Major Incident Triage: development and validation of a modified primary triage tool

By

James M A Vassallo

MBBS, LCGI

Student number: VSSJAM002

Thesis presented for the degree of:
DOCTOR OF PHILOSOPHY (EMERGENCY MEDICINE) in the
Faculty of Health Sciences at the University of Cape Town

Supervisors: Prof Jason E Smith, Prof Lee A Wallis

February 2018

Table of Contents

Acknowledgements

For my wife and best friend, Vicki, thank you for your constant support, patience and encouragement. Without you I simply couldn't have done this.

To both Jason Smith and Lee Wallis, thank you for your belief in me and for all the guidance you have both given me over the past six years. This has led me to develop my passion in academic Emergency Medicine, to pursue and develop this project and ultimately to produce this thesis.

Thank you to all others for their support: Fiona Lecky, Omar Bouamra and Antoinette Edwards at TARN, John Beavis at the University of Bournemouth, Joanne Thomson and the team at the Defence Library, Ed Barnard, Royal Navy and lastly, Stevan Bruijns.

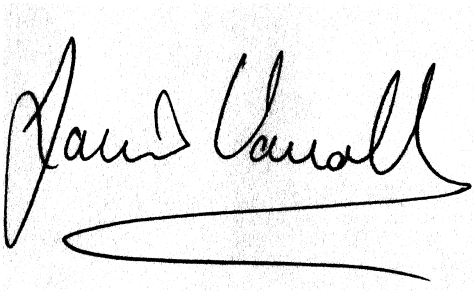
Signed by candidate

13th February 2018

Declaration

I, James Vassallo, hereby declare that the work on which this thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university. I authorise the University to reproduce for the purpose of research either the whole or any portion of the contents in any manner whatsoever. I further declare the following:

1. I know that plagiarism is a serious form of academic dishonesty.
2. I have read the document about avoiding plagiarism, am familiar with its contents and have avoided all forms of plagiarism mentioned there.
3. Where I have used the words of others, I have indicated this by the use of quotation marks.
4. I have referenced all quotations and properly acknowledged other ideas borrowed from others.
5. I have not and shall not allow others to plagiarise my work.
6. I declare that this is my own work.



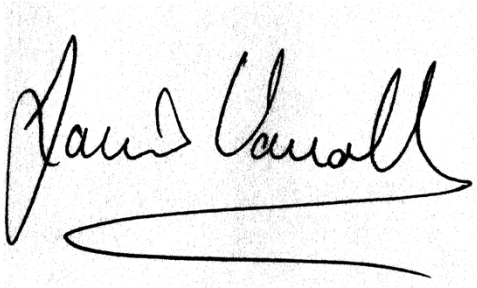
Signature: **Date: 13th February 2018**

Approval for inclusion of publications in thesis

I confirm that I have been granted permission by the University of Cape Town's Doctoral Degrees Board to include the following publications in my PhD thesis, and where co-authorships are involved, my co-authors have agreed that I may include the publications:

1. Investigating the effects of under-triage by existing major incident triage tools. **Vassallo J,** Smith JE, Wallis LA. Eur J Emerg Med 2017 doi: 10.1097/MEJ.0000000000000513.
2. Major incident triage and the implementation of a new triage tool, the MPTT-24. **Vassallo J,** Smith JE, Wallis LA. J R Army Med Corp*s*. 2017. doi: 10.1136/jramc-2017-000819.
3. The civilian validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to primary major incident triage. **Vassallo J,** Smith JE, Bouamra O, Lecky F, Wallis LA. Emerg Med J. 2017 Dec;34(12):810-815.
4. The prospective validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to major incident triage. **Vassallo J**, Horne S, Smith JE, Wallis LA. J R Army Med Corps. 2017 Dec; 163(6):383-387.
5. Major incident triage: derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT). **Vassallo J,** Beavis J, Smith JE, Wallis LA. Injury. 2017 May;48(5):992-999
6. Major incident triage: a consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident. **Vassallo J**, Smith JE, Bruijns SR, Wallis LA. Injury. 2016 Sep; 47(9):1898-1902

Name: Dr James Vassallo
Student number: VSSJAM002
Signature:



Date: 13th February 2018

ABSTRACT

Introduction

A key principle in the effective management of a major incident is triage, prioritising patients on the basis of their clinical acuity. However, existing methods of primary major incident triage demonstrate poor performance at identifying the Priority One patient in need of a life-saving intervention. The aim of this thesis was to derive an improved triage tool.

Methods

The first part of the thesis defined what constitutes a life-saving intervention. Then using a retrospective military cohort, the optimum physiological thresholds for identifying the need for life-saving intervention were determined; the combination of which was used to define the Modified Physiological Triage Tool (MPTT). The MPTT was validated using a large civilian trauma database and a prospective military cohort. Subsequently, to describe the safety profile of the MPTT, an analysis of the implications of under-triage was undertaken. Finally, pragmatic changes were made to the MPTT (MPTT-24) - in order to provide a more useable method of primary triage. Statistical analysis was conducted using sensitivities and specificities, with triage tool performance compared using a McNemar test.

Results

32 interventions were considered life-saving and the optimum physiological thresholds to identify these were a GCS <14,12< RR $\leq$22 and a HR>100. Within both the military and civilian populations, the MPTT outperformed all existing methods of triage with the greatest sensitivity and lowest rates of under-triage, but at the expense of over-triage. Applying pragmatic changes, the MPTT-24 had comparable performance to the MPTT and continued to outperform existing methods.

Conclusion

The priority of primary major incident triage is to identify patients in need of life-saving intervention and to minimise under-triage. Fulfilling these priorities, the MPTT-24 outperforms existing methods of triage and its use is recommended as an alternative to existing methods of primary major incident triage. The MPTT-24 also offers a theoretical reduction in time required to triage and uses a simplified conscious level assessment, thus allowing it to be used by less experienced providers.

