61	0.85	0.82	0.88	0.13	0.98	3.81	3.12	4.66	0.51	0.41	0.63
22	YAS	1135	291	114	530	200	0.59	0.55	0.64	0.82	0.79	0.85	0.11	0.98	3.35	2.79	4.02	0.49	0.41	0.60

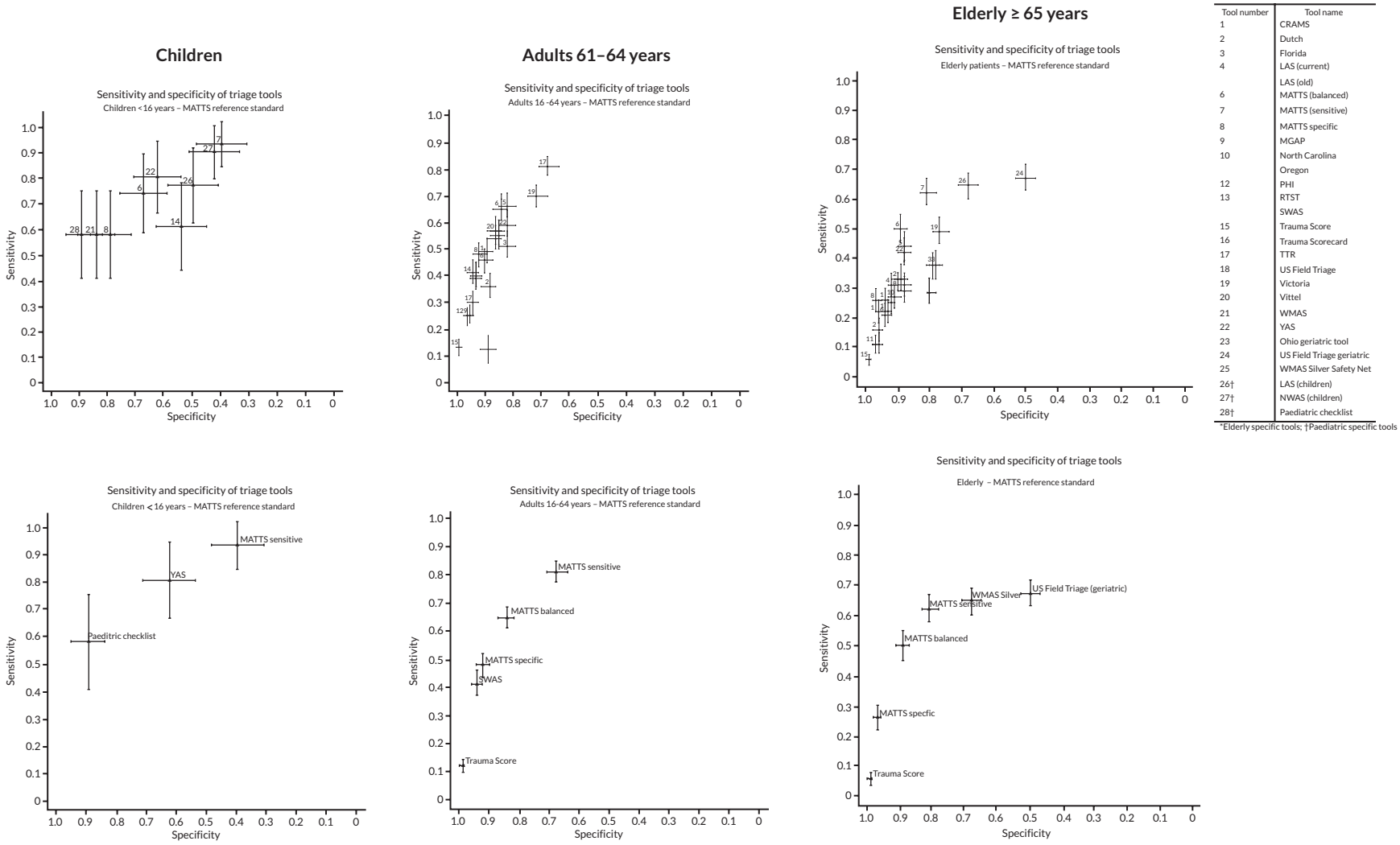
CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

TABLE 59 Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 65 years

Tool number	Tool name	*n*	Sensitivity	LCL	UCL	Specificity	LCL	UCL	Accuracy	TP	FP	TN	FN	PPV	NPV	Positive LR	Negative LR
1	CRAMS	1472	0.26	0.22	0.30	0.94	0.92	0.95	0.74	112	63	972	325	0.07	0.99	4.21	0.79
2	Dutch	1472	0.16	0.13	0.20	0.96	0.95	0.98	0.73	72	37	998	365	0.07	0.98	4.61	0.87
3	Florida	1472	0.29	0.25	0.34	0.88	0.86	0.90	0.71	128	120	915	309	0.04	0.99	2.53	0.80
4	LAS (current)	1472	0.31	0.27	0.35	0.92	0.90	0.93	0.74	136	86	949	301	0.07	0.99	3.75	0.75
5	LAS (old)	1472	0.44	0.39	0.49	0.88	0.86	0.90	0.75	192	124	911	245	0.07	0.99	3.67	0.64
6	MATTS balanced	1472	0.50	0.45	0.55	0.89	0.87	0.91	0.77	219	118	917	218	0.08	0.99	4.40	0.56
7	MATTS sensitive	1472	0.62	0.58	0.67	0.81	0.78	0.83	0.75	272	199	836	165	0.06	0.99	3.24	0.47
8	MATTS specific	1472	0.26	0.22	0.30	0.97	0.96	0.98	0.76	112	33	1002	325	0.14	0.99	8.04	0.77
9	MGAP	1472	0.38	0.33	0.42	0.79	0.76	0.81	0.66	164	222	813	273	0.03	0.99	1.75	0.80
10	North Carolina	1472	0.27	0.23	0.31	0.91	0.89	0.93	0.72	118	93	942	319	0.05	0.99	3.01	0.80
11	Oregon	1472	0.25	0.21	0.29	0.92	0.91	0.94	0.72	109	78	957	328	0.06	0.99	3.31	0.81
12	PHI	1472	0.11	0.08	0.14	0.96	0.95	0.97	0.71	47	38	997	390	0.05	0.98	2.93	0.93
13	RTST	1472	0.22	0.18	0.26	0.93	0.91	0.94	0.72	96	74	961	341	0.05	0.98	3.07	0.84
14	SWAS	1472	0.22	0.18	0.26	0.96	0.95	0.97	0.74	97	41	994	340	0.10	0.99	5.60	0.81
15	Trauma Score	1472	0.06	0.04	0.08	0.99	0.99	1.00	0.72	27	7	1028	410	0.18	0.98	9.14	0.95
16	Trauma Scorecard	1472	0.21	0.17	0.25	0.94	0.92	0.95	0.72	93	65	970	344	0.06	0.98	3.39	0.84
17	TTR	1472	0.11	0.08	0.14	0.97	0.96	0.98	0.72	48	27	1008	389	0.07	0.98	4.21	0.91
18	US Field Triage	1472	0.30	0.26	0.35	0.90	0.88	0.91	0.72	132	108	927	305	0.05	0.99	2.90	0.78
19	Victoria	1472	0.49	0.45	0.54	0.77	0.74	0.79	0.69	216	239	796	221	0.04	0.99	2.14	0.66
20	Vittel	1472	0.31	0.27	0.35	0.88	0.86	0.90	0.71	136	123	912	301	0.04	0.99	2.62	0.78
21	WMAS	1472	0.33	0.29	0.38	0.89	0.88	0.91	0.73	146	109	926	291	0.06	0.99	3.17	0.74
22	YAS	1472	0.42	0.38	0.47	0.88	0.86	0.90	0.74	185	124	911	252	0.07	0.99	3.53	0.66
23[a]	Ohio geriatric tool	1472	0.38	0.33	0.43	0.78	0.76	0.81	0.67	146	212	759	237	0.03	0.99	1.75	0.79
24[a]	US Field Triage geriatric	1472	0.67	0.63	0.72	0.5	0.47	0.53	0.56	294	522	513	143	0.02	0.99	1.33	0.66
25[a]	WMAS Silver Safety Net	1472	0.65	0.60	0.69	0.68	0.65	0.71	0.67	282	333	702	155	0.04	0.99	2.01	0.52

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.
a Geriatric-specific tools.

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Tool number	Tool name
1	CRAMS
2	Dutch
3	Florida
4	LAS (current)
	LAS (old)
6	MATTS (balanced)
7	MATTS (sensitive)
8	MATTS specific
9	MGAP
10	North Carolina
	Oregon
12	PHI
13	RTST
	SWAS
15	Trauma Score
16	Trauma Scorecard
17	TTR
18	US Field Triage
19	Victoria
20	Vittel
21	WMAS
22	YAS
23	Ohio geriatric tool
24	US Field Triage geriatric
25	WMAS Silver Safety Net
26†	LAS (children)
27†	NWAS (children)
28†	Paediatric checklist

*Elderly specific tools; †Paediatric specific tools

FIGURE 36 Sensitivity–specificity plot triage tools evaluated against the primary MATTS reference standard in different age subgroups. Upper panel shows all triage tools. Lower panel shows maximum realisable ROC curve/Pareto front of optimal tools, excluding tools with worse accuracy.

TABLE 60 Sensitivity analysis examining non-selected working codes

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	PPV	NPV	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
1	CRAMS	2680	327	107	1572	674	0.33	0.30	0.36	0.94	0.93	0.95	0.12	0.98	5.50	4.49	6.74	0.71	0.59	0.86
2	Dutch	2680	261	113	1566	740	0.26	0.23	0.29	0.93	0.92	0.94	0.09	0.98	3.71	3.02	4.57	0.80	0.66	0.95
3	Florida	2680	392	239	1440	609	0.39	0.36	0.42	0.86	0.84	0.88	0.07	0.98	2.79	2.42	3.21	0.71	0.62	0.81
4	LAS (current)	2680	436	176	1503	565	0.44	0.41	0.47	0.90	0.89	0.91	0.10	0.98	4.40	3.76	5.15	0.62	0.54	0.72
5	LAS (old)	2680	553	238	1441	448	0.55	0.52	0.58	0.86	0.84	0.88	0.09	0.99	3.93	3.45	4.48	0.52	0.46	0.60
6	MATTS balanced	2680	571	219	1460	430	0.57	0.54	0.60	0.87	0.85	0.89	0.10	0.99	4.38	3.83	5.02	0.49	0.43	0.57
7	MATTS sensitive	2680	716	407	1272	285	0.72	0.69	0.75	0.76	0.74	0.78	0.07	0.99	3.00	2.73	3.29	0.37	0.32	0.42
8	MATTS specific	2680	369	81	1598	632	0.37	0.34	0.40	0.95	0.94	0.96	0.17	0.98	7.40	5.89	9.29	0.66	0.53	0.82
9	MGAP	2680	305	253	1426	696	0.30	0.27	0.33	0.85	0.83	0.87	0.05	0.98	2.00	1.73	2.32	0.82	0.73	0.93
10	North Carolina	2680	405	181	1498	596	0.40	0.37	0.43	0.89	0.88	0.90	0.09	0.98	3.64	3.11	4.25	0.67	0.58	0.78
11	Oregon	2680	366	146	1533	635	0.37	0.34	0.40	0.91	0.90	0.92	0.10	0.98	4.11	3.45	4.90	0.69	0.59	0.81
12	PHI	2680	171	66	1613	830	0.17	0.15	0.19	0.96	0.95	0.97	0.11	0.98	4.25	3.23	5.58	0.86	0.68	1.10
13	RTST	2680	302	121	1558	699	0.30	0.27	0.33	0.93	0.92	0.94	0.10	0.98	4.29	3.52	5.21	0.75	0.63	0.90
14	SWAS	2680	319	80	1599	682	0.32	0.29	0.35	0.95	0.94	0.96	0.15	0.98	6.40	5.07	8.07	0.72	0.58	0.89
15	Trauma Score	2680	96	14	1665	905	0.10	0.08	0.12	0.99	0.99	0.99	0.26	0.98	10.00	5.74	17.42	0.91	0.54	1.53
16	Trauma Scorecard	2680	333	131	1548	668	0.33	0.30	0.36	0.92	0.91	0.93	0.10	0.98	4.13	3.42	4.97	0.73	0.61	0.86
17	TTR	2680	199	66	1613	802	0.20	0.18	0.22	0.96	0.95	0.97	0.13	0.98	5.00	3.83	6.53	0.83	0.66	1.06
18	US Field Triage	2680	422	206	1473	579	0.42	0.39	0.45	0.88	0.86	0.90	0.08	0.98	3.50	3.02	4.05	0.66	0.57	0.76
19	Victoria	2680	588	422	1257	413	0.59	0.56	0.62	0.75	0.73	0.77	0.06	0.99	2.36	2.14	2.60	0.55	0.49	0.61
20	Vittel	2680	437	211	1468	564	0.44	0.41	0.47	0.87	0.85	0.89	0.08	0.98	3.38	2.93	3.91	0.64	0.56	0.74
21	WMAS	2680	447	205	1474	554	0.45	0.42	0.48	0.88	0.86	0.90	0.09	0.98	3.75	3.24	4.34	0.62	0.54	0.72
22	YAS	2680	510	238	1441	491	0.51	0.48	0.54	0.86	0.84	0.88	0.09	0.99	3.64	3.19	4.16	0.57	0.50	0.65

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

Note
Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years, including reference standard positive cases with non-selected WI codes.