List of tables

List of figures

List of abbreviations

ALS/ACLS	Advanced Life Support/Advanced Cardiac Life Support
AIS	Abbreviated Injury Scale
ASAV	Amberg-Schwandorf-Algorithmus
ATLS	Advanced Trauma Life Support
AUROC	Area under receiver operator characteristic
AVPU	Alert, responds to Voice, responds to Pain, Unconscious
BPM	Breaths/Beats per minute
CCS	Casualty clearing station
CPR	Cardiopulmonary resuscitation
DMS	Defence Medical Services
ED	Emergency Department
EMS	Emergency Medical Services
GCS	Glasgow Coma Scale
HR	Heart rate
IQR	Interquartile range
JTTR	Joint Theatre Trauma Registry
ISS	Injury Severity Score
MIMMS	Major Incident Medical Management and Support
MPTT	Modified Physiological Triage Tool
MPTT-24	Modified Physiological Triage Tool-24
NARU	National Ambulance Resilience Unit
NHS	National Health Service
NPA	Nasopharyngeal airway
NPV	Negative predictive value
OPA	Oropharyngeal airway
PPV	Positive predictive value
PRIOR	Primary Ranking for Initial Orientation in Emergency Medical Services
RCDM	Royal Centre for Defence Medicine
RR	Respiratory rate
SALT	Sort, Assess, Life-saving intervention, Treatment and Transport
SBP	Systolic blood pressure
START	Simple Triage And Rapid Treatment
STM	Sacco triage method
TARN	Trauma Audit and Research Network
UK	United Kingdom
USA	United States of America

Chapter 1: Introduction

Major incidents are common and are brought to our attention through 24-hour media. In 2017, there were five major incidents, resulting in approximately 120 deaths, with a further 400 injured.[1,2] Despite occurring regularly for many years, it was only following the 1991 bombing of a British Army medical facility that the reflection of two British emergency physicians led to the development of the Major Incident Medical Management and Support (MIMMS) course.[3] Defining a major incident as one "*where the location, number, severity, or type of live casualties requires extraordinary resources",* the MIMMS course teaches a series of key management principles designed to assist providers in the effective management of the incident **(Figure 1)**.

1) **Command**
2) **Safety**
3) **Communications**
4) **Assessment**
5) **Triage**
6) **Treatment**
7) **Transport**

Figure 1.1: Principles of major incident response.[3]

Despite the adoption of MIMMS in over 30 countries, in many locations there has been no standardised or integrated approach to their management.[4] Indeed, a standard understanding as to what constitutes a major incident has not been agreed, with the term frequently being used interchangeably with *mass casualty incident.*[5,6]

However they are defined, triage is the first of the medical principles involved with the major incident response. As a concept, triage has its origins firmly rooted in military medicine. Napoleon's surgeon, Larrey, is frequently credited as being the founding father of triage as we know it today; describing the process in 1792 he stated that "*those who are dangerously wounded should receive the first attention, without regard to rank or distinction".*[7,8] But it was Wilson, a Royal Naval Surgeon, who in 1846 formally described categorising patients on the basis of their injuries, be them 'slight', 'serious' or 'fatal'.[9,10]

There are a number of methods of major incident triage in use worldwide; each of these methods or triage tools uses an assessment of the patient's physiological status in order to determine their acuity or severity. Unlike Australia and America, where there is a single triage process (using the Careflight and Simple Triage and Rapid Treatment (START) algorithms respectively),[11,12] in the United Kingdom (UK), major incident triage is conducted using a two-stage process, with an initial rapid primary assessment (MIMMS Triage Sieve) followed by a more detailed secondary assessment (Triage Sort).[3] Each of these triage tools allocate living patients to one of three categories corresponding to their clinical severity (Priority One/Immediate, Priority

Two/Urgent, Priority Three/Delayed). Major incident triage is a dynamic process, designed to be repeated several times in the patient's journey from point of injury through to treatment in hospital. This repetition means that if a patient deteriorates, this can be detected and the triage category can be changed.[3,13] In certain circumstances, a fourth category (Priority Four/Expectant) may be used, although this requires authorisation by senior medical commanders. This Priority Four category is usually reserved for patients with such severe injuries that even with intensive treatment they are unlikely to survive and whose treatment would divert from potentially salvageable patients.[3]

The Priority One patient is defined in the MIMMS course as a patient who requires an immediate life-saving intervention.[3] Within the major incident setting where healthcare resources are overwhelmed, the purpose of the triage process must be to identify those patients in need of life-saving interventions, i.e. the Priority One patients. A successful triage tool is one which is able to accurately identify not only those patients genuinely in need of a life-saving intervention, but also those not in need of one. If triage tools are treated as diagnostic tests, a successful triage tool would have optimum sensitivity and specificity. Despite being in use for decades, the triage tools most commonly used lack an evidence-base with questions raised about their reliability.[14] Studies looking at the performance of these triage tools have previously demonstrated limited ability to identify those patients in need of life-saving intervention, with sensitivity as low as 50%.[12,15]

There is limited guidance describing how accurate the triage process should be at a major incident; the American College of Surgeons choose to assess triage tool performance in terms of rates of under-triage (misclassifying patients as not needing a life-saving intervention) and over-triage (misclassifying patients as needing a life-saving intervention). In the major incident setting, the American College of Surgeons simply state that both under and over-triage should be kept to a minimum.[16] By contrast, for field triage, the process of identifying the individual trauma patient who requires treatment at a major trauma centre, they specify that under and over-triage should be kept to a maximum of 5% and 35% respectively.[16] In common with major incident triage, the field triage process assesses the patient's current physiological instability, but also includes an assessment of anatomical injury and injury mechanism. With the field triage process being a more exhaustive assessment, it is logical that the performance of major incident triage tools, assessing physiology alone, will be lower.

Despite numerous calls to develop an evidence-based approach to triage, the unexpected nature of major incidents makes research in this area difficult. As a result, we frequently turn to either the retrospective analysis of major incidents[15,17] or studies using trauma registries as a surrogate for the major incident population.[12,18] With only three adult prospective studies using consecutive trauma patients,[19-21] researchers often look to alternative means, such as simulation or major incident exercises in an attempt to validate triage tools.[22,23] With limited evidence to support the use of the primary triage tool, the MIMMS Triage Sieve, and with studies demonstrating poor performance at identifying Priority One patients, this programme of work

sought to identify whether changes could be made to the MIMMS Triage Sieve in order to improve its performance.