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TABLE 61 Best-case missing data sensitivity analysis

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	PPV	NPV	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
1	CRAMS	2790	343	115	1666	666	0.34	0.31	0.37	0.94	0.92	0.95	0.12	0.98	5.26	4.33	6.41	0.71	0.59	0.85
2	Dutch	2790	293	124	1657	716	0.29	0.26	0.32	0.93	0.92	0.94	0.10	0.98	4.17	3.43	5.07	0.76	0.64	0.91
3	Florida	2790	429	253	1528	580	0.43	0.39	0.46	0.86	0.84	0.87	0.07	0.98	2.99	2.62	3.42	0.67	0.59	0.76
4	LAS (current)	2790	460	189	1592	549	0.46	0.43	0.49	0.89	0.88	0.91	0.11	0.98	4.30	3.70	4.99	0.61	0.53	0.70
5	LAS (old)	2790	569	251	1530	440	0.56	0.53	0.59	0.86	0.84	0.88	0.10	0.99	4.00	3.52	4.54	0.51	0.44	0.58
6	MATTS balanced	2790	588	236	1545	421	0.58	0.55	0.61	0.87	0.85	0.88	0.11	0.99	4.40	3.86	5.01	0.48	0.42	0.55
7	MATTS sensitive	2790	732	435	1346	277	0.73	0.70	0.75	0.76	0.74	0.78	0.07	0.99	2.97	2.71	3.25	0.36	0.32	0.41
8	MATTS specific	2790	385	87	1694	624	0.38	0.35	0.41	0.95	0.94	0.96	0.18	0.98	7.81	6.27	9.73	0.65	0.53	0.80
9	MGAP	2790	316	271	1510	693	0.31	0.28	0.34	0.85	0.83	0.86	0.05	0.98	2.06	1.78	2.37	0.81	0.72	0.91
10	North Carolina	2790	434	190	1591	575	0.43	0.40	0.46	0.89	0.88	0.91	0.10	0.98	4.03	3.46	4.69	0.64	0.55	0.74
11	Oregon	2790	396	154	1627	613	0.39	0.36	0.42	0.91	0.90	0.93	0.11	0.98	4.54	3.83	5.38	0.67	0.57	0.78
12	PHI	2790	202	71	1710	807	0.20	0.18	0.22	0.96	0.95	0.97	0.12	0.98	5.02	3.88	6.51	0.83	0.66	1.05
13	RTST	2790	326	128	1653	683	0.32	0.29	0.35	0.93	0.92	0.94	0.11	0.98	4.50	3.72	5.43	0.73	0.61	0.87
14	SWAS	2790	337	88	1693	672	0.33	0.30	0.36	0.95	0.94	0.96	0.15	0.98	6.76	5.42	8.44	0.70	0.57	0.86
15	Trauma Score	2790	106	16	1765	903	0.11	0.09	0.12	0.99	0.99	1.00	0.26	0.98	11.69	6.95	19.67	0.90	0.55	1.47
16	Trauma Scorecard	2790	361	139	1642	648	0.36	0.33	0.39	0.92	0.91	0.93	0.11	0.98	4.58	3.83	5.49	0.70	0.59	0.82
17	TTR	2790	222	71	1710	787	0.22	0.19	0.25	0.96	0.95	0.97	0.13	0.98	5.52	4.27	7.13	0.81	0.65	1.02
18	US Field Triage	2790	450	219	1562	559	0.45	0.42	0.48	0.88	0.86	0.89	0.09	0.98	3.63	3.15	4.18	0.63	0.55	0.72
19	Victoria	2790	620	447	1334	389	0.61	0.58	0.64	0.75	0.73	0.77	0.06	0.99	2.45	2.23	2.69	0.51	0.46	0.58
20	Vittel	2790	475	226	1555	534	0.47	0.44	0.50	0.87	0.86	0.89	0.09	0.98	3.71	3.23	4.26	0.61	0.53	0.69
21	WMAS	2790	478	219	1562	531	0.47	0.44	0.50	0.88	0.86	0.89	0.09	0.98	3.85	3.35	4.43	0.60	0.52	0.69
22	YAS	2790	524	251	1530	485	0.52	0.49	0.55	0.86	0.84	0.88	0.09	0.99	3.68	3.24	4.19	0.56	0.49	0.64

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; LR, likelihood ratio; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

Note
Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years, cases with missing data assumed to be triage tool negative.

TABLE 62 Worst-case missing data sensitivity analysis

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	PPV	NPV	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
1	CRAMS	2790	380	176	1605	629	0.38	0.35	0.41	0.90	0.89	0.92	0.09	0.98	3.81	3.24	4.48	0.69	0.60	0.80
2	Dutch	2790	322	182	1599	687	0.32	0.29	0.35	0.90	0.88	0.91	0.08	0.98	3.12	2.65	3.68	0.76	0.66	0.88
3	Florida	2790	456	326	1455	553	0.45	0.42	0.48	0.82	0.80	0.83	0.06	0.98	2.47	2.19	2.78	0.67	0.60	0.75
4	LAS (current)	2790	495	255	1526	514	0.49	0.46	0.52	0.86	0.84	0.87	0.08	0.98	3.43	3.01	3.90	0.59	0.52	0.68
5	LAS (old)	2790	600	318	1463	409	0.59	0.56	0.62	0.82	0.80	0.84	0.08	0.99	3.33	2.98	3.72	0.49	0.44	0.56
6	MATTS balanced	2790	620	297	1484	389	0.61	0.58	0.64	0.83	0.82	0.85	0.09	0.99	3.68	3.29	4.13	0.46	0.41	0.53
7	MATTS sensitive	2790	754	490	1291	255	0.75	0.72	0.77	0.72	0.70	0.75	0.07	0.99	2.72	2.50	2.95	0.35	0.31	0.40
8	MATTS specific	2790	444	155	1626	565	0.44	0.41	0.47	0.91	0.90	0.93	0.12	0.98	5.06	4.28	5.97	0.61	0.52	0.72
9	MGAP	2790	358	312	1469	651	0.35	0.33	0.38	0.82	0.81	0.84	0.05	0.98	2.03	1.78	2.31	0.78	0.70	0.87
10	North Carolina	2790	464	261	1520	545	0.46	0.43	0.49	0.85	0.84	0.87	0.08	0.98	3.14	2.75	3.58	0.63	0.56	0.72
11	Oregon	2790	430	226	1555	579	0.43	0.40	0.46	0.87	0.86	0.89	0.08	0.98	3.36	2.92	3.87	0.66	0.58	0.75
12	PHI	2790	227	121	1660	782	0.22	0.20	0.25	0.93	0.92	0.94	0.08	0.98	3.31	2.69	4.07	0.83	0.70	0.99
13	RTST	2790	369	202	1579	640	0.37	0.34	0.40	0.89	0.87	0.90	0.08	0.98	3.22	2.77	3.76	0.72	0.62	0.82
14	SWAS	2790	374	158	1623	635	0.37	0.34	0.40	0.91	0.90	0.92	0.10	0.98	4.18	3.53	4.95	0.69	0.59	0.81
15	Trauma Score	2790	148	50	1731	861	0.15	0.12	0.17	0.97	0.96	0.98	0.11	0.98	5.22	3.83	7.13	0.88	0.67	1.16
16	Trauma Scorecard	2790	397	211	1570	612	0.39	0.36	0.42	0.88	0.87	0.90	0.08	0.98	3.32	2.86	3.85	0.69	0.60	0.79
17	TTR	2790	260	132	1649	749	0.26	0.23	0.28	0.93	0.91	0.94	0.08	0.98	3.48	2.86	4.22	0.80	0.68	0.95
18	US Field Triage	2790	480	286	1495	529	0.48	0.44	0.51	0.84	0.82	0.86	0.07	0.98	2.96	2.62	3.35	0.62	0.55	0.71
19	Victoria	2790	668	552	1229	341	0.66	0.63	0.69	0.69	0.67	0.71	0.05	0.99	2.14	1.97	2.32	0.49	0.44	0.55
20	Vittel	2790	533	331	1450	476	0.53	0.50	0.56	0.81	0.80	0.83	0.07	0.99	2.84	2.54	3.18	0.58	0.52	0.65
21	WMAS	2790	504	285	1496	505	0.50	0.47	0.53	0.84	0.82	0.86	0.08	0.98	3.12	2.76	3.53	0.60	0.53	0.67
22	YAS	2790	557	318	1463	452	0.55	0.52	0.58	0.82	0.80	0.84	0.08	0.99	3.09	2.76	3.47	0.55	0.48	0.62

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; FN, false negative; FP, false positive; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; NPV, negative predictive value; PPV, positive predictive value; TN, true negative; TP, true positive; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

Note
Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years, cases with missing data assumed to be triage tool positive.

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TABLE 63 DATA missing at random sensitivity analysis

Tool number	Tool name	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL
1	CRAMS	0.35	0.32	0.38	0.93	0.92	0.94
2	Dutch	0.29	0.26	0.32	0.93	0.92	0.94
3	Florida	0.43	0.40	0.46	0.86	0.84	0.87
4	LAS (current)	0.46	0.43	0.49	0.89	0.88	0.91
5	LAS (old)	0.57	0.54	0.60	0.86	0.84	0.87
6	MATTS balanced	0.59	0.56	0.62	0.86	0.85	0.88
7	MATTS sensitive	0.73	0.70	0.76	0.75	0.73	0.77
8	MATTS specific	0.39	0.36	0.42	0.95	0.94	0.96
9	MGAP	0.32	0.29	0.35	0.85	0.83	0.86
10	North Carolina	0.43	0.40	0.46	0.89	0.88	0.91
11	Oregon	0.40	0.37	0.43	0.91	0.90	0.92
12	PHI	0.20	0.18	0.23	0.96	0.95	0.97
13	RTST	0.33	0.30	0.36	0.93	0.91	0.94
14	SWAS	0.34	0.31	0.37	0.95	0.94	0.96
15	Trauma Score	0.11	0.09	0.13	0.99	0.98	0.99
16	Trauma Scorecard	0.36	0.33	0.39	0.92	0.91	0.93
17	TTR	0.22	0.20	0.25	0.96	0.95	0.97
18	US Field Triage	0.45	0.42	0.48	0.88	0.86	0.89
19	Victoria	0.62	0.59	0.65	0.75	0.72	0.77
20	Vittel	0.48	0.45	0.51	0.87	0.85	0.89
21	WMAS	0.48	0.45	0.51	0.88	0.86	0.89
22	YAS	0.53	0.49	0.56	0.86	0.84	0.87

CRAMS, Circulation, Respirations, Abdomen, Motor, Speech score; LCL, lower 95% confidence limit; MGAP, Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score; TTR, Trauma Triage Rule; UCL, upper 95% confidence limit.

Note
Diagnostic accuracy metrics for selected triage tools evaluated against the primary MATTS reference standard in patients aged over 16 years sustaining non-trivial injury (multiply imputed data).

TABLE 64 Diagnostic accuracy metrics for ambulance service triage tools and prehospital provider triage decisions (conveyed to MTC with pre-alert) evaluated against the MATTS reference standard excluding open fractures

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
1	LAS Step 1	2691	299	151	1655	586	0.34	0.31	0.37	0.92	0.90	0.93	4.04	3.38	4.83	0.72	0.62	0.85
2	LAS Steps 1/2	2691	509	270	1536	376	0.58	0.54	0.61	0.85	0.83	0.87	3.85	3.40	4.35	0.50	0.44	0.57
3	LAS Steps 1/2/3	2691	517	271	1535	368	0.58	0.55	0.62	0.85	0.83	0.87	3.89	3.44	4.40	0.49	0.43	0.56
4	LAS Steps 1/2/3/4	2691	775	1279	527	110	0.88	0.85	0.90	0.29	0.27	0.31	1.24	1.19	1.29	0.43	0.36	0.51
5	SWAS	2691	284	138	1668	601	0.32	0.29	0.35	0.92	0.91	0.94	4.20	3.48	5.06	0.74	0.62	0.87
6	WMAS Step 1	2691	324	164	1642	561	0.37	0.33	0.40	0.91	0.90	0.92	4.03	3.40	4.78	0.70	0.60	0.81
7	WMAS Steps 1/2	2691	421	226	1580	464	0.48	0.44	0.51	0.87	0.86	0.89	3.80	3.30	4.37	0.60	0.52	0.69
8	WMAS Steps 1/2/3	2691	479	263	1543	406	0.54	0.51	0.57	0.85	0.84	0.87	3.72	3.27	4.22	0.54	0.47	0.61
9	WMAS Steps 1/2/3/4	2691	770	1300	506	115	0.87	0.85	0.89	0.28	0.26	0.30	1.21	1.16	1.26	0.46	0.39	0.55
10	YAS Step 1	2691	303	168	1638	582	0.34	0.31	0.37	0.91	0.89	0.92	3.68	3.10	4.36	0.73	0.62	0.84
11	YAS Steps 1/2	2691	494	284	1522	391	0.56	0.53	0.59	0.84	0.83	0.86	3.55	3.14	4.01	0.52	0.46	0.60
12	YAS Steps 1/2/3	2691	502	285	1521	383	0.57	0.53	0.60	0.84	0.83	0.86	3.59	3.18	4.06	0.51	0.45	0.59
13	YAS Steps 1/2/3/4	2691	764	1293	513	121	0.86	0.84	0.89	0.28	0.26	0.30	1.21	1.16	1.25	0.48	0.41	0.57
14	LAS triage decisions	525	58	58	406	3	0.95	0.90	1.01	0.88	0.84	0.91	7.61	5.94	9.74	0.06	0.02	0.17
15	SWAS triage decisions	500	32	12	429	27	0.54	0.42	0.67	0.97	0.96	0.99	19.93	10.88	36.51	0.47	0.25	0.88
16	WMAS triage decisions	578	73	13	474	18	0.80	0.72	0.88	0.97	0.96	0.99	30.05	17.41	51.87	0.20	0.10	0.40
17	YAS triage decisions	530	73	25	420	12	0.86	0.78	0.93	0.94	0.92	0.97	15.29	10.35	22.59	0.15	0.08	0.29
18	Overall triage decisions	2691	416	95	1703	477	0.47	0.43	0.50	0.95	0.94	0.96	8.82	7.16	10.85	0.56	0.46	0.69

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

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TABLE 65 Diagnostic accuracy metrics for ambulance service triage tools and prehospital provider triage decisions (conveyed to MTC with pre-alert) evaluated against the urgent trauma intervention reference standard

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
1	LAS Step 1	2646	292	152	1662	540	0.35	0.32	0.38	0.92	0.90	0.93	4.19	3.51	5.00	0.71	0.60	0.83
2	LAS Steps 1/2	2646	450	274	1540	382	0.54	0.51	0.57	0.85	0.83	0.87	3.58	3.16	4.06	0.54	0.47	0.62
3	LAS Steps 1/2/3	2646	457	275	1539	375	0.55	0.52	0.58	0.85	0.83	0.86	3.62	3.20	4.11	0.53	0.47	0.61
4	LAS Steps 1/2/3/4	2646	759	1283	531	73	0.91	0.89	0.93	0.29	0.27	0.31	1.29	1.24	1.34	0.30	0.24	0.37
5	SWAS	2646	246	140	1674	586	0.30	0.26	0.33	0.92	0.91	0.94	3.83	3.17	4.64	0.76	0.65	0.90
6	WMAS Step 1	2646	310	165	1649	522	0.37	0.34	0.41	0.91	0.90	0.92	4.10	3.46	4.86	0.69	0.59	0.81
7	WMAS Steps 1/2	2646	368	230	1584	464	0.44	0.41	0.48	0.87	0.86	0.89	3.49	3.02	4.02	0.64	0.56	0.73
8	WMAS Steps 1/2/3	2646	412	268	1546	420	0.50	0.46	0.53	0.85	0.84	0.87	3.35	2.94	3.82	0.59	0.52	0.67
9	WMAS Steps 1/2/3/4	2646	748	1304	510	84	0.90	0.88	0.92	0.28	0.26	0.30	1.25	1.21	1.30	0.36	0.29	0.44
10	YAS Step 1	2646	296	169	1645	536	0.36	0.32	0.39	0.91	0.89	0.92	3.82	3.22	4.53	0.71	0.61	0.83
11	YAS Steps 1/2	2646	451	288	1526	381	0.54	0.51	0.58	0.84	0.82	0.86	3.41	3.02	3.86	0.54	0.48	0.62
12	YAS Steps 1/2/3	2646	458	289	1525	374	0.55	0.52	0.58	0.84	0.82	0.86	3.46	3.06	3.90	0.53	0.47	0.61
13	YAS Steps 1/2/3/4	2646	761	1297	517	71	0.91	0.90	0.93	0.29	0.26	0.31	1.28	1.23	1.33	0.30	0.24	0.37
14	LAS triage decisions	601	87	55	404	55	0.61	0.53	0.69	0.88	0.85	0.91	5.11	3.86	6.77	0.44	0.32	0.61
15	SWAS triage decisions	666	55	10	422	179	0.24	0.18	0.29	0.98	0.96	0.99	10.15	5.28	19.54	0.78	0.42	1.45
16	WMAS triage decisions	771	121	13	473	164	0.42	0.37	0.48	0.97	0.96	0.99	15.87	9.13	27.59	0.59	0.34	1.02
17	YAS triage decisions	708	87	26	411	184	0.32	0.27	0.38	0.94	0.92	0.96	5.40	3.58	8.14	0.72	0.49	1.06
18	Overall triage decisions	2646	350	104	1710	482	0.42	0.39	0.45	0.94	0.93	0.95	7.34	5.99	8.99	0.61	0.51	0.75

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

TABLE 66 Diagnostic accuracy metrics for ambulance service triage tools and prehospital provider triage decisions (conveyed to MTC with pre-alert) evaluated against the urgent trauma intervention reference standard

Tool number	Tool name	*n*	TP	FP	TN	FN	Sensitivity	Sensitivity LCL	Sensitivity UCL	Specificity	Specificity LCL	Specificity UCL	Positive LR	Positive LR LCL	Positive LR UCL	Negative LR	Negative LR LCL	Negative LR UCL
1	LAS Step 1	2133	153	155	1682	143	0.52	0.46	0.57	0.92	0.90	0.93	6.13	5.08	7.38	0.53	0.44	0.64
2	LAS Steps 1/2	2133	229	282	1555	67	0.77	0.73	0.82	0.85	0.83	0.86	5.04	4.45	5.70	0.27	0.21	0.34
3	LAS Steps 1/2/3	2133	233	283	1554	63	0.79	0.74	0.83	0.85	0.83	0.86	5.11	4.52	5.78	0.25	0.20	0.32
4	LAS Steps 1/2/3/4	2133	264	1302	535	32	0.89	0.86	0.93	0.29	0.27	0.31	1.26	1.20	1.32	0.37	0.27	0.52
5	SWAS	2133	172	145	1692	124	0.58	0.52	0.64	0.92	0.91	0.93	7.36	6.13	8.85	0.45	0.37	0.56
6	WMAS Step 1	2133	164	169	1668	132	0.55	0.50	0.61	0.91	0.89	0.92	6.02	5.05	7.18	0.49	0.41	0.59
7	WMAS Steps 1/2	2133	217	236	1601	79	0.73	0.68	0.78	0.87	0.86	0.89	5.71	4.97	6.55	0.31	0.24	0.38
8	WMAS Steps 1/2/3	2133	237	274	1563	59	0.80	0.76	0.85	0.85	0.83	0.87	5.37	4.75	6.07	0.23	0.18	0.30
9	WMAS Steps 1/2/3/4	2133	264	1323	514	32	0.89	0.86	0.93	0.28	0.26	0.30	1.24	1.18	1.30	0.39	0.28	0.54
10	YAS Step 1	2133	154	172	1665	142	0.52	0.46	0.58	0.91	0.89	0.92	5.56	4.64	6.65	0.53	0.44	0.64
11	YAS Steps 1/2	2133	215	296	1541	81	0.73	0.68	0.78	0.84	0.82	0.86	4.51	3.98	5.11	0.33	0.26	0.40
12	YAS Steps 1/2/3	2133	219	297	1540	77	0.74	0.69	0.79	0.84	0.82	0.86	4.58	4.04	5.18	0.31	0.25	0.39
13	YAS Steps 1/2/3/4	2133	254	1316	521	42	0.86	0.82	0.90	0.28	0.26	0.30	1.20	1.13	1.26	0.50	0.38	0.66
14	LAS triage decisions	525	58	58	406	3	0.95	0.90	1.01	0.88	0.84	0.91	7.61	5.94	9.74	0.06	0.02	0.17
15	SWAS triage decisions	500	32	12	429	27	0.54	0.42	0.67	0.97	0.96	0.99	19.93	10.88	36.51	0.47	0.25	0.88
16	WMAS triage decisions	578	73	13	474	18	0.80	0.72	0.88	0.97	0.96	0.99	30.05	17.41	51.87	0.20	0.10	0.40
17	YAS triage decisions	530	73	25	420	12	0.86	0.78	0.93	0.94	0.92	0.97	15.29	10.35	22.59	0.15	0.08	0.29
18	Overall triage decisions	2133	236	108	1729	60	0.80	0.75	0.84	0.94	0.93	0.95	13.56	11.19	16.43	0.22	0.16	0.29

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

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TABLE 67 Critical appraisal/risk of bias assessment according to QUADAS-2 criteria

QUADAS 2 domain	Potential source of bias	Risk-of-bias rating	Comments/mitigation
Patient selection	Selection bias arising from non-consecutive or non-random sampling	Low	• Inclusion of consecutive eligible ambulance service patients
	Selection bias arising from case-control design	Low	• Single gate case–cohort design
	Selection bias from inappropriate exclusions	Low	• Inclusion criteria targeting patients where triage tool would plausibly be used • Exploration of spectrum effects in subgroups with higher energy injury mechanisms.
	Selection bias from non-paired comparative accuracy design	Low	• All triage tools evaluated in same patient sample
Index test	Test review bias	Low	• Data coders blinded to reference standard status • Statistical coding of triage tools performed blinded to reference standard status, with quality control by independent statistician.
	Bias from selecting test threshold to optimise sensitivity/specificity	Low	• Prediction models assessed at pre-published recommended cut points
	Information bias from conduct or interpretation of the index test	Moderate	• Triage tools evaluated using routinely collected ambulance service data, with possibility of erroneous, missing, or inaccurate data leading to index test misclassification.
	Undergoing one index test likely to affect the performance of the other index test(s)	Low	• Coding of individual triage tools independently performed
Reference standard	Reference standard misclassification	Unclear	• Reference standard coded for TARN cases using routinely collected hospital data, with possibility of erroneous, missing, or inaccurate data. • Possibility of non-identification of reference standard positive cases due to TARN inclusion criteria, for example penetrating trauma patient discharge < 72 hours. • Possibility of non-enrolment/submission of reference standard positive cases to TARN, especially in TUs not paid for case submissions (mitigated by selection of high-performing trauma networks) • Possibility for reference standards including interventions (e.g. interventional radiology) that treatment was not received if patient was transported to a TU, rather than a MTC, due to lack of availability, rather than non-requirement. Partially mitigated by inclusion of 'hot' transfer to MTC within 6 hours of presentation as positive criterion in reference standard. • Possibility of delayed enrolment/submission of reference standard positive cases to TARN due post-mortems (mitigated by final TARN data transfer 9 months after study inclusion dates). • Inaccurate matching of TARN and ambulances service records. Very small proportion of reference standard positive cases not matched to a corresponding ambulance service record (< 5%). However, it is likely that these represent non-participating ambulance service cases. Also, there is a low probability that a genuinely unmatched ambulance service record would be randomly sampled as a 'non-case' (< 5%).
	Diagnostic review bias	Low	• Reference standard coded independently by TARN without knowledge of index test status.
	Incorporation bias	Low	• Reference standard classification independent of index test information

TABLE 67 Critical appraisal/risk of bias assessment according to QUADAS-2 criteria (*continued*)

QUADAS 2 domain	Potential source of bias	Risk-of-bias rating	Comments/mitigation
Patient flow	Partial verification bias	Low	• All patients had potential for TARN submission and reference standard coding, regardless of triage status.
	Differential verification bias	Low	• Triage tool positive and negative patients received the same reference standard classification procedures
	Selection bias from loss to follow up or missing data	Low	• Complete-case main analysis performed with potential for bias if missing data not missing completely at random • However, sensitivity analyses demonstrate that results are robust to missing at random, or extreme missing not at random, assumptions.
	Different reference standards used for different tests	Low	• All triage tools assessed with same primary and secondary reference standards
	Selection bias from differential loss to follow-up or missing data across different triage tools	Low	• Missing data levels similar across triage tools (as most triage tools include similar physiology) • Sensitivity analyses demonstrate that results are robust to missing at random, or extreme missing not at random, assumptions.
	Disease progression bias	Low	• Reference standard classification performed from time of injury to defined time points

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Appendix 7 Phase 3 triage tool implementation study supplementary information

TABLE 68 Participating trauma networks and hospitals

ID	Ambulance service	Hospital	Trauma Network	Accepts adults	Accepts children	Designation-children	Designation-adults	Receives ambulances	Included in MATTS?	Incomplete TARN data
1	WMAS	Alexandra Hospital	Birmingham and the Black Country	Y	Y	LEH	LEH	Y	Y	
2	WMAS	Birmingham Children's Hospital	Birmingham and the Black Country	N	Y	MTC-P	N/A	Y	Y	
3	WMAS	Birmingham Heartlands Hospital	Birmingham and the Black Country	Y	Y	TU	TU	Y	Y	Excluded
4	WMAS	Hereford County Hospital	Birmingham and the Black Country	Y	Y	TU	TU	Y	Y	
5	WMAS	Manor Hospital (Walsall)	Birmingham and the Black Country	Y	Y	TU	TU	Y	Y	
6	WMAS	New Cross Hospital	Birmingham and the Black Country	Y	Y	TU	TU	Y	Y	
7	WMAS	Queen Elizabeth Hospital Birmingham	Birmingham and the Black Country	Y	Y	N/A	MTC-A	Y	Y	
8	WMAS	Russells Hall Hospital	Birmingham and the Black Country	Y	Y	TU	TU	Y	Y	
9	WMAS	Sandwell General Hospital	Birmingham and the Black Country	Y	Y	TU	TU	Y	Y	Excluded
10	WMAS	Worcestershire Royal Hospital	Birmingham and the Black Country	Y	Y	TU	TU	Y	Y	
11	EMAS	Kettering General Hospital	Central England	Y	Y	TU	TU	Y	N	
12	EMAS	Northampton General Hospital	Central England	Y	Y	TU	TU	Y	N	
13	WMAS	University Hospital of Coventry and Warwickshire	Central England	Y	Y	TU	MTC-A	Y	Y	
14	WAS	Glan Clwyd Hospital	North West Midlands and North Wales	Y	Y	TU	TU	Y	N	
15	NWAS	Leighton Hospital	North West Midlands and North Wales	Y	Y	TU	TU	Y	N	
16	WMAS	Princess Royal Hospital, Telford	North West Midlands and North Wales	Y	Y	LEH	LEH	Y	Y	
17	WMAS	Royal Shrewsbury Hospital	North West Midlands and North Wales	Y	Y	TU	TU	Y	Y	
18	WMAS	Royal Stoke University Hospital	North West Midlands and North Wales	Y	Y	TU	MTC-A	Y	Y	
19	WAS	Wrexham Maelor Hospital	North West Midlands and North Wales	Y	Y	TU	TU	Y	N	
20	WAS	Ysbyty Gwynedd District General	North West Midlands and North Wales	Y	Y	TU	TU	Y	N	
21	WMAS	City Hospital	Birmingham and the Black Country	Y	Y	LEH	LEH	Y	Y	
22	WMAS	County Hospital, Stafford	North West Midlands and North Wales	Y	Y	LEH	LEH	Y (not at night)	Y	
23	WMAS	George Eliot Hospital	Central England	Y	Y	LEH	LEH	Y	Y	
24	WMAS	Good Hope Hospital	Birmingham and the Black Country	Y	Y	LEH	LEH	Y	Y	Excluded
25	WMAS	Solihull Hospital	Birmingham and the Black Country	Y	Y	LEH	LEH	N	N	

continued

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TABLE 68 Participating trauma networks and hospitals (*continued*)

ID	Ambulance service	Hospital	Trauma Network	Accepts adults	Accepts children	Designation-children	Designation-adults	Receives ambulances	Included in MATTS?	Incomplete TARN data
26	WMAS	Warwick Hospital	Central England	N	Y	LEH	LEH	Y	Y	
101	EMAS	Diana, Princess of Wales Hospital	North Yorkshire and Humberside	Y	Y	TU	TU	Y	N	
102	YAS	Hull Royal Infirmary	North Yorkshire and Humberside	Y	Y	TU	MTC-A	Y	Y	
103	YAS	Scarborough Hospital	North Yorkshire and Humberside	Y	Y	TU	TU	Y	Y	
104	YAS	Scunthorpe General Hospital	North Yorkshire and Humberside	Y	Y	TU	TU	Y	Y	
105	YAS	York Hospital	North Yorkshire and Humberside	Y	Y	TU	TU	Y	Y	
106	YAS	Barnsley District General Hospital	South Yorkshire	Y	Y	TU	TU	Y	Y	
107	YAS	Bassetlaw District General Hospital	South Yorkshire	Y	Y	LEH	LEH	Y	Y	Excluded
108	EMAS	Chesterfield Royal Infirmary	South Yorkshire	Y	Y	TU	TU	Y	N	
109	YAS	Doncaster Royal Infirmary	South Yorkshire	Y	Y	TU	TU	Y	Y	Excluded
110	YAS	Rotherham General Hospital	South Yorkshire	Y	Y	TU	TU	Y	Y	Excluded
111	YAS	Sheffield Children's Hospital	South Yorkshire	Y	Y	MTC-P	N/A	Y	Y	
112	YAS	Sheffield Teaching Hospitals NHS Foundation Trust	South Yorkshire	Y	Y	N/A	MTC-A	Y	Y	
113	YAS	Airedale General Hospital	West Yorkshire	Y	Y	TU	TU	Y	Y	Excluded
114	YAS	Bradford Royal Infirmary	West Yorkshire	Y	Y	TU	TU	Y	Y	
115	YAS	Calderdale Royal Hospital	West Yorkshire	Y	Y	TU	TU	Y	Y	
116	YAS	Dewsbury and District Hospital	West Yorkshire	Y	Y	LEH	LEH	Y	Y	
117	YAS	Harrogate District Hospital	West Yorkshire	Y	Y	TU	TU	Y	Y	Excluded
118	YAS	Huddersfield Royal Infirmary	West Yorkshire	Y	Y	TU	TU	Y	Y	
119	YAS	Leeds General Infirmary	West Yorkshire	Y	Y	MTC-P	MTC-A	Y	Y	
120	YAS	Pinderfields General Hospital	West Yorkshire	Y	Y	TU	TU	Y	Y	
121	YAS	St James' University Hospital	West Yorkshire	Y	Y	TU	TU	Y	Y	

A, adult; N, no; N/A, not applicable; P, paediatric; Y, yes.