Research Questions

Can modifications to the MIMMS Triage Sieve increase its test characteristics significantly and safely?

If an improvement can be made, how does the modified tool perform in relation to existing major incident triage tools?

Aim

The aim of this thesis was to derive and validate a primary physiological triage tool for use in the major incident setting.

Objectives

1. Determine the life-saving interventions that define the Priority One patient.
2. Identify the optimum physiological thresholds that predict the need for life-saving intervention and derive a new physiological triage tool.
3. Determine the performance of the new physiological triage tool when compared to existing methods of primary major incident triage.
4. Validate the new physiological triage tool.
5. Describe the implications of mis-triage.
6. Consider pragmatic changes to the new physiological triage tool in order to improve its applicability as a primary major incident triage tool.

Ethical clearance

The study received ethical approval from the Human Research Ethics Committee of the University of Cape Town (reference 285/2013). Additionally, it was registered as a service improvement project with the Royal Centre for Defence Medicine (RCDM) (project number RCDM/Res/Audit/1036/12/0050).

Reporting structure

Each of the six objectives were investigated as individual studies and are presented in the following chapters. Each chapter contains a peer-reviewed publication, reporting the methodology and findings from the individual studies. Where applicable, supplementary methods, results and limitations are discussed using unpublished material relating to the individual study. Chapter 8 is the final chapter of this thesis, linking the findings from all of the related work strands, and drawing together conclusions and recommendations for implementation and further work.

Literature review

EMBASE *Ovid* and MEDLINE *Ovid* were searched for the period 1974-2017 using the following search strategy.

Triage [AND] Major incident*

Triage [AND] Multiple casualt*

Triage [AND] Mass casualt*

Triage [AND] Disaster

Triage [AND] Sieve

Triage [AND] Sort

Triage [AND] Careflight

Triage [AND] START

Non-English studies and those studies without an abstract were removed. Following removal of duplicates, the output of the search strategy was interrogated by title to identify potential relevant studies by the author. Studies focussing on routine triage of patients within the ED were removed. In addition, papers relating to the paediatric population and Chemical, Biological, Radiological or Nuclear triage were removed. The results of the search strategy are demonstrated in **Figure 1.2.**

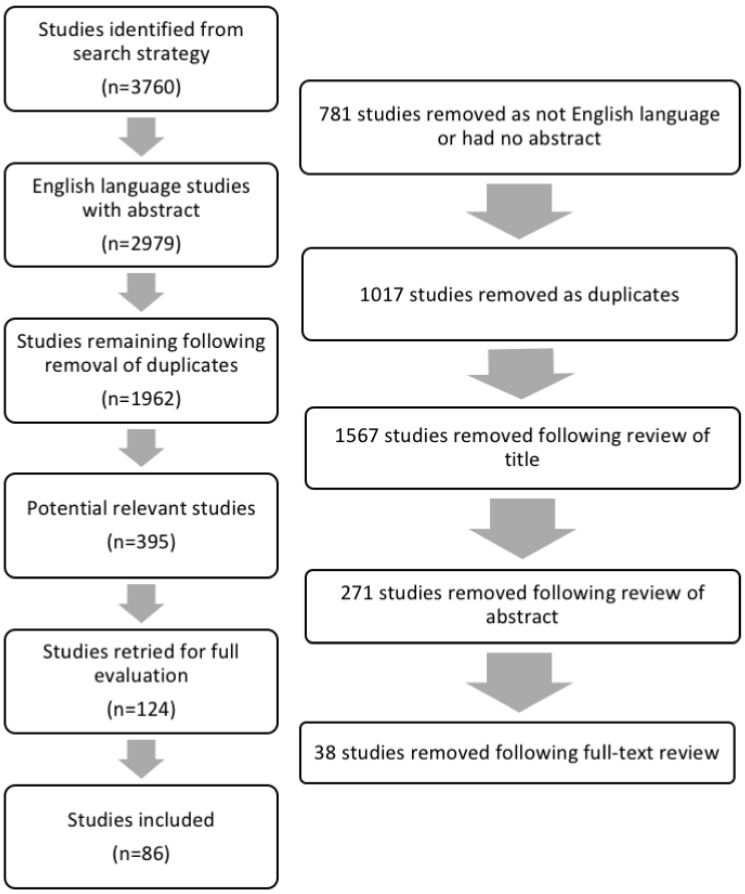


Figure 1.2: Results of search strategy.

Pre-hospital and Emergency Department triage

Stemming from the French verb *trier,* meaning *to sort*, triage is the process of prioritising patients on the basis of their clinical acuity.[24] Within the UK, like many other countries, triage is performed routinely on a daily basis in both the pre-hospital and the Emergency Department (ED) environments. In the ED, triage methods such as the Manchester Triage System and the Canadian Triage and Acuity Scale are used to assess the patient's clinical condition and review their presenting complaint in order to determine the priority in which they need to be seen by a clinician.[25-27]

In the pre-hospital setting, triage typically determines the priority of the individual trauma patient and their requirement for treatment at a major trauma centre. As the organisation of trauma services has developed, so too has the process of field triage. In 1971, Kirkpatrick and Youmans developed the Triage Index, a simple assessment of anatomical injury and physiological instability used to determine which patients needed to be transported to hospital.[28] This was later refined with the Revised Trauma Score, which remains the physiological assessment in the Field Triage Decision Scheme (**Figure 1.3)**, employed by Emergency Medical Services (EMS) in the United States of America (USA).[16,28,29]