TABLE 69 Characteristics of participating regions

Characteristic	Yorkshire and Humber region	West Midlands region
Area	15,560 km^2	12,998 km^2
Population	5.5 million	6.0 million
Population density	360/km^2	463/km^2
Urban population	82%	85%
Rural population	18%	15%
Over 65s	19%	19%
White ethnicity	85%	77%
Life expectancy	78.3 years	78.5 years
Unemployment	3.4%	
Trauma network model	Inclusive	Inclusive
Included trauma networks	West Yorkshire, South Yorkshire, North Yorkshire and Humberside	North-West Midlands and North Wales, Central England, Birmingham and the Black Country
Ambulance service	Yorkshire Ambulance Service	West Midlands Ambulance Service
Staff	7073	7500
Trauma desk	Yes	Yes
Critical care paramedics	Yes	Yes
Air ambulance	Yes	Yes
Inclusive trauma networks	Yes	Yes

Note
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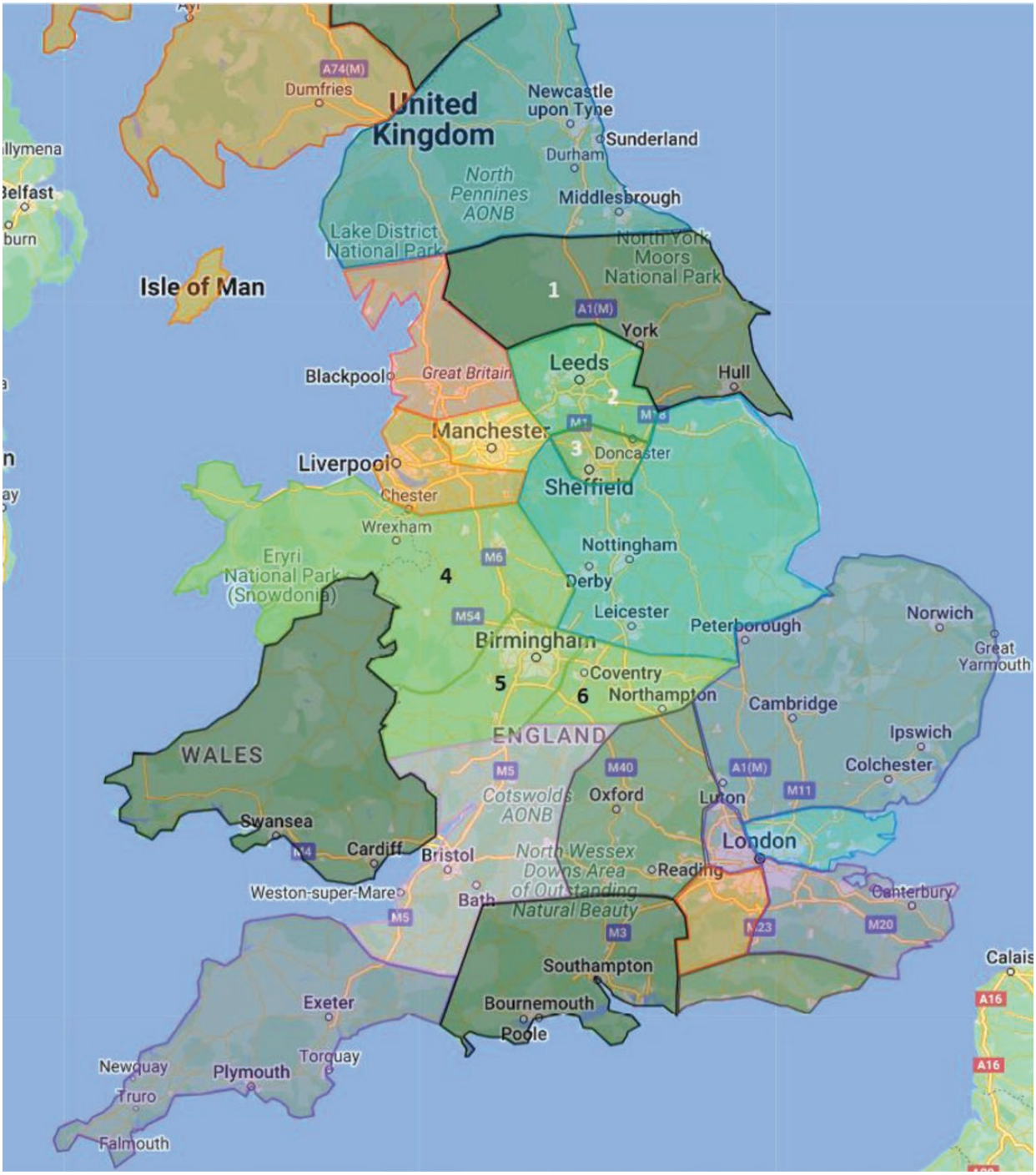


FIGURE 37 Geographical location and extent of trauma networks participating in the Phase 3 implementation cohort study. 1, North Yorkshire and Humberside network; 2, West Yorkshire; 3, South Yorkshire; 4, North-West Midlands and North Wales; 5, Birmingham and the Black Country; 6, Central England network.

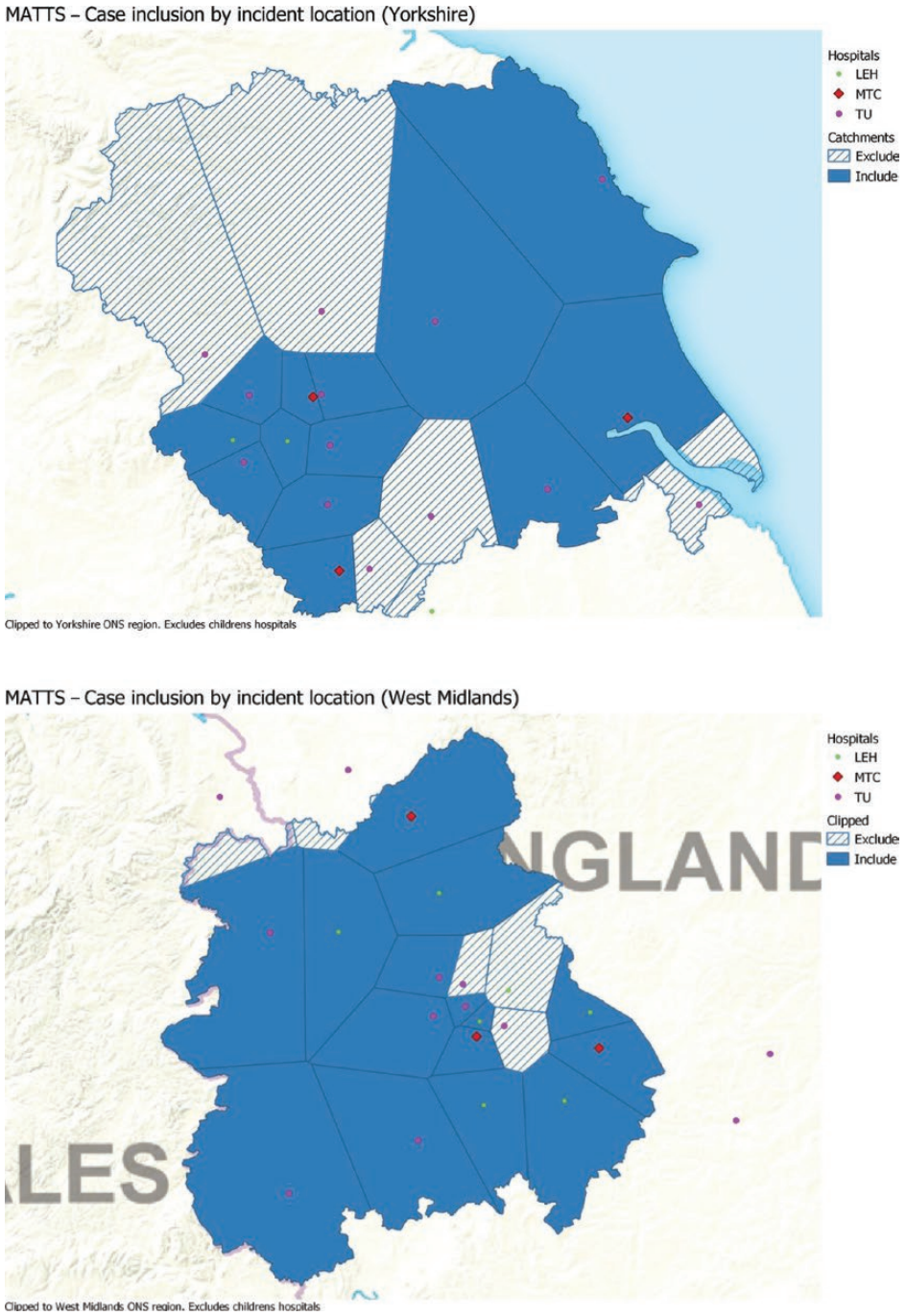


FIGURE 38 Included geographical areas within included Phase 3 trauma networks. Areas served by hospitals with imperfect TARN data collection excluded.

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TABLE 70 Characteristics of matched and unmatched participants

Characteristic		Matched *N* = 3306	Unmatched *N* = 122
Age	*n*	3306	122
	Mean (SD)	67.03 (22.59)	70.41 (19.13)
	Median (IQR)	73.30 (54.70–85.00)	75.10 (61.17–84.30)
	Minimum–maximum	0–102.2	20.6–99.8
Sex	Male	1659 (50.2%)	58 (47.5%)
	Female	1647 (49.8%)	64 (52.5%)
ISS	*n*	3306	122
	Mean (SD)	13.58 (8.99)	12.40 (8.18)
	Median (IQR)	9.00 (9.00–17.00)	9.00 (8.25–17.00)
	Minimum–maximum	0–75	0–41
Primary reference standard	Reference standard positive	993 (30.0%)	37 (30.3%)
	Reference standard negative	2313 (70.0%)	85 (69.7%)
MATTS reference standard – excluding open fractures	Reference standard positive	839 (25.4%)	36 (29.5%)
	Reference standard negative	2467 (74.6%)	86 (70.5%)
US consensus reference standard	Reference standard positive	190 (5.7%)	6 (4.9%)
	Reference standard negative	3116 (94.3%)	116 (95.1%)

TABLE 71 Number of patients in the cohort population with at least one measurement taken for physiology variables

	N = 38,010
Age	36,963 (97.2%)
Sex	36,901 (97.1%)
Electronic patient record identifier	37,100 (97.6%)
At scene time	36,212 (95.3%)
At hospital time	36,022 (94.8%)
Location	36,554 (96.2%)
GCS motor	36,422 (95.8%)
GCS total	36,410 (95.8%)
AVPU	35,265 (92.8%)
Systolic blood pressure (mmHg)	35,529 (93.5%)
Diastolic blood pressure (mmHg)	35,525 (93.5%)
Pulse	36,653 (96.4%)
Pain score	25,266 (66.5%)
Respiratory rate	36,805 (96.8%)
Oxygen saturation	27,477 (72.3%)
Temperature (°C)	33,875 (89.1%)

TABLE 72 Accuracy of differing definitions of algorithmically coded triage decisions for major trauma (MATTS primary reference standard, main cohort)

Triage decisions[a]	Reference standard negative	Reference standard positive	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Main cohort, primary MATTS reference standard						
N	36,601	838	61.3% (57.9% to 64.6%)	89.1% (88.8% to 89.5%)	11.5% (10.5% to 12.4%)	99.0% (98.9% to 99.1%)
TU/LEH/direct to MTC without pre-alert	32,626 (89.1%)	324 (38.7%)				
MTC bypass/direct to MTC with pre-alert	3975 (10.9%)	514 (61.3%)				
N	37,167	838	76.5% (73.5% to 79.3%)	62.6% (62.1% to 63.1%)	4.4% (4.1% to 4.7%)	99.2% (99.0% to 99.3%)
TU/LEH	23,273 (62.6%)	197 (23.5%)				
MTC	13,894 (37.4%)	641 (76.5%)				

NPV, negative predictive value; PPV, positive predictive value.
a Algorithmically coded.

TABLE 73 Accuracy of triage decisions against differing definitions of major trauma (main cohort)

Triage decision[a]	Reference standard negative	Reference standard positive	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Main cohort, primary MATTS reference standard						
N	37,167	838	55.3% (51.8% to 58.7%)	94.3% (94.1% to 94.6%)	18.0% (16.5% to 19.5%)	98.9% (98.8% to 99.0%)
Negative	35,060 (94.3%)	375 (44.7%)				
Positive	2107 (5.7%)	463 (55.3%)				
Main cohort, secondary ISS ≥ 16 reference standard						
N	37,024	981	41.6% (38.5% to 44.7%)	94.2% (93.9% to 94.4%)	15.9% (14.5% to 17.3%)	98.4% (98.3% to 98.5%)
Negative	34,862 (94.2%)	573 (58.4%)				
Positive	2162 (5.8%)	408 (41.6%)				
Main cohort, secondary US consensus definition reference standard						
N	37,859	146	87.0% (80.4% to 92.0%)	93.5% (93.3% to 93.8%)	4.9% (4.1% to 5.8%)	99.9% (99.9% to 100.0%)
Negative	35,416 (93.5%)	19 (13.0%)				
Positive	2443 (6.5%)	127 (87.0%)				
Main cohort, secondary MATTS reference standard excluding open fractures						
N	37,295	710	55.6% (51.9% to 59.3%)	94.2% (93.9% to 94.4%)	15.4% (14.0% to 16.8%)	99.1% (99.0% to 99.2%)
Negative	35,120 (94.2%)	315 (44.4%)				
Positive	2175 (5.8%)	395 (55.6%)				

NPV, negative predictive value; PPV, positive predictive value.
a TU/LEH/MTC with no pre-alert versus MTC with pre-alert.

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TABLE 74 Accuracy of triage decisions against the MATTS primary reference standard for major trauma in different injury mechanism and location subgroups (case–cohort sample)

Triage decision[a]	Reference standard negative	Reference standard positive	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)[b]	NPV (95% CI)[b]
Blunt injury sub-group, primary MATTS reference standard, case–cohort sample						
N	3439	778	52.2% (48.6% to 55.7%)	94.0% (93.1% to 94.8%)	16.3% (14.1% to 18.7%)	98.9% (98.8% to 99.0%)
Negative	3232 (94.0%)	372 (47.8%)				
Positive	207 (6.0%)	406 (52.2%)				
Penetrating injury sub-group, primary MATTS reference standard, case–cohort sample						
N	113	60	95.0% (86.1% to 99.0%)	75.2% (66.2% to 82.9%)	16.6% (11.1% to 24.0%)	99.6% (98.9% to 99.9%)
Negative	85 (75.2%)	3 (5.0%)				
Positive	28 (24.8%)	57 (95.0%)				
Low energy sub-group, primary MATTS reference standard, case–cohort sample						
N	2581	288	29.5% (24.3% to 35.1%)	96.4% (95.6% to 97.1%)	8.1% (6.2% to 10.7%)	99.2% (99.1% to 99.3%)
Negative	2488 (96.4%)	203 (70.5%)				
Positive	93 (3.6%)	85 (29.5%)				
High energy sub-group, primary MATTS reference standard, case–cohort sample						
N	971	550	68.7% (64.7% to 72.6%)	85.4% (83.0% to 87.5%)	21.0% (18.0% to 24.4%)	98.1% (97.7% to 98.3%)
Negative	829 (85.4%)	172 (31.3%)				
Positive	142 (14.6%)	378 (68.7%)				
MTC catchment area subgroup, primary MATTS reference standard, case–cohort sample						
N	1172	316	58.9% (53.2% to 64.3%)	87.4% (85.3% to 89.2%)	11.1% (9.1% to 13.4%)	98.8% (98.6% to 99.0%)
Negative	1024 (87.4%)	130 (41.1%)				
Positive	148 (12.6%)	186 (58.9%)				
Non-MTC catchment area subgroup, Primary MATTS reference standard, case–cohort sample						
N	2380	522	53.1% (48.7% to 57.4%)	96.3% (95.5% to 97.1%)	23.7% (19.6% to 28.4%)	99.0% (98.9% to 99.1%)
Negative	1293 (96.3%)	245 (46.9%)				
Positive	87 (3.7%)	277 (53.1%)				

NPV, negative predictive value; PPV, positive predictive value.

a Positive triage decision = transported to MTC with pre-alert; negative triage decision = all other triage outcomes.

b Predictive values in case–cohort analyses are calculated using inverse probability sampling weights to account for underlying prevalence of major trauma and provide inference for the main cohort.