The major trauma patient is frequently defined as one with an Injury Severity Score (ISS) >15. Field triage processes such as the Field Triage Decision Scheme are therefore frequently validated against the ISS or mortality, with successful triage being defined as patients with an ISS >15 being treated at a major trauma centre.[30,31] Whilst there is clear evidence to support this, it is not without limitation. The ISS is a retrospective measurement which can only be applied once the full extent of the patient's injuries are known and this is not possible in the pre-hospital environment.[15] Secondly, the ISS correlates poorly with the resource-based requirements of the trauma patient (or the need for a life-saving intervention). As the purpose of field triage is to identify those patients who require the resources of a major trauma centre the ISS represents a flawed metric with which to validate field triage algorithms.[32,33]

Mortality is a simple metric to objectively measure and quantify. However, its prevalence following trauma is relatively low, making it an inappropriate measure with which to determine requirement for treatment at a major trauma centre.[30] Although the physiological component of the Field Triage Decision Scheme (the Revised Trauma Score) has been shown to accurately predict mortality, it too has demonstrated limited ability at identifying the need for life-saving intervention.[29,34]

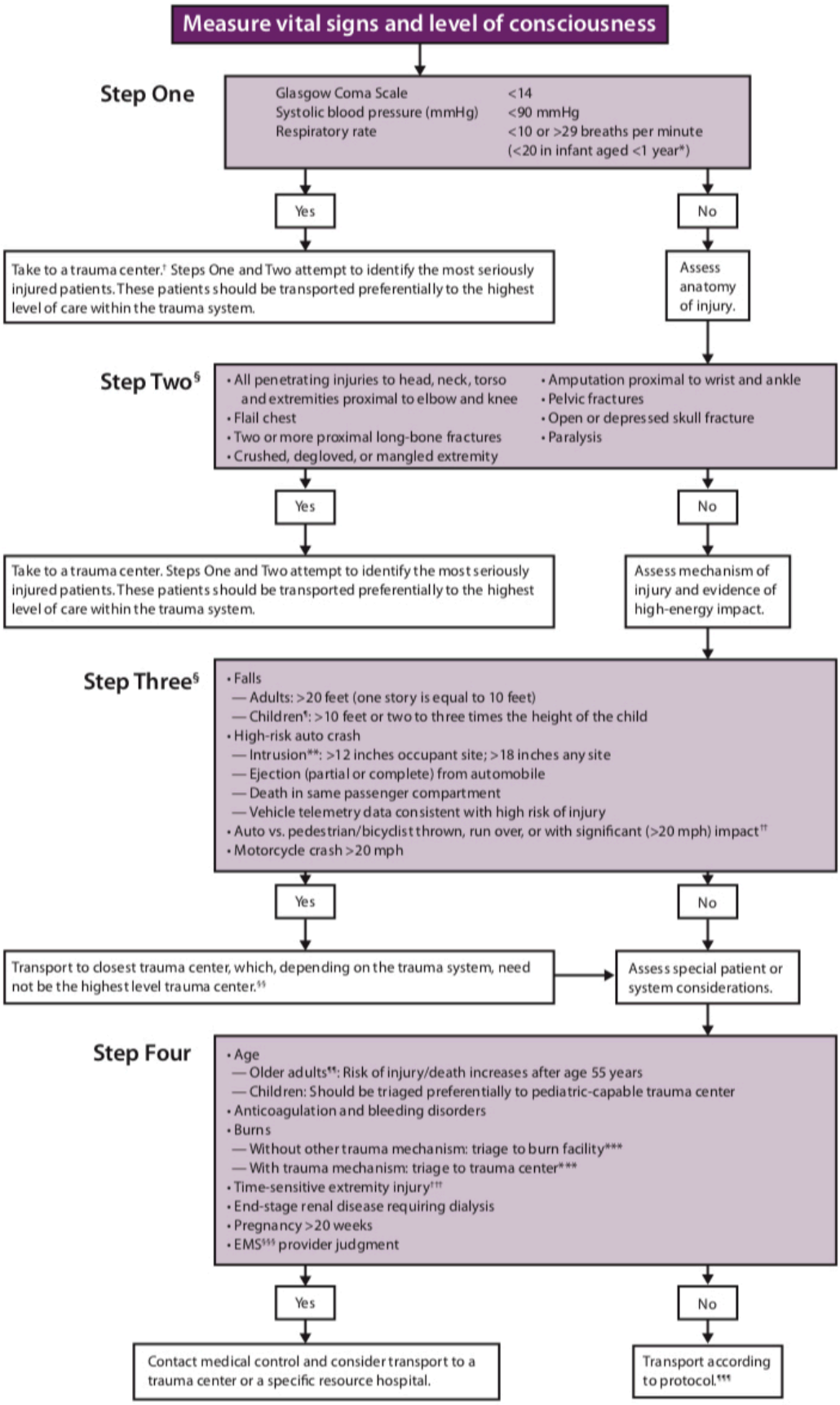


Figure 1.3: Field Triage Decision Scheme.[16]

Major incident triage

When a large number of patients present simultaneously, and with a limited supply (certainly initially) of medical resources, triage performed in the major incident setting differs to that encountered routinely on a daily basis in both the ED and pre-hospital setting.[11,13] Instead of determining the need for care in a major trauma centre, the aim of major incident triage is to rapidly identify the critically injured and to determine the priorities for treatment.[35-40] Faced with large numbers of patients, triage helps to bring order to what is likely to be a chaotic environment, making the initially unmanageable situation manageable.[41,42] Unlike field triage, major incident triage is typically a much quicker and simpler process, frequently using an assessment of physiology alone to identify the critically injured. Whilst physiological derangement is sensitive for identifying serious injury and gives an impression of the patient's current stability or decompensation it is not without its limitations.[14,29,30,41,43,44]

A number of methods (triage tools) for major incident triage exist worldwide, with the MIMMS Triage Sieve, START and Careflight being the most frequently described.[3,12,14,17] In the UK, despite being taught on the MIMMS course, the MIMMS Triage Sieve has been modified in both the civilian (National Ambulance Resilience Unit (NARU) Sieve) and military settings (Military Sieve); both of these (NARU and Military Sieve) are analogous with one another.[45,46] In Europe and the USA, alternative triage tools have been proposed including the modified START, the Amberg-Schwandorf-Algorithmus (ASAV)[47], the Primary Ranking for Initial Orientation in Emergency Medical Services (PRIOR)[21], the Sacco Triage Method (STM) and the Sort, Assess, Life-saving intervention, Treatment and Transport (SALT).[48,49] A summary of the triage tools identified in the literature review is provided in **table 1.1.**