TABLE 75 Accuracy of differing definitions of hand-coded triage decisions for major trauma (MATTS primary reference standard, main cohort)

Triage decisions[a]	Reference standard negative	Reference standard positive	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Case–cohort sample, primary MATTS reference standard						
N	3568	710	55.6% (51.9% to 59.3%)	93.2% (92.3% to 94.0%)	13.5% (10.9% to 16.2%)	99.1% (98.8% to 99.4%)
TU/LEH/MTC without pre-alert	3326 (93.2%)	315 (44.4%)				
MTC with pre-alert	242 (6.8%)	395 (55.6%)				
N	3328	821	62.1% (58.7% to 65.4%)	88.7% (87.6% to 89.8%)	11.5% (9.4% to 13.6%)	99.0% (98.7% to 99.3%)
TU/LEH/direct to MTC without pre-alert	2953 (88.7%)	311 (37.9%)				
MTC bypass/direct to MTC with pre-alert	375 (11.3%)	510 (62.1%)				
N	3568	710	77.6% (74.4% to 80.6%)	60.8% (59.1% to 62.4%)	3.6% (2.8 to 4.5%)	99.3% (99.0% to 99.6%)
TU/LEH	2168 (60.8%)	159 (22.4%)				
MTC	1400 (39.2%)	551 (77.6%)				

NPV, negative predictive value; PPV, positive predictive value.
a Hand coded by research paramedics.

TABLE 76 Theoretical accuracy of the MATTS triage tool for major trauma (defined by the MATTS primary reference standard) in the overall case–cohort sample and subgroups

Theoretical triage tool result	Reference standard negative	Reference standard positive	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
All patients, primary MATTS reference standard						
N	3552	838	51.1% (47.6% to 54.5%)	93.6% (92.7% to 94.4%)	15.2% (12.5% to 18.0%)	98.8% (98.5% to 99.2%)
Negative	3324 (93.6%)	410 (48.9%)				
Positive	228 (6.4%)	428 (51.1%)				
Paediatric subgroup, primary MATTS reference standard						
N	165	31	67.7% (48.6% to 83.3%)	72.7% (65.3% to 79.4%)	4.4% (0.0% to 9.3%)	99.2% (97.7% to 100.7%)
Negative	120 (72.7%)	10 (32.3%)				
Positive	45 (27.3%)	21 (67.7%)				
Adult sub-group, primary MATTS reference standard						
N	1235	429	59.4% (54.6% to 64.1%)	91.2% (89.5% to 92.7%)	18.2% (14.2% to 22.1%)	98.6% (97.9% to 99.2%)
Negative	1126 (91.2%)	174 (40.6%)				
Positive	109 (8.8%)	255 (59.4%)				

continued

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TABLE 76 Theoretical accuracy of the MATTS triage tool for major trauma (defined by the MATTS primary reference standard) in the overall case-cohort sample and subgroups (*continued*)

Theoretical triage tool result	Reference standard negative	Reference standard positive	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Elderly subgroup, primary MATTS reference standard						
N	2152	378	40.2% (35.2% to 45.3%)	96.6% (95.7% to 97.3%)	16.6% (11.7% to 21.4%)	99.0% (98.5% to 99.4%)
Negative	2078 (96.6%)	226 (59.8%)				
Positive	74 (3.4%)	152 (40.2%)				
Blunt injury subgroup, primary MATTS reference standard						
N	3439	778	48.3% (44.8% to 51.9%)	94.6% (93.8% to 95.3%)	16.0% (13.7% to 18.5%)	98.8% (97.7% to 98.9%)
Negative	3253 (94.6%)	402 (51.7%)				
Positive	186 (5.0%)	376 (48.3%)				
Penetrating injury subgroup, primary MATTS reference standard						
N	113	60	86.7% (75.4% to 94.1%)	62.8% (53.2% to 71.7%)	10.6% (7.3% to 15.3%)	98.9% (97.8% to 99.5%)
Negative	71 (62.8%)	8 (13.3%)				
Positive	42 (37.2%)	52 (86.7%)				
Rural subgroup, primary MATTS reference standard						
N	515	186	48.4% (41.0% to 55.8%)	93.2% (90.7% to 95.2%)	19.6% (12.6% to 26.5%)	98.1% (97.0% to 99.2%)
Negative	480 (93.2%)	96 (51.6%)				
Positive	35 (6.8%)	90 (48.4%)				
Urban subgroup, primary MATTS reference standard						
N	3037	652	51.8% (47.9% to 55.7%)	93.6% (92.7% to 94.5%)	14.6% (11.6% to 17.6%)	98.9% (98.6% to 99.3%)
Negative	2844 (93.6%)	314 (48.2%)				
Positive	193 (6.4%)	338 (51.8%)				
Low energy subgroup, primary MATTS reference standard						
N	2581	288	35.4% (29.9% to 41.2%)	95.4% (94.5% to 96.1%)	7.2% (5.6% to 9.2%)	99.3% (99.2% to 99.4%)
Negative	2461 (95.4%)	186 (64.6)				
Positive	120 (4.7%)	102 (35.4%)				
High energy subgroup, primary MATTS reference standard						
N	971	550	59.3% (55.0% to 63.4%)	88.9% (86.7% to 90.8%)	22.8% (19.2% to 26.9%)	97.5% (97.2% to 97.9%)
Negative	863 (88.9%)	224 (40.7%)				
Positive	108 (11.1%)	326 (59.3%)				

NPV, negative predictive value; PPV, positive predictive value.

TABLE 77 Theoretical triage tool accuracy against differing definitions for major trauma (case–cohort sample)

Theoretical triage tool result	Reference standard negative	Reference standard positive	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Primary MATTS reference standard						
N	3552	838	51.1% (47.6% to 54.5%)	93.6% (92.7% to 94.4%)	15.2% (12.5% to 18.0%)	98.8% (98.5% to 99.2%)
Negative	3324 (93.6%)	410 (48.9%)				
Positive	228 (6.4%)	428 (51.1%)				
Secondary ISS ≥ 16 reference standard						
N	3555	981	32.1% (29.2% to 35.1%)	93.1% (92.2% to 93.9%)	11.0% (8.4% to 13.6%)	98.1% (97.7% to 98.5%)
Negative	3310 (93.1%)	666 (67.9%)				
Positive	245 (6.9%)	315 (32.1%)				
Secondary US consensus definition reference standard						
N	3615	146	78.8% (71.2% to 85.1%)	92.7% (91.8% to 93.6%)	4.0% (2.0% to 6.0%)	99.9% (99.8% to 100.0%)
Negative	3352 (92.7%)	31 (21.2%)				
Positive	263 (7.3%)	115 (78.8%)				

NPV, negative predictive value; PPV, positive predictive value.

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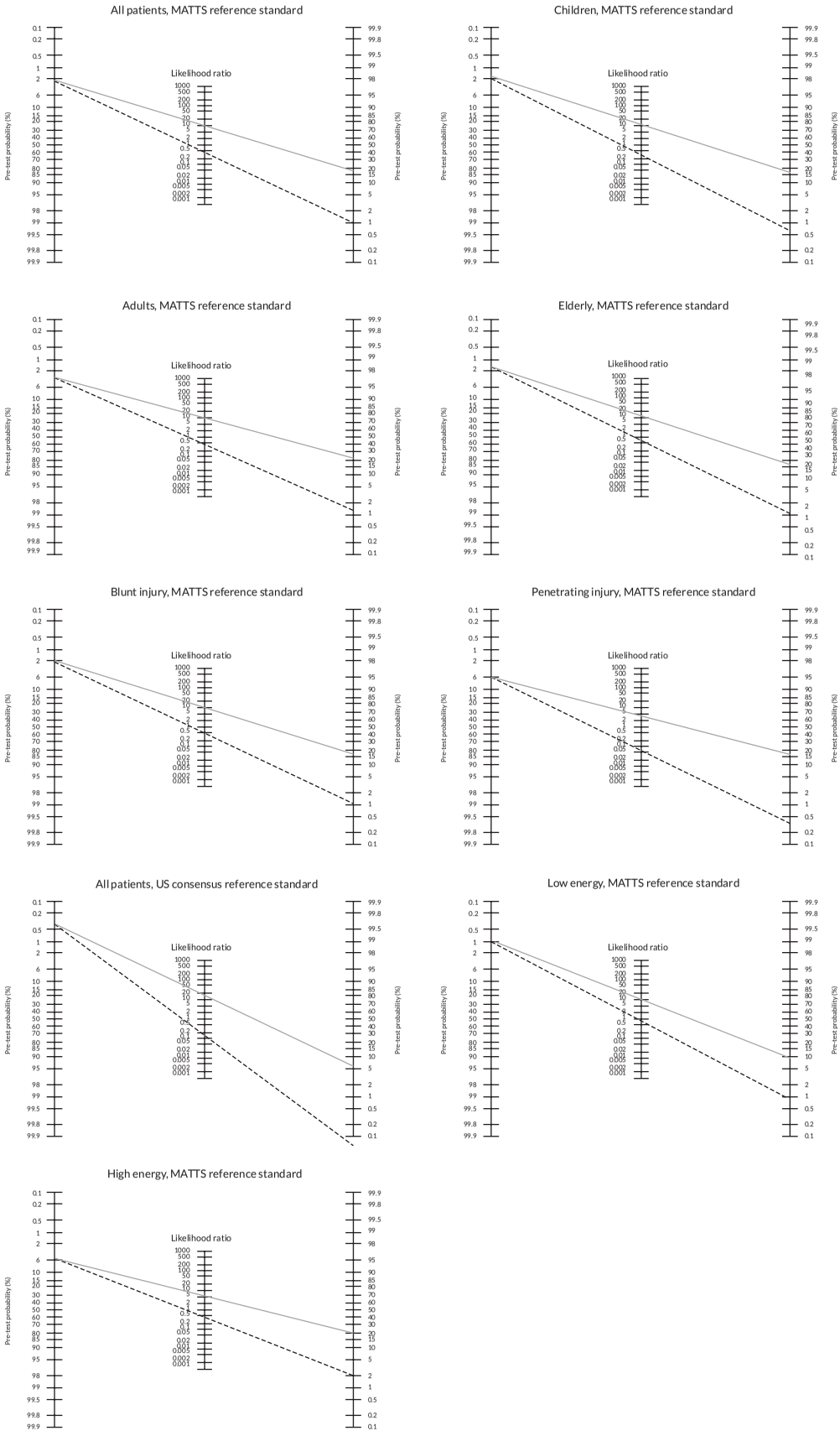


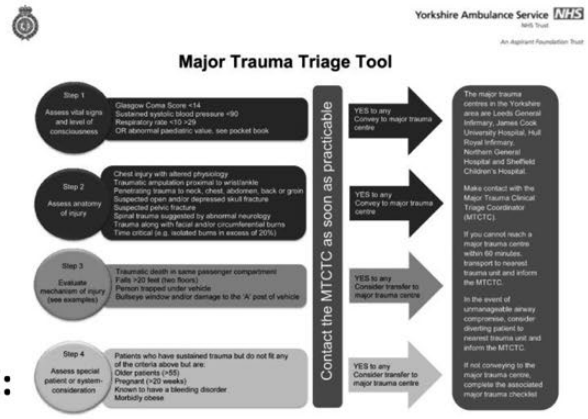
FIGURE 39 Fagan's nomograms showing pre-test and post-test probability of major trauma before and after prehospital triage decisions (MTC pre-alert). Grey line indicates positive triage decision. Broken black line indicates negative triage decision. Pre-test probability of major trauma, and accuracy of major trauma decisions, varies across different subgroups. In the event of a negative triage decision (no MTC pre-alert), the probability of major trauma is generally ≤ 1% both overall and across important subgroups. Following a positive prehospital triage decision for MTC pre-alert the probability of major trauma is generally > 15%, depending on subgroup of patients.

Appendix 8 Phase 3 before-and-after study supplementary results

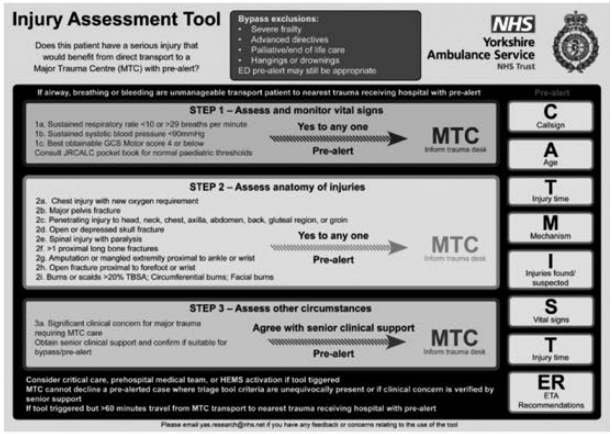
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YORKSHIRE AMBULANCE SERVICE

BEFORE:

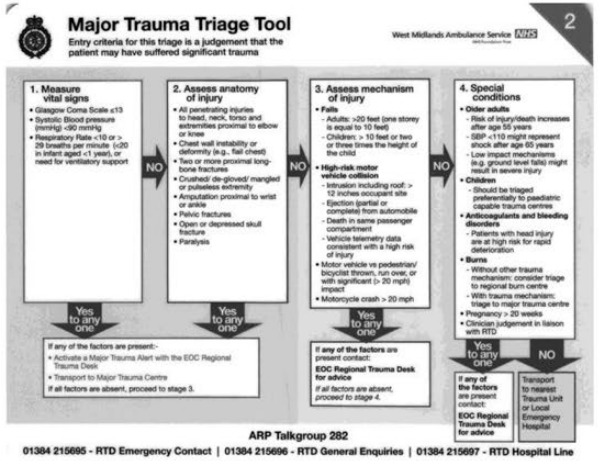


AFTER:



WEST MIDLANDS AMBULANCE SERVICE

BEFORE:



AFTER:

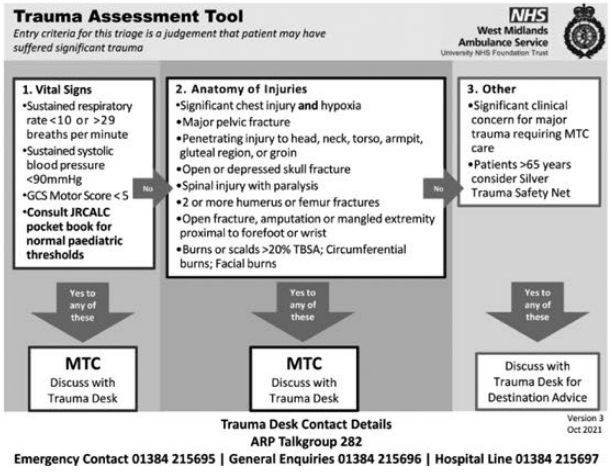


FIGURE 40 Triage tools used in each ambulance service before and after implementation of the MATTS tool.

TABLE 78 Sensitivity and specificity of triage decisions[a] for major trauma[b] before and after implementation of the MATTS triage tool in WMAS and YAS (ISS ≥ 16 reference standard)

Study period	Triage tool	Sensitivity	95% LCL	95% UCL	Specificity	95% LCL	95% UCL	TP	FP	TN	FN
WMAS											
Before[c]	WMAS	0.46	0.40	0.52	0.97	0.96	0.99	141	13	502	167
After[d]	MATTS	0.47	0.43	0.52	0.96	0.96	0.96	230	847	19,773	256
YAS											
Before[c]	YAS	0.51	0.43	0.58	0.94	0.92	0.96	90	27	450	87
After[d]	MATTS	0.36	0.32	0.40	0.92	0.92	0.93	178	1283	15,126	317

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

a Conveyance to a MTC with a pre-alert.
b MATTS reference standard.
c Case–cohort study data.
d Cohort study data.

TABLE 79 Theoretical sensitivity and specificity of triage tools[a] for major trauma[b] before and after implementation of the MATTS triage tool in WMAS and YAS (ISS ≥ 16 reference standard)

Study period	Triage tool	Sensitivity	95% LCL	95% UCL	Specificity	95% LCL	95% UCL	TP	FP	TN	FN
WMAS											
Before[c]	WMAS	0.53	0.47	0.60	0.87	0.84	0.90	129	61	425	112
After[c]	MATTS	0.35	0.31	0.40	0.92	0.91	0.93	172	139	165	314
YAS											
Before[c]	YAS	0.51	0.43	0.59	0.86	0.82	0.89	79	62	375	77
After[c]	MATTS	0.29	0.25	0.33	0.94	0.93	0.95	143	106	1655	352

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

a Objective evidence of positive triage tool variable in patient record; discretionary variables ignored.
b MATTS reference standard.
c Case–cohort study data.

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TABLE 80 Sensitivity and specificity of triage decisions[a] for major trauma[b] before and after implementation of the MATTS triage tool in WMAS and YAS (US consensus criteria for trauma centre need reference standard)

Study period	Triage tool	Sensitivity	95% LCL	95% UCL	Specificity	95% LCL	95% UCL	TP	FP	TN	FN
WMAS											
Before[c]	WMAS	0.83	0.75	0.90	0.98	0.96	0.99	91	13	503	18
After[d]	MATTS	0.89	0.80	0.95	0.95	0.95	0.96	73	1004	20,020	9
YAS											
Before[c]	YAS	0.87	0.78	0.93	0.95	0.92	0.97	78	26	460	12
After[d]	MATTS	0.84	0.73	0.92	0.92	0.91	0.92	54	1407	15,433	10

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

a Conveyance to a MTC with a pre-alert.
b MATTS reference standard.
c Case–cohort study data.
d Cohort study data.

TABLE 81 Theoretical sensitivity and specificity of triage tools[a] for major trauma[b] before and after implementation of the MATTS triage tool in WMAS and YAS (US consensus criteria for trauma centre need reference standard)

Study period	Triage tool	Sensitivity	95% LCL	95% UCL	Specificity	95% LCL	95% UCL	TP	FP	TN	FN
WMAS											
Before[c]	WMAS	0.82	0.73	0.90	0.87	0.84	0.90	75	62	425	16
After[c]	MATTS	0.73	0.62	0.82	0.92	0.91	0.93	60	148	1670	22
YAS											
Before[c]	YAS	0.62	0.51	0.72	0.86	0.83	0.89	52	62	383	32
After[c]	MATTS	0.86	0.75	0.93	0.94	0.92	0.95	55	115	1682	9

FN, false negative; FP, false positive; LCL, lower 95% confidence limit; TN, true negative; TP, true positive; UCL, upper 95% confidence limit.

a Objective evidence of positive triage tool variable in patient record; discretionary variables ignored.
b MATTS reference standard.
c Case–cohort study data.

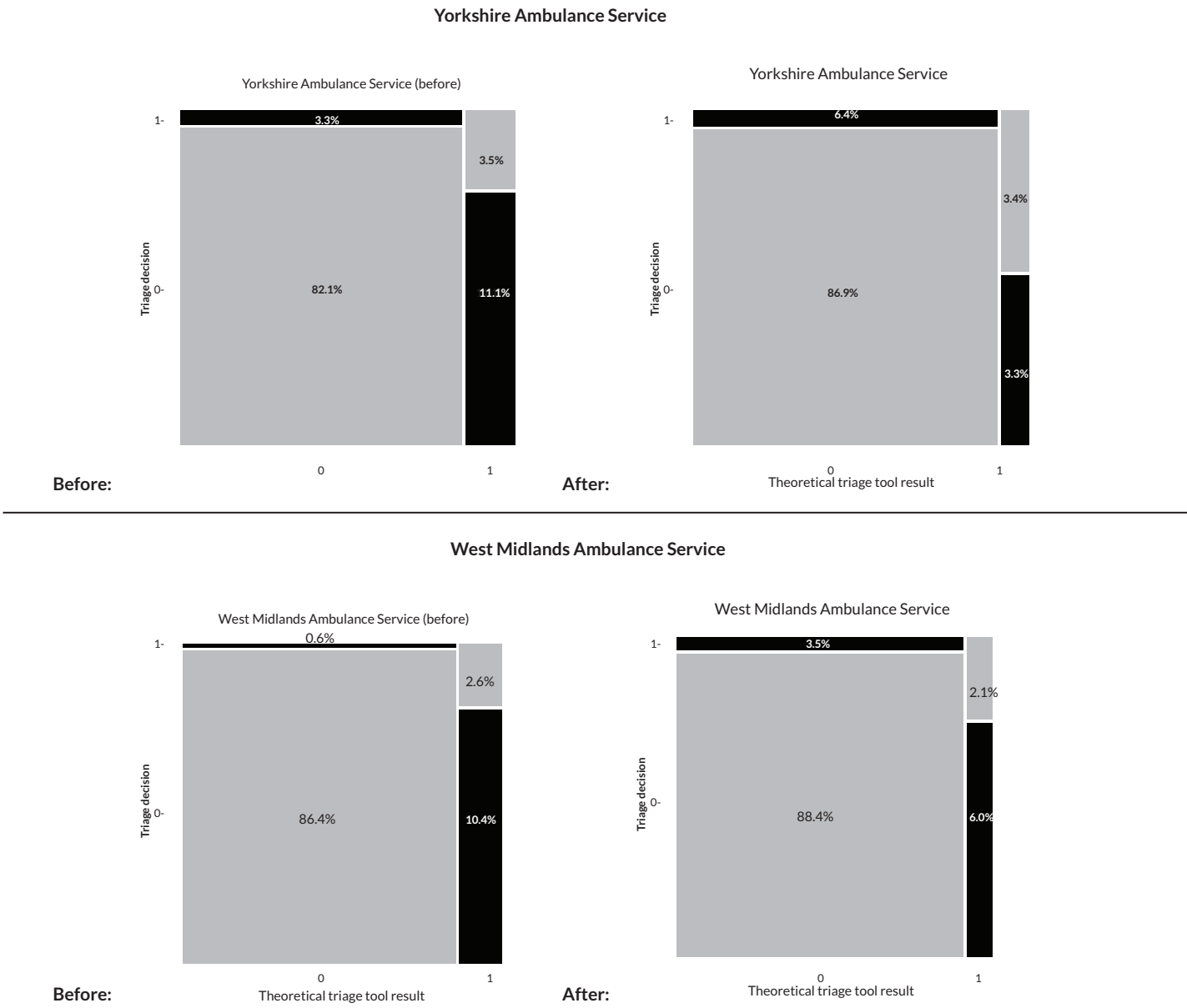


FIGURE 41 Agreement between theoretical triage tool result and actual triage decisions before and after implementation of the MATTS triage tool.

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TABLE 82 Risk-of-bias assessment for Phase 3 before-and-after study

Source of bias	Description	Evaluation	Risk of bias
Confounding	• Possibility of different case-mix across 'before' and 'after' time periods	• Similar patient characteristics in each study group. • Unlikely that case-mix and triage tool implementation are correlated.	Low to moderate
Selection bias	• Selection into 'before' or 'after' study group is associated with the triage tool used in that period. • Exclusion of individuals with missing information about intervention status or other variables such as confounders. • Selection bias arising from non-consecutive or non-random sampling • Selection bias arising from case-control design • Selection bias from inappropriate exclusions	• Different WI codes used in each period, although every effort made to ensure conformity. • Complete-case sample used for 'before' case–cohort sample. However, low levels of missing data < 5%, and results previously shown to be robust to selection bias. • Inclusion of consecutive eligible ambulance service patients • Single gate case–cohort design • Inclusion criteria targeting patients where triage tool would plausibly be used	Uncertain

Bias due to classification of interventions	• Misclassification of intervention status:
	  • Test review bias
	  • Information bias from conduct or interpretation of the index test
		• Objective determination of intervention status by location and date. Data coders blinded to reference standard status. Statistical coding of triage tools performed blinded to reference standard status, with quality control by independent statistician.
		• Triage tools evaluated using routinely collected ambulance service data, with possibility of erroneous, missing, or inaccurate data leading to index test misclassification.
			Low

Bias due to deviations from intended interventions	• Systematic differences between experimental intervention and comparator groups in the care provided, which represent a deviation from the intended interventions.	• Study aim was to evaluate ultimate triage decisions	Not applicable

Bias due to measurement of outcomes	• Differential or non-differential errors in measurement of outcome data:
	  • Reference standard misclassification
	  • Diagnostic review bias
	  • Incorporation bias
	  • Partial verification bias
	  • Differential verification bias
	  • Disease progression bias
		• Reference standard coded for TARN cases using routinely collected hospital data, with possibility of erroneous, missing, or inaccurate data. Possibility of non-identification of reference standard positive cases due to TARN inclusion criteria, for example penetrating trauma patient discharge < 72 hours. Possibility of non-enrolment/submission of reference standard positive cases to TARN, especially in TUs not paid for case submissions (mitigated by selection of high performing trauma networks). Possibility for reference standards including interventions (e.g. interventional radiology) that treatment was not received if patient was transported to a TU, rather than a MTC, due to lack of availability, rather than non-requirement. Partially mitigated by inclusion of 'hot' transfer to MTC within 6 hours of presentation as positive criterion in reference standard. Possibility of delayed enrolment/submission of reference standard positive cases to TARN due post-mortems (mitigated by final TARN data transfer 9 months after study inclusion dates) Inaccurate matching of TARN and ambulances service records. Very small proportion of reference standard positive cases not matched to a corresponding ambulance service record (< 5%). However, it is likely that these represent non-participating ambulance service cases. Also, there is a low probability that a genuinely unmatched ambulance service record would be randomly sampled as a 'non-case' (< 5%).
		• Reference standard coded independently by TARN without knowledge of index test status.
		• Reference standard classification independent of index test information
		• All patients had potential for TARN submission and reference standard coding, regardless of triage status.
		• Triage positive and negative patients received the same reference standard classification procedures
		• Reference standard classification performed from time of injury to defined time points
			Uncertain

Appendix 9 Phase 3 survey results

TABLE 83 Results of Phase 3 survey exploring stakeholder views on the newly implemented MATTS triage tool

	Ambulance clinicians[a] (%, *n*/*N*)	Trauma desk personnel (%, *n*/*N*)	Comments/themes
Tool use			
Seen new tool?	84% (166/197)	100% (15/15)	
Used new tool?	75% (110/147)	100% (15/15)	• Not used if obvious major trauma • Prefer to use own clinical judgement
How frequently use new tool?	Daily: 7% (10/147) Weekly: 26% (38/147) Monthly: 36% (53/147) < Monthly: 30% (44/147) Unsure: 1% (2/147)	Daily: 53% (8/15) Weekly: 47% (7/15)	
When used?	All injuries: 35% (48/139) Specific cases only: 65% (91/139)		• High-energy mechanisms of injury • Suspected major trauma • Borderline cases only • To update trauma desk • To justify pre-alert conveyance decisions • Elderly or children
Used in all cases where major trauma suspected?	Always: 48% (67/140) Usually: 46% (65/140) Occasionally: 3% (4/140) Rarely: 3% (4/140)	All cases: 100% (13/13)	
How tool is used?	Guideline: 66% (120/181) Protocol: 15% (28/181)	Guideline: 100% (12/12) Protocol: 0% (0/12)	• Used to support personal clinical judgement • MTCs use step 1 variables as protocol
Over-ruling positive triage tool triggers?	Yes: 61% (91/149) No: 39% (58/149)	Yes: 77%% (10/13) No: 23% (3/13)	• GCS if alcohol/drugs suspected • Clinical judgement that not major trauma • Elderly/frail patients
Triggered tool at step 3 in absence of other positive variables?	Frequently: 3% (3/88) Occasionally: 75% (66/88) Never: 22% (19/88)	Yes: 100% (13/13) No: 0% (0/13)	
Could anything be done to increase use of the tool?	Yes: 30% (68/227) No: 70% (159/227)	N/A	• Increased physical access to tool, for example cop yin access • EPR prompt • Increased advertising
Tool acceptability			
Easy to use?	Strongly agree: 34% (47/139) Agree: 53% (74/139) Neutral: 6% (9/139) Disagree: 2% (3/139) Strongly disagree: 4% (6/139)	Strongly agree: 54% (7/13) Agree: 46% (6/13)	
Supporting information is useful?	Strongly agree: 33% (46/139) Agree: 54% (75/139) Neutral: 7% (10/139) Disagree: 3% (4/139) Strongly disagree: 3% (4/139)	Strongly agree: 69% (9/13) Agree: 31% (4/13)	
Appearance is good?	Strongly agree: 30% (42/139) Agree: 55% (77/139) Neutral: 10% (14/139) Disagree: 3% (4/139) Strongly disagree: 1% (2/139)	Strongly agree: 54% (7/13) Agree: 46% (6/13)	

continued

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TABLE 83 Results of Phase 3 survey exploring stakeholder views on the newly implemented MATTS triage tool (*continued*)