These triage tools all typically utilise an assessment of the patient's physiology, either objectively (e.g. quantifying the respiratory rate (RR)) or subjectively (presence of respiratory distress) and allocate the patient to one of three treatment categories: Priority One/Immediate, Priority Two/Urgent and Priority Three/Delayed, depending on the patient's clinical acuity. Dependent on the incident, if a patient's injuries are so severe that they are unlikely to survive even with treatment, or if their treatment will detract from those with potentially salvageable injuries, a fourth category (Priority Four/Expectant) may be allocated at the discretion of the senior medical commanders.[3] Terminology using SALT differs, with Priority Two and Three patients being labelled as Delayed and Minimal respectively. Within this thesis, categorisations are referred to using the Priority One, Two, and Three system. Despite this delineation, with the exception of the Priority Three patient (allocated to those who are 'walking wounded'), there is limited guidance as to what constitutes the Priority One or Two patient, with the descriptions provided by both MIMMS and the World Medical Association differing in the time period required to quantify an immediate patient.[3,25]

"those who can be saved but whose lives are in immediate danger, requiring treatment immediately or within a few hours" – World Medical Association.[25]

"*casualties who require immediate life-saving interventions"* - MIMMS.[3]

Triage Tool	Country	Components	Outcome
ASAV[47]	Germany	Walking Mortally injured Breathing Catastrophic haemorrhage Radial pulse Obeys commands	Category 1, 2, 3 or Dead
Careflight[12]	Australia	Walking Obeys commands Breathing Palpable radial pulse	Immediate, Urgent, Delayed or Dead.
First impression triage[52]	Japan	Walking Breathing Eyes opening to voice (or worse) Tachy/Bradycardia or weak pulse Tachypneoa or bradypneoa Pallor or sweating	Immediate, Delayed, Minor or Expectant.
Military Sieve[46]	United Kingdom	Walking Breathing Catastrophic limb bleeding Respiratory rate Pulse rate Unconscious	P1, P2, P3 or Dead.
Modified START (1)[52]	Japan	Walking Breathing Respiratory rate Systolic blood pressure Consciousness	Immediate, Delayed, Minor or Expectant.
Modified START (2)[20]	Germany	Walking Mortally injured Respiratory rate Catastrophic haemorrhage Radial pulse Obeys commands	P1, P2, P3 or Expectant
NARU Sieve[45]	United Kingdom	Catastrophic haemorrhage Injured Walking Breathing Unconscious	P1, P2, P3 or Dead.

		Respiratory rate Pulse rate or capillary refill	
PRIOR[21]	Germany	Unconscious Respiratory distress Pulse rate Consciousness Severe pain Mobilisation	P1, P2 or P3
Sacco Triage Method[48]	United States	Respiratory rate Pulse rate Motor response Existing resources available	Survival prediction based on physiological assessment and existing resources.
SALT[49]	United States	Walking Purposeful movement Obvious threat to life Catastrophic haemorrhage Breathing Peripheral pulse Respiratory distress	Immediate, Delayed, Minimal, Dead or Expectant.
START[11]	United States	Walking Breathing Respiratory rate Palpable pulse Obeys commands Catastrophic haemorrhage	Immediate, Urgent, Delayed or Dead.
Triage Sieve[3]	International	Walking Breathing Respiratory rate Pulse rate	P1, P2, P3 or Dead.
ASAV – Amberg-Schwandorf-Algorithmus, START – simple triage and rapid treatment, NARU – National ambulance resilience unit, PRIOR – primary ranking for initial orientation in Emergency Medical Services, SALT – sort, assess life-saving interventions, treatment and transport,			

Table 1.1: Summary of triage tools identified in the literature review.

Identifying the Priority One patient

The aim of major incident triage is to rapidly and accurately identify patients who are critically injured, i.e. Priority One.[37] However, with comparative studies using a variety of outcome measures (ISS, mortality, need for life-saving intervention),[18,50-55] a lack of a standardised outcome makes it "*impossible… to effectively evaluate or compare existing mass casualty triage systems"* and is a key limitation in advancing research in major incident triage.[56] As with field triage, the assessment of injury severity or prediction of mortality is not the aim of the provider triaging at a major incident; identifying patients in need of life-saving intervention to prevent death or severe disability is key.[50,57]

As our management of the trauma patient has evolved, so too has the definition of what constitutes a life-saving intervention. First discussed in reference to field triage, Baxt identified five categories of life-saving intervention ranging from surgical procedures to fluid resuscitation requirements and invasive intracranial pressure monitoring.[32] Modifying these criteria for the major incident setting (modified-Baxt criteria), Garner reduced the time for non-orthopaedic surgical procedures to be considered life-saving (from 48 hours to 6 hours).[12] Further expanding on this work, Horne et al refined the modified-Baxt criteria and identified 31 life-saving interventions.[18] Whilst the life-saving interventions derived from this latter study are more exhaustive than those previously documented, there are limitations associated with the study. Firstly, it was a military study that focussed on combat trauma (a different population and mechanism of injury to that of civilian trauma), and secondly, not all medical capabilities available in the civilian setting are deployable in all military environments (e.g. interventional radiology). When trying to identify the gold standard life-saving interventions, this will limit the generalisability of these interventions into the civilian setting.[18]

In order to help to facilitate further research into the development of major incident triage tools, Lerner et al used a Delphi process to identify 18 interventions that defined the Priority One patient, and additionally provided definitions for the Priority Two and Priority Three patients.[56] Whilst this work is a novel but important contribution to the literature, it has a number of limitations. Methodologically, whilst a Delphi was attempted, the numbers of participants differed between rounds, with one participant missing a round but continuing to participate in subsequent rounds, and another participant joining the study from round two. Additionally, the panel consisted of a limited number of participants, which as the authors describe, may not represent a *"broad enough view on the topic"* of major incident triage.[56]