	Ambulance clinicians[a] (%, *n*/*N*)	Trauma desk personnel (%, *n*/*N*)	Comments/themes
Makes speedy decisions?	Strongly agree: 25% (35/139) Agree: 48% (66/139) Neutral: 20% (28/139) Disagree: 5% (7/139) Strongly disagree: 2% (3/139)	Strongly agree: 39% (5/13) Agree: 54% (7/13) Neutral: 7% (1/13)	
Makes consistent decisions?	Strongly agree: 25% (34/139) Agree: 56% (78/139) Neutral: 13% (18/139) Disagree: 6% (8/139) Strongly disagree: 1% (1/139)	Strongly agree: 46% (6/13) Agree: 39% (5/13) Neutral: 7% (1/13) Disagree: 7% (1/13)	
Makes good decisions?	Strongly agree: 21% (29/139) Agree: 57% (79/139) Neutral: 19% (27/139) Disagree: 3% (3/139) Strongly disagree: 1% (1/139)	Strongly agree: 46% (6/13) Agree: 39% (5/13) Neutral: 15% (2/13)	
Tool exclusions			
Severe frailty	Strongly agree: 19% (32/173) Agree: 43% (74/173) Neutral: 23% (39/173) Disagree: 13% (23/173) Strongly disagree: 3% (5/173)	Strongly agree: 54% (7/13) Agree: 39% (5/13) Unsure: 7% (1/13)	
Advanced directives	Strongly agree: 30% (53/175) Agree: 42% (74/175) Neutral: 20% (35/175) Disagree: 6% (14/175) Strongly disagree: 1% (2/175)	Strongly agree: 54% (7/13) Agree: 31% (4/13) Disagree: 15% (2/13)	
Palliative care	Strongly agree: 39% (67/174) Agree: 36% (63/174) Neutral: 17% (29/174) Disagree: 8% (14/174) Strongly disagree: 1% (1/174)	Strongly agree: 62% (8/13) Agree: 23% (3/13) Disagree: 15% (2/13)	
Hangings/drownings	Strongly agree: 16% (27/172) Agree: 37% (64/172) Neutral: 24% (41/172) Disagree: 19% (33/139) Strongly disagree: 4% (7/139)	Strongly agree: 39% (5/13) Agree: 54% (7/13) Neutral: 7% (1/13)	• Drownings/hangings can rarely be associated with major trauma • Suspended vs. 'long drop' hangings
Tool variables			
Any variables that are poor predictors?	Yes: 12% (22/183) No: 88% (161/183)	Yes: 15% (2/13) No: 85% (11/13)	• Vital signs: respiratory rate, GCS (especially children and elderly)
Any missing variables?	Yes: 11% (21/183) No: 89% (162/183)	Yes: 0% (0/13) No: 100% (13/13)	• Abdominal injury
Step 3 is helpful?	Strongly agree: 33% (56/170) Agree: 58% (99/170) Neutral: 5% (9/170) Disagree: 1% (1/170) Unsure: 3% (5/170)	Strongly agree: 92% (11/12) Disagree: 8% (1/12)	• Clinical judgement is important/useful • Collaborative decision-making between trauma desk and on-scene crew
Senior support is helpful?	Strongly agree: 17% (29/170) Agree: 38% (65/170) Neutral: 22% (37/170) Disagree: 3% (5/170) Strongly disagree: 4% (7/170) Unsure: 16% (27/170)	N/A	

TABLE 83 Results of Phase 3 survey exploring stakeholder views on the newly implemented MATTS triage tool (*continued*)

	Ambulance clinicians[a] (%, *n*/*N*)	Trauma desk personnel (%, *n*/*N*)	Comments/themes
When is the trauma desk used?[b]	Unsure whether to use the tool: 12% (20/170) Tool is negative, clinical suspicion of major trauma: 67% (114/170) Tool is positive: 42% (72/170)	Unsure whether to use the tool: 62% (8/13) Tool is positive: 62% (8/13) Tool is negative, clinical suspicion of major trauma: 62% (8/13)	• Majority of pre-alerted patients • More WMAS ambulance clinicians would consult trauma desk if tool is positive, compared to YAS
Pre-alerts			
Who makes hospital pre-alerts?	Trauma desk: 59% (87/146) On scene clinician: 41% (59/146)	Trauma desk: 85% (11/13) On scene clinician: 15% (2/13)	• Trauma desk more common in WMAS, on-scene clinician in YAS
How are pre-alerts made?	Structured: 94% (145/154) Unstructured: 6% (9/154)	Structured: 100% (12/12) Unstructured: 0% (0/12)	• MTC interrupts structured handover • Varies across hospitals
Does the MTC ever decline pre-alerts?	Often: 3% (5/155) Occasionally: 25% (39/155) Rarely: 45% (70/155) Never: 26% (41/155)	Often: 8% (1/13) Occasionally: 31% (4/13) Rarely: 38% (5/13) Never: 15% (2/13) Unsure: 8% (1/13)	• Variable and dependent on consultant on duty in ED
TU pre-alerts?	Often: 22% (35/163) Occasionally: 49% (80/163) Rarely: 17% (28/163) Never: 8% (13/163) Unsure: 3% (5/163)	Often: 8% (1/13) Occasionally: 31% (4/13) Rarely: 38% (5/13) Never: 15% (2/13) Unsure: 8% (1/13)	• Silver trauma • Not major trauma but early assessment beneficial • TUs resistant to accepting trauma patients

N/A, not applicable.

a No systematic differences between WMAS and YAS responses, unless stated.
b More than one answer possible.

TABLE 84 Themes and illustrative quotes from Phase 3 focus groups exploring stakeholder views on the newly implemented MATTS triage tool

Theme	Issues	Illustrative responses
Awareness, availability and format	• Awareness of new tool • Format of tool	• *'. . . the research team are, you know, are very good at engaging with internal stakeholders so we knew something was coming and we had a lot of questions pushed out' [TD1: Trauma desk CCP].* • *'. . . for me the tool really helps in comparison to previous versions, the bit we've used, because of all the clarifications you've included in it. That for me has made it really useful and cut and dried for the most part' [PH 1: On-scene prehospital provider].*
Application	• When tool used • Barriers to use	• *'I just think with newly qualified paramedics, the tool is very useful for them to use because they haven't maybe seen so much trauma and use the tool and systematically go through it, would help' [PH 1: On-scene prehospital provider].* • *'I'd like to think I've got a good idea from what potentially looks like a major trauma to what is quite a minor trauma. [. . .]' [PH 2: On-scene prehospital provider].* • *'. . .when you're on a job and there's so much going on, sometimes, it's not that you forget something it's just a good prompt to look at something, look at obs and stuff' [PH 1: On-scene prehospital provider].* • *'I know our local A&E will often challenge crews in bringing trauma patients to the local A&E and so on. So a lot of paramedics will use it just to tick the box. . . .So, you don't get the flak from the nurses at handover' [PH 2: On-scene prehospital provider].* • *'. . . quite frankly I'm absolutely swimming in algorithms on my ambulance, which is partly why I probably don't use them as much as I should (laughs) . . . ' [on-scene prehospital provider].* • *'If someone's been there some time, they'll have their gut well-honed and perhaps won't want to use the tools. Rightly or wrongly' [PH2: On-scene prehospital provider].* • *'Because, our services are supremely stretched at the moment, we have only eight bays. So, in a way, I do look at it, so that I just want to understand whether the, the patient is suitable to come to us or whether a TU could receive the patient' [ED 1: MTC ED Physician].* •

continued

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TABLE 84 Themes and illustrative quotes from Phase 3 focus groups exploring stakeholder views on the newly implemented MATTS triage tool (*continued*)

Theme	Issues	Illustrative responses
Application	• When tool used • Barriers to use	• *'I just think with newly qualified paramedics, the tool is very useful for them to use because they haven't maybe seen so much trauma and use the tool and systematically go through it, would help' [PH 1: On-scene prehospital provider].* • *'I'd like to think I've got a good idea from what potentially looks like a major trauma to what is quite a minor trauma. [. . .]' [PH 2: On-scene prehospital provider].* • *'. . .when you're on a job and there's so much going on, sometimes, it's not that you forget something it's just a good prompt to look at something, look at obs and stuff' [PH 1: On-scene prehospital provider].* • *'I know our local A&E will often challenge crews in bringing trauma patients to the local A&E and so on. So a lot of paramedics will use it just to tick the box. . . .So, you don't get the flak from the nurses at handover' [PH 2: On-scene prehospital provider].* • *'. . . quite frankly I'm absolutely swimming in algorithms on my ambulance, which is partly why I probably don't use them as much as I should (laughs) . . . .' [on-scene prehospital provider].* • *'If someone's been there some time, they'll have their gut well-honed and perhaps won't want to use the tools. Rightly or wrongly' [PH2: On-scene prehospital provider].* • *'Because, our services are supremely stretched at the moment, we have only eight bays. So, in a way, I do look at it, so that I just want to understand whether the, the patient is suitable to come to us or whether a TU could receive the patient' [ED 1: MTC ED Physician].* • *'If you end up with an MTC person in a TU, then, personally I feel that they get a very raw deal. So I use it to make sure that we're making appropriate decisions to, to send someone to a TU, not an MTC' [ED 1: TU ED Physician].*
Clinical judgement and triage decision-making	• How tool is used • Impact of clinical judgement step 3	• *'Sometimes [. . .] the way the person's presenting isn't necessarily because of trauma. An elevated respiratory rate isn't necessarily because they've undergone trauma, it's because they're scared' [PH 1: On-scene prehospital provider].* • *'. . . with experience, twenty, thirty years, you go a lot with gut. We still use tools, but you go a lot with gut' [PH 1: On-scene prehospital provider].* • *'. . . my experience is very much that there is a gulf of care between trauma units and MTCs, you are not talking like anything like equivalency of care' [TD1: trauma desk personnel].* • *'. . . do you have the skillset or do you, you know, the ability to manage this patient for the time it takes them to the major trauma centre' [PH 1: on-scene prehospital provider].* • *'Sometimes [. . .] they just invoke step three, which is, if you're worried, take them to the major trauma centre and I think that's the current weakness of the tool' [ED 1: MTC ED Physician].*
Triage performance	• Overall triage performance with new MATTS tool • Changes in triage/ patient flow with new tool	• *'. . . we really can't have a system that is perfectly sensitive. We have to accept that some seriously injured patients are going to be taken to trauma units and then transferred on, otherwise we'll just break the [major] trauma centres, they'll be inundated' [ED 1: MTC ED Physician].* • *'. . . there isn't a lot of mechanism [in the new tool] whereas when you speak to the hospitals, when you hand over at hospitals, I feel like there is quite a lot of emphasis put on what the mechanism was. . .' [PH 1: On-scene prehospital provider].* • *'. . . what the old tools that we used were good for were saying these patients definitely need to go to a major trauma centre, this patient should probably go to the trauma unit, and this patient may go to the trauma unit but could go to the LEH [. . .] we have lost that little bit of nuance in the MATTs tool' [TD 1: Trauma desk CCP].*
Patient subgroups: elderly and children	• Tool use in patient subgroups • Tool performance in patient subgroups	• *'. . . It doesn't quite explain whether or not we should be trying to use it for paeds entirely or not I would say' [PH 2: On-scene prehospital provider].* • *'. . . the tool tells you to use paediatric reference values in JRCALC for assessing observations in paediatric patients, but the problem is that paediatric observation values in JRCALC are extraordinarily risk averse' [PH 1: On-scene prehospital provider].* • *'. . ., if they're admitted, and they don't need MTC level care, they're going to be admitted, they're going to spend potentially months in a trauma centre waiting to go, to be ready to go out into community rehab. So, it, it is important for the silver trauma that they only go to an MTC if they need the care that cannot be given at a TU' [ED 1:* MTC *ED Physician].* • *'. . . it's an elderly patient, and you think, my goodness, I know that I'm gonna put them through a trauma CT and it's highly likely they're gonna have multiple injuries and yet that doesn't, and there is no trigger for that' [ED 1: TU ED Physician].* • *'Obviously we should use it [silver trauma tool], but not everyone does, cos it's not in the trauma tool itself. Not everyone is aware of the silver trauma tool. Because it was brought in, and then it was late introduced a few years later, I believe' [PH 2: On-scene prehospital provider].*

TABLE 84 Themes and illustrative quotes from Phase 3 focus groups exploring stakeholder views on the newly implemented MATTS triage tool (*continued*)

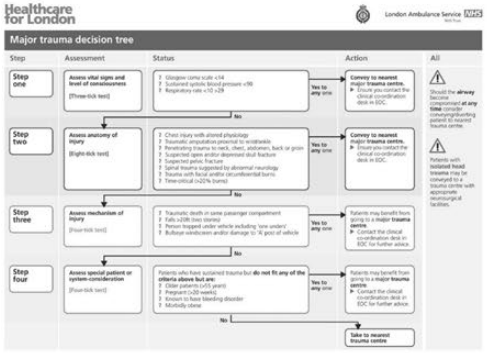
Theme	Issues	Illustrative responses
Trauma desk	• Interface with trauma desk • Effectiveness of trauma desk	• *'We're encouraged to ring the trauma desk; you'd probably get in trouble if you haven't and you've got quite a serious job and you haven't rung them' [PH2: on-scene prehospital provider (WMAS)].* • *'I personally feel if it's triggering steps one, two or three I don't really need any help from the trauma coordinator, I'm just going to drive them to where they need to be. Erm, maybe that's a bit naughty of me, but I find I use the trauma coordinator if I'm personally unsure' [PH 1: on-scene prehospital provider (YAS)].* • *'. . . . I'll phone the regional trauma desk and say, I think they trigger on step one or step two or step three. Um, what's the, what's the rationale for sending them to us and not to the MTC? [. . .]' [ED 1: TU ED physician (WMAS region)].* • *'A lot of the time they do want to know far more about the job than perhaps they need to know and you're there trying to deal with someone who is perhaps in peri-arrest and you just need to get back to the patient. . .' [PH 2: On-scene prehospital provider (YAS)].* • *". . . it's very hard to quantify, but you can often quickly get a feel for how much of a grip that crew have on the scene, how well they've assessed the patient, you know, and how confident they are in that assessment' [TD 1: trauma desk personnel].*
Pre-alerts	• Prehospital–emergency department interface • Pre-alert processes	• *'. . . they are very quick to push back and question the decision and say "why is this coming here?", and a lot of our time is saying because that is the tool, this is the framework we make decisions on, we're not just sitting here making an opinion, a guessed opinion' [PH 2: On-scene prehospital provider].* • *'. . . you can actually go through it and say, look, I don't think you meet, you know, step one, step two, step three on that basis, tell me if I'm missing anything. [. . .]' [ED 1: MTC ED Physician].*

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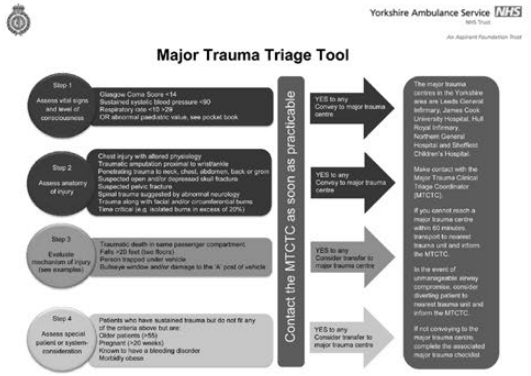
Appendix 10 Phase 3 economic evaluation supplementary information

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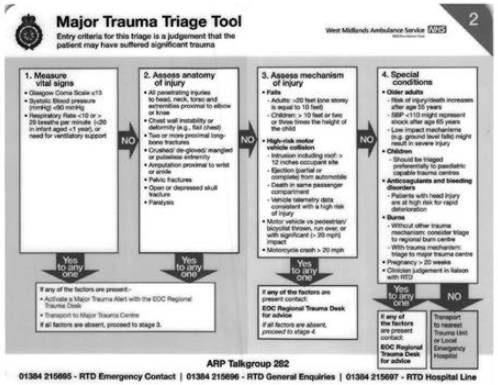
London Ambulance Service (LAS – pre-2020)