Successful triage

Successful triage is defined by the American College of Surgeons by the proportions of patients who are under and over-triaged, i.e. misclassified as either Priority One (over-triage) or Not Priority One (under-triage); with guidance for major incident triage simply being to keep both to a minimum.[16] In comparison, they suggest that for field triage, the upper thresholds for under and over-triage be kept to a maximum of 5% and 35% respectively; due to the relatively simplistic nature of major incident triage tools, these thresholds are unlikely to be achievable.[16] Irrespective of the mechanism of injury, the proportion of Priority One patients at a major

incident is typically low (10-20%), and the main challenge for those involved in triage is to accurately identify this group.[36,40,50,58-61]

Under and over-triage

Under-triage in the field triage setting is associated with increased mortality, and it is very likely that within the major incident environment, it will be associated with not only increased mortality but also increased morbidity.[21,23,40,42,62,63] With over-triage, the concern is overwhelming limited healthcare resources with non-critically injured patients and delaying life-saving interventions for those requiring them.[13,42] Whilst originally thought to simply represent a logistical burden, Frykberg et al reported that there was a direct linear relationship between over-triage and critical mortality (defined as the number of deaths among the injured, excluding immediate deaths).[36,64] However, contrary to this, Aylwin et al reported no impact on critical mortality despite an overall over-triage rate of 64% following the London 7/7 bombings, and this was supported in subsequent computer simulations where no consistent relationship with mortality was identified.[61,65]

Owing to the unpredictable nature of major incidents, prospective research studying triage - including randomised controlled trials - is not only largely impossible but associated with ethical implications.[55,66,67] Instead, studies describing the performance of triage tools use surrogates for analysis and these can be grouped into the following categories:[12,15,17-21,47,49,52,68-72]

- Retrospective analysis of major incident data
- Retrospective analysis of trauma registry data
- Prospective collected data of individual trauma patients
- Simulation using live actors
- Simulation using patient dummies
- Simulation using virtual reality modalities
- Paper or computer-based patient scenarios

Retrospective major incident studies

To date there are only a limited number of studies comparing triage tool performance using data collected from major incidents. Whilst these studies have the advantage of using the actual population involved in the incident, they are not without limitations and with different outcome measures described between studies, triage tool performances differ considerably.

The first study was by Kahn et al, who identified the performance of START at identifying a need for life-saving intervention (using the modified-Baxt criteria) following a 2003 US train crash.[17] Despite retrospective major incident studies typically being associated with limited availability of complete records, the authors were able to analyse records for the majority of patients (n=148, 91.3%). Twenty-two patients (14.9%) were triaged as Priority One by START, with only two (1.4%) receiving a life-saving intervention.[12,17] Whilst sensitivity was 100% with no patients being under-triaged, the specificity was lower (77.3% (95% CIs 67.1-

85.5)) with an extremely high rate of over-triage (90.9%).[73] The study has two main limitations; firstly there were only a small number of genuine Priority One patients, considerably lower than has previously described[36,40,58,59] and secondly the analysis was performed using START only.

Subsequently, Challen performed a comparative analysis of START, Careflight and the MIMMS Triage Sieve and their ability to identify need for life-saving intervention (modified-Baxt criteria) following the 2005 London 7/7 terrorist bombings.[15] An identical sensitivity (50.0%) and specificity (100.0%) were reported for all three triage tools. As with Kahn's study, there were only a small number of actual Priority One patients (n=8), with a further limitation that data were only available for half of these patients (n=4). The use of a systolic blood pressure (SBP) surrogate of 110mmHg to represent the presence of a palpable pulse for the characterisation using START and Careflight may represent an additional limitation of this study. It is likely that most patients will have a palpable pulse, some of whom will have a SBP less than 110mmHg.[12,43] In the context of a retrospective analysis this may lead to falsely elevated rates of over-triage by START and Careflight on the basis of the SBP, which may not be replicated in an actual major incident setting.

In an attempt to validate the triage decisions made by Israeli triage officers at a single hospital, Ashkenazi et al performed a retrospective analysis of patients involved in two terrorist major incidents.[68] Of 202 patients injured, 104 were admitted (51.5%), with data available for 94 (90.4%); 10 were categorised by the triage officer as Priority One (10.6%). ISS was calculated for all patients, and using an ISS >15 to define gold standard Priority One, 11 (11.7%) were identified as Priority One. The triage officers correctly identified eight Priority One patients yielding a sensitivity of 72.7% and an under and over-triage rate of 27.3% and 20.0% respectively.[68,73] There are two key limitations to this study; firstly it is not clear what triage process was used by the clinicians as it only took a few seconds, "*not long enough to allow for careful decision-making, which relies on physiological parameters"* or whether the decisions were simply based on the "*clinical acumen of the triage officer"*.[68] Additionally, triage performance was measured against the ISS, which confers the previously described limitations.

Following an airplane crash in 2009, Postma et al conducted a retrospective study examining the performance of the MIMMS Triage Sieve at identifying need for life-saving intervention with a secondary aim of identifying patients with an ISS >15.[74] 20 patients were classified by the MIMMS Triage Sieve as Priority One, with only four requiring a life-saving intervention, yielding a 20.0% sensitivity and high over-triage rate of 80.0%. Under-triage is quoted as only 12.0%, but this was determined by Priority Three patients having at least one serious injury (defined as an Abbreviated Injury Scale (AIS) score ≥3), rather than the need for life-saving intervention. Sensitivity improved greatly (65.0%) when ISS >15 was used to determine Priority One patients but as has previously been described it reflects injury severity and not necessarily acuity and is therefore an inappropriate marker to define the Priority One patient.[15,74]

The last study to use retrospective major incident data follows a train crash in Japan, and compares the performance of a modified form of START with an abbreviated triage method (First Impression Triage).[52] 562 patients were injured following the train crash with 113 (20.1%) admitted to one hospital of whom 39 (34.5%) required admission to an intensive care unit. Standard procedure for this hospital is to triage using the modified START protocol (presence of a palpable radial pulse replaced by a non-invasive SBP measurement $\geq$80mmHg, and obeys commands assessment replaced by an assessment of the individual components of the Glasgow Coma Scale (GCS)). Using a lower threshold than other studies to define the Priority One patient (ISS $\geq$15 versus ISS >15), 10 patients (8.8%) were identified as Priority One. The modified START had a sensitivity of 60.0%, corresponding to an under-triage rate of 40.0% with an over-triage rate of 16.7% (1-positive predictive value, (PPV)).[52,73] As with previous studies, the use of the ISS represents a limitation, as do alternative methods of triage (modified START and First Impression Triage), which have not been described subsequently.

Retrospective trauma registry studies

When major incident data are not available, studies frequently turn to the use of trauma registries as a surrogate, allowing for the analysis of large numbers of patients.[55,67] However, these studies are associated with limitations; firstly, trauma registries typically report consecutive, single patients, which when assessing the performance of triage tools, is not the environment or setting in which they are designed to function in.[50] Secondly, trauma registries including the UK Trauma Audit and Research Network (TARN) often have specific inclusion criteria (**Appendix 1)** which, whilst likely to capture severely injured patients, may not include those without such injuries (true negatives) - for example, those discharged from hospital within a short period of time may not be included on the database.[75] When assessing triage tool performance, the reported sensitivity may therefore be accurate, but the specificity will need to be interpreted with caution as not all 'true negatives' will have been included. Finally, in common with real-life major incidents, documentation can represent a limitation with the use of trauma registries resulting in missing data, which then requires either assumptions to be made to replace the data, or to remove the missing data, thereby introducing a form of selection bias.[76]

In 2001, Garner et al performed a comparative analysis of START, Careflight and the MIMMS Triage Sieve using data from an Australian trauma registry.[12] Using the modified-Baxt criteria to determine the Priority One patient, they reported a sensitivity of 84% and 82% for START and Careflight respectively, with both having a specificity in excess of 90%. In contrast, the MIMMS Triage Sieve demonstrated poor sensitivity (45%) and the lowest specificity (88%). The presence of a palpable pulse and the ability to obey commands were identified as being the greatest predictors of the need for life-saving intervention.

Using START, Gebhart et al determined the performance of the individual components of the triage tool, and their ability to identify the Priority One patient (defined using mortality) from a random selection of 355 trauma registry patients.[51] Whilst the study is limited by a lack of comparison with other triage tools and an analysis

with START as a whole, it demonstrated that patients with only one of three Priority One defining criteria had a mortality of 21.0% which increased to 50.0% when all three defining criteria were present.[51]

Using a military cohort, Horne et al compared the performance of the MIMMS Triage Sieve to the Military Sieve (which includes an assessment of conscious level) at identifying adult patients in need of life-saving intervention.[18] The MIMMS Triage Sieve demonstrated limited sensitivity (53.2%), but with the inclusion of conscious level assessment (Military Sieve), this increased to 58.5% ($p<0.001$). Subsequently they explored the effect on sensitivity and specificity when the physiological variables within the Military Sieve were adjusted and speculated that a change in RR thresholds (from 10>RR>30 to 12>RR>24) and the inclusion of a lower HR threshold (40>HR>120) could improve sensitivity (71.2%) whilst maintaining an acceptable level of specificity (79.3%).[18]

The largest trauma registry study (over half a million adult patients) compared the performance of six triage tools including START, Careflight and the Sacco Triage Method (STM).[55] The STM is a mathematical triage tool developed to guide triage decisions based on a combination of physiological status, probability of patient survival and an estimation of patient deterioration.[49] Whilst derivation studies demonstrate that the STM outperforms START at predicting survival, there four key limitations associated with it, a) it is designed to predict survival and not acuity; whilst the two outcome measures are related, they are not interchangeable and primary triage tools such as START, are not designed to predict this; [77] b) the STM was derived using trauma registry data and is therefore subject to the limitations previously described; c) concerns have been raised regarding the methodology used to determine survivability and deterioration;[78,79] d) a logistical infrastructure including Information Technology facilities is required to support the use of the STM, which in a facility already inundated with patients from a major incident may be difficult to implement.[78,80] Lastly as a proprietary system, the STM is only currently licenced for commercial use.

The primary outcome of the study was mortality, with a secondary outcome being the requirement for ventilator use at any point during hospital stay.[55] Unlike previous studies, statistical analysis was conducted using a comparison of area under the receiver operator characteristic (AUROC) curve. For the primary outcome (mortality) the STM outperformed all other triage tools (AUROC = 0.883). The AUROC is a combined measurement of sensitivity and specificity yielding a quantifiable measure of overall accuracy. However for triage tool performance, sensitivity is of greater importance than specificity, as the aim is to identify those patients in need of a life-saving intervention; therefore an assessment of triage tool sensitivity would be more suitable than the AUROC.[55]

The use of mortality as the primary outcome metric is again of questionable relevance to primary triage tools, and this was raised in correspondence to the authors.[77] In response, the authors provided an additional analysis using need for life-saving intervention (modified-Baxt criteria) as the outcome. In this analysis the STM demonstrated the worst performance (AUROC = 0.615), with START and Careflight having equal

performance (AUROC = 0.717).[77,81] Unfortunately, the authors did not include the MIMMS Triage Sieve or the Military/NARU Sieve for comparison within their analysis.[55]

Using the Emergo Train System victim database, Badiali et al compared the performance of non-medically qualified ambulance crew members triaging patients with and without START.[82] Using two cohorts of crew members, they demonstrated a statistically significant difference ($p<0.01$) in performance when START was used to identify Priority One patients (94.1% accuracy versus 70.5%). Sensitivities and specificities are not provided, but the authors describe 1554 expected Priority One patients, of whom 1598 were triaged by START as Priority One. With a 94.1% accuracy of predicting this categorisation, this implies good sensitivity using START, with only minimal over-triage (n=44, 0.73%). Whilst not a comparative analysis with other triage tools, the study demonstrates the ability for an improvement in triage accuracy with even last-minute training.[82]