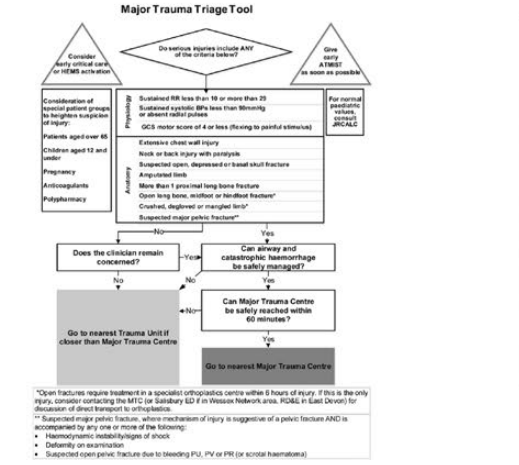
Yorkshire Ambulance Service (YAS – pre-2020)



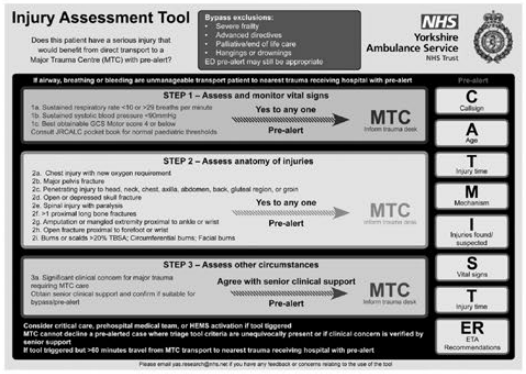
West Midlands Ambulance Service (WMAS – pre-2020)



South Western Ambulance Service (SWAS – pre-2020)



Yorkshire Ambulance Service (YAS – MATTS)



West Midlands Ambulance Service (WMAS – MATTS)

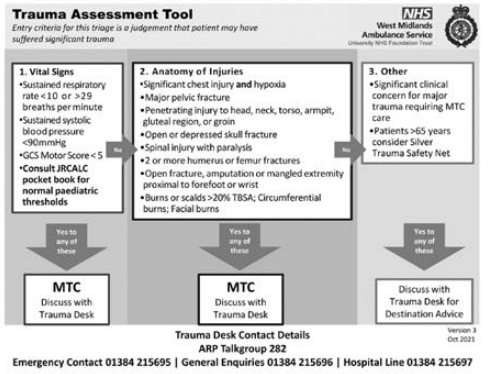


FIGURE 42 Triage tools used by ambulance services during each study period.

TABLE 85 Comparators included in the Phase 3 economic evaluation primary and secondary analyses

Comparators	Triage tool used	Relative accuracy of triage tool	Sensitivity of triage decisions, age 16–64, mean (95% CI)	Specificity of triage decisions, age 16–64, mean (95% CI)	Sensitivity of triage decisions, age ≥ 65 years, mean (95% CI)	Specificity of triage decisions, age ≥ 65 years, mean (95% CI)
Primary analysis – actual triage decisions in terms of hospital destination						
LAS (pre-2020)[a]	LAS (pre-2020)	More sensitive	75.0% (65.8% to 83.8%)	84.0% (79.1% to 88.3%)	37.7% (28.3% to 47.1%)	93.8% (90.3% to 96.9%)
WMAS (pre-MATTS)[a]	WMAS (pre-MATTS)	More sensitive	63.5% (55.9% to 71.2%)	96.0% (93.3% to 98.5%)	24.2% (17.8% to 30.9%)	99.3% (98.1% to 100.0%)
SWAS (pre-2020)[a]	SWAS (pre-2020)	More specific	40.8% (31.9% to 50.0%)	95.8% (92.5% to 98.7%)	16.5% (10.8% to 22.3%)	99.3% (98.2% to 100.0%)
YAS (pre-MATTS)[a]	YAS (pre-MATTS)	More sensitive	77.1% (66.7% to 87.0%)	89.0% (83.2% to 94.1%)	32.2% (24.0% to 40.6%)	96.3% (93.9% to 98.2%)
WMAS (post-MATTS)[b]	MATTS tool	More specific	65.6% (55.3% to 75.6%)	95.4% (94.8% to 96.0%)	28.9% (20.8% to 37.1%)	98.1% (97.8% to 98.4%)
YAS (post-MATTS)[b]	MATTS tool	More specific	63.6% (54.1% to 72.7%)	88.7% (87.6% to 89.8%)	21.7% (15.3% to 28.6%)	95.2% (94.6% to 95.8%)
Secondary analysis – theoretical triage tool performance in terms of observed data, regardless of hospital destination						
LAS (pre-2020)[a]	LAS (pre-2020)	More sensitive	66.8% (62.1% to 71.4%)	83.3% (80.0% to 86.5%)	43.0% (37.5% to 48.0%)	88.2% (86.0% to 90.2%)
WMAS (pre-MATTS)[a]	WMAS (pre-MATTS)	More sensitive	58.2% (53.1% to 63.1%)	86.2% (83.1% to 89.0%)	34.8% (29.7% to 39.8%)	89.7% (87.6% to 91.6%)
SWAS (pre-2020)[a]	SWAS (pre-2020)	More specific	42.6% (37.8% to 47.6%)	93.8% (91.8% to 95.8%)	23.6% (19.1% to 27.9%)	95.8% (94.4% to 97.1%)
YAS (pre-MATTS)[a]	YAS (Pre-MATTS)	More sensitive	59.2% (54.5% to 64.0%)	83.3% (80.0% to 86.5%)	41.3% (36.1% to 46.4%)	88.2% (86.0% to 90.2%)
MATTS tool[a]	MATTS tool	More specific	49.0% (44.0% to 53.8%)	92.9% (90.7% to 95.0%)	26.1% (21.5% to 30.4%)	96.7% (95.6% to 97.8%)

a Data from MATTS Phase 2 case–cohort study.
b Data from MATTS Phase 3 cohort study.

Note
All data are for patient injured within the catchment area of a non-MTC. Sensitivity and specificity are defined in terms of hospital destination MTC versus non-MTC.

TABLE 86 Summary of parameters and data sources used in Phase 3 model

Parameter	Value	Source
Clinical parameters		
Probability of patients having a transfer from a local hospital to a MTC if		
They were a true positive	0%	Haslam *et al.*[222]
They were a false negative	36.3%	
They were a true negative	0%	

TABLE 86 Summary of parameters and data sources used in Phase 3 model (*continued*)

Parameter	Value	Source
They were a false positive	0%	
Probability of death within 30 days	Risk equation	(Trauma Audit and Research Network, personal communication)
Major trauma centre effectiveness and short-term outcomes (age under 65)		
Relative risk of death within 30 days of hospitalisation for patients with an ISS ≥ 16 who were treated at a local hospital	1.25	Newgard *et al.*[91]
Relative risk of death within 30 days of hospitalisation for patients with an ISS < 16 who were treated at a local hospital	1	Assumption
Probability of death between 30 days post-injury and 1 year post injury for patients with an ISS ≥ 16	3.6%	Mackenzie *et al.*[26]
Relative risk of death between 30 days and 1 year post hospitalisation for patients with an ISS ≥ 16 who were treated at an local hospital	1.64	
Probability of death between 30 days post injury and 1-year post-injury for patients with an ISS < 16	1.7%	Davidson *et al.*[120]
Major trauma centre effectiveness and short-term outcomes (age 65+)		
Relative risk of death within 30 days of hospitalisation for patients with an ISS ≥ 16 who were treated at a local hospital (65–74)	1.078	Maughan *et al.*[45]
Relative risk of death within 30 days of hospitalisation for patients with an ISS ≥ 16 who were treated at a local hospital (65–84)	1.041	
Relative risk of death within 30 days of hospitalisation for patients with an ISS ≥ 16 who were treated at a local hospital (85+)	1.037	
Probability of death between 30 days post injury and 1 year post injury for patients with an ISS ≥ 16 (65–74)	19.6%	
Probability of death between 30 days post injury and 1 year post injury for patients with an ISS ≥ 16 (75–84)	25.3%	
Probability of death between 30 days post injury and 1 year post injury for patients with an ISS ≥ 16 (85+)	42.8%	
Relative risk of death between 30 days and 1 year post hospitalisation for patients with an ISS ≥ 16 who were treated at a local hospital	1.025	
Probability of death between 30 days post injury and 1 year post injury for patients with an ISS < 16 (65–74)	12.0%	
Probability of death between 30 days post injury and 1 year post injury for patients with an ISS < 16 (75–84)	15.6%	
Probability of death between 30 days post injury and 1 year post injury for patients with an ISS < 16 (85+)	26.1%	
Long term outcomes		
Probability of death after 1 year	Age and gender dependent	Office of National Statistics[223]
Hazard ratio for the risk of death following major trauma: ISS < 16, age < 65	1.38	Newgard *et al.*[44]
Hazard ratio for the risk of death following major trauma: ISS ≥ 16, Age < 65	5.19	Cameron *et al.*[128]
Hazard ratio for the risk of death following major trauma: ISS < 16, age ≥ 65	1.025	Maughan *et al.*[45]
Hazard ratio for the risk of death following major trauma: ISS ≥ 16, age ≥ 65	1.025	Maughan *et al.*[45]
Utility parameters		

continued

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TABLE 86 Summary of parameters and data sources used in Phase 3 model (*continued*)

Parameter	Value	Source
Utilities for injured patients		
ISS between 1 and 3 – preinjury	0.86	Kruithof *et al.*[224]
ISS between 1 and 3 – 1 week post injury	0.63	
ISS between 1 and 3 – 1 month post injury	0.69	
ISS between 1 and 3 – 3 months post injury	0.78	
ISS between 1 and 3 – 6 months post injury	0.79	
ISS between 1 and 3 – 12 months post injury	0.79	
ISS between 1 and 3 – 24 months post injury	0.81	
ISS between 4 and 8 – preinjury	0.89	
ISS between 4 and 8 – 1 week post injury	0.46	
ISS between 4 and 8 – 1 month post injury	0.56	
ISS between 4 and 8 – 3 months post injury	0.71	
ISS between 4 and 8 – 6 months post injury	0.77	
ISS between 4 and 8 – 12 months post injury	0.8	
ISS between 4 and 8 – 24 months post injury	0.81	
ISS between 9 and 15 – preinjury	0.8	
ISS between 9 and 15 – 1 week post injury	0.43	
ISS between 9 and 15 – 1 month post injury	0.5	
ISS between 9 and 15 – 3 months post injury	0.63	
ISS between 9 and 15 – 6 months post injury	0.68	
ISS between 9 and 15 – 12 months post injury	0.7	
ISS between 9 and 15 – 24 months post injury	0.72	
ISS 15+ – preinjury	0.9	
ISS 15+ – 1 week post injury	0.37	
ISS 15+ – 1 month post injury	0.5	
ISS 15+ – 3 months post injury	0.65	
ISS 15+ – 6 months post injury	0.74	
ISS 15+ – 12 months post injury	0.77	
ISS 15+ – 24 months post injury	0.77	
General population utility		
Constant	0.9508566	Ara and Brazier[124]
Age	−0.0002587	
Age squared	−0.0000332	
Male (1 = male, 0 = otherwise)	0.0212126	

TABLE 86 Summary of parameters and data sources used in Phase 3 model (*continued*)

Parameter	Value	Source
Cost parameters		
Admission costs – base case		NHS reference costs[125]
Transfers between local hospitals and MTCs	£252	
MTC admission if ISS is 16 or over	£2819	
MTC admission if ISS is < 16 and over 8	£1466	
Treatment of a patient with blunt trauma and an ISS in the range of		
ISS ≤ 9	£9162	Christensen *et al.*[126]
9 < ISS ≤ 16	£13,288	
16 < ISS ≤ 25	£20,999	
ISS > 25	£31,300	
Treatment of a patient with penetrating trauma and an ISS in the range of		
ISS ≤ 9	£9610	Christensen *et al.*[127]
9 < ISS ≤ 15	£8921	
15 < ISS ≤ 24	£13,974	
24 < ISS ≤ 34	£18,252	
ISS > 34	£24,300	
Post discharge costs		
Cost between discharge and 6 months post treatment	£1944	Nichol[225,226]
Relative increase in lifetime treatment costs for patients with an ISS ≥ 16 compared to the general population	1.45	Cameron *et al.*[128] Delgado *et al.*[129]
Relative increase in lifetime treatment costs for patients with an ISS < 16 compared to the general population	1.25	Cameron *et al.*[128] Delgado *et al.*[129]
Yearly costs of NHS treatment	Age and gender dependent	Asaria *et al.*[130]

Note
Distributions and the standard errors around each parameter are provided in the data inputs sheet in the open-source model.

TABLE 87 Details of Phase 3 scenario analyses (all analysed probabilistically)

Scenario analysis	Parameter values	Parameter source	Rationale
YAS strategies removed	N/A	N/A	YAS Phase 3 triage appears to have lower sensitivity and specificity than WMAS
Ahmed *et al.* utility values	Utility for: ISS ≥ 16 = 0.65 ISS < 16 = 0.65	Ahmed *et al.*[123]	UK-based utility values
Same MTC benefits for elderly as adults	Assumption	Assumption	Uncertainty around MTC effectiveness determined by observational studies
TARN 2006 survival equation		Bouamra *et al.* 2006[117]	To allow comparison with previously published UK economic model
MTCs have 25–75% benefit for ISS in the range 16 > ISS ≥ 9	Assumption	Assumption	Uncertainty around MTC effectiveness determined by observational studies

N/A, not applicable.

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TABLE 88 A summary of scenario analysis results examining actual triage decisions in terms of hospital destination

Scenario	Cost-effective tool at £20,000 per QALY gained	Cost-effective tool at £30,000 per QALY gained
Base case		
Base case	SWAS (pre-2020)	YAS (pre-MATTS)
Scenario analyses		
YAS strategies removed	SWAS (pre-2020)	WMAS (pre-MATTS)
Ahmed *et al.* utility values[123]	SWAS (pre-2020)	YAS (pre-MATTS)
Same MTC benefits for elderly as adults	SWAS (pre-2020)	YAS (pre-MATTS)
TARN 2006 survival equation[117]	SWAS (pre-2020)	YAS (pre-MATTS)
MTC benefit for people with and ISS in the range 16 > ISS ≥ 9		
MTCs have 25% benefit	SWAS (pre-2020)	YAS (pre-2020)
MTCs have 50% benefit	SWAS (pre-2020)	LAS (pre-2020)
MTCs have 75% benefit	LAS (pre-2020)	LAS (pre-2020)

TABLE 89 The expected value of perfect information and expected value of perfect parameter information at a MAICER of £20,000 per QALY gained

Parameters	Per person EVPI/EVPPI	Approximate standard error	Indexed to overall EVPI	EVPI/EVPPI over 10 years
Overall EVPI				
All parameters	£5.21	N/A	100.0%	£1,041,122
EVPPI				
Probability that patients go to a MTC (triage tool sensitivity and specificity and probability of being transferred if a false negative)	£2.24	0.19	43.1%	£448,918
All parameters that determine the probability of death	£3.54	0.16	68.1%	£708,883
Parameters that are estimates of the effectiveness of MTCs at preventing death	£2.71	0.21	52.1%	£542,958
Utilities	£2.41	0.17	46.3%	£482,205
Costs	£2.09	0.21	40.2%%	£418,798

N/A, not applicable.

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