Using a database of consecutive trauma patients (n=500), Neidel et al performed a comparative analysis of triage tools that included the assessment of palpable radial pulse (including modified START, ASAV and Careflight) at identifying Priority One patients.[37] The modified START triage tool in this study differs to that used by Hashimoto et al, and includes life-saving interventions if required for the Priority One patient and an extension to the tool if the patient doesn't fulfil Priority One criteria.[20,52] Using SBP as a surrogate for palpable radial pulse, the authors compared triage tool performance when different SBP surrogates were used (ranging from 60mmHg to 130mmHg). In addition to measuring sensitivity and specificity, the authors reported the Youden Index (a statistical marker combining sensitivity and specificity, ranging from -1 to +1) of the triage tools as their primary comparison. As with AUROC, the Youden Index allows for an objective assessment of the overall performance of the triage tool utilising a combination of sensitivity and specificity.[55] However, a triage tool with low sensitivity but high specificity may well have a higher Youden Index, leading to a more favourable result than a triage tool with high sensitivity and low specificity. In the major incident setting the priority of triage is to identify those in need of a life-saving intervention, therefore the sensitivity of the triage tool is the more appropriate assessment.

Across all patients included in the database (including non-trauma patients), the ASAV demonstrated the greatest Youden Index (0.64); by comparison the modified START had a value of 0.56 and Careflight had a value of 0.45.[37] The performance of the triage tools (measured using the Youden Index) was typically greater when a lower SBP threshold was used to represent a palpable radial pulse. However, the use of a SBP surrogate of 60mmHg may be an inappropriately low threshold. Previous studies have documented a weak radial pulse at SBP of 99mmHg,[38] and it is therefore likely that very few patients would have a palpable radial pulse at a SBP of 60mmHg. Although the Priority One patient is described as being in *vital threat* with the consequence of needing *immediate treatment,* no further description is provided, with categories assigned by a *"group of experienced doctors in disaster medicine"*. This suggests that a subjective assessment was used to determine Priority One criteria (rather than an objective assessment), and this, in addition to the statistical methodology reported, represents a limitation of the study.

Prospective Studies

The prospective analysis of major incident triage tools using consecutive trauma patients is limited to just three adult studies.[19-21] The first was a pilot study to explore the potential benefit of the modified START triage tool, with EMS personnel prospectively applying it to consecutive adult trauma patients.[20] EMS triage categories were then compared with the 'gold standard' categories applied retrospectively in hospital with Priority One patients defined by the need for a life-saving intervention. Absolute numbers of EMS and 'gold standard' triage categorisations are not provided, but the authors report 50.0% sensitivity and 97.1% specificity with the modified START, producing an under and over-triage rate of 50.0% and 40.0% respectively. A limitation of this study is the small number of patients included (n=151), but it is acknowledged that it was a pilot study in order to determine the feasibility of the modified START; it was not the authors' aim to undertake a comparative analysis.

The second prospective study took place in the deployed military environment with the authors comparing the performance of existing triage tools to a modified version of the Military Sieve (Modified Military Sieve).[19] Using a list of previously defined life-saving interventions[18] to define the Priority One patient they found the Modified Military Sieve outperformed all existing triage tools (military and civilian) at predicting the need for life-saving intervention with the greatest sensitivity (68.3%), whilst maintaining an acceptable level of specificity (79.4%).[19,83] In comparison, the existing Military/NARU Sieve, had lower sensitivity (63.3%) but demonstrated a slight increase in specificity (82.4%). Although demonstrating greater specificity than the Modified Military Sieve, both START and Careflight had low sensitivities (51.8% and 44.7% respectively). Whilst the study provides a comparative analysis of existing triage tools, it is limited by the cohort of patients studied – predominately young, fit males with limited medical co-morbidities injured by explosion or gunshot wounds. Although terrorism related incidents have the potential to produce similar mechanisms to those observed in this study,[84] this mechanism is not representative of that likely to be seen in a civilian major incident.

The final study involved the retrospective analysis of prospectively collected data from 500 consecutive Helicopter Emergency Medical Service missions.[21] Using recorded physiology, patients were triaged using multiple triage tools (PRIOR, modified START, ASAV, START, Careflight and MIMMS Triage Sieve) and comparison was made with triage categorisations defined *a priori* by a panel of 19 doctors. START and modified START were virtually identical and comparable to the ASAV (sensitivity (all): 78%, specificity (range): 80-83%).[21] The PRIOR triage tool had the greatest sensitivity (90%), but the lowest specificity (54%), with the MIMMS Triage Sieve having the worst performance of all tools (34% sensitivity, 96% specificity). Careflight had a sensitivity and specificity of 70% and 87% respectively. As explained by the authors, a limitation of the study was the inclusion of Priority Four patients, those *"without chance of survival"*, with Priority One patients. Additionally, whilst the study has the benefit of including multiple triage tools, it doesn't include the Military/NARU Sieve (introduced in 2015) for comparison.[45]

Simulation studies

The last category of studies comparing triage tool performance uses a variety of methodologies, from paper based or table-top triage exercises to simulation using actors or patient mannequins and more recently, virtual reality to replicate the major incident environment.[47,69-71,85] Chen et al compared the performance of students triaging patients in a table-top exercise both before and after education was given on START.[72] Although the study was limited by a small number of participants (n=30), the use of a single triage tool and reporting overall triage accuracy (all triage categories), it demonstrated the feasibility of conducting low-fidelity triage training, resulting in an improvement in overall triage performance (pre-education accuracy 55.8%, post-education accuracy 87.8%).[72] Using a larger study population of EMS paramedics (n=109), Risavi et al demonstrated comparable pre and post education accuracy (55% and 76% respectively). Testing knowledge retention at one month, accuracy was maintained at 75%, not only demonstrating agreement with Chen that simple training improves immediate accuracy using START, but that this accuracy can be maintained for at least one month afterwards.[86]

Again, using a paper-based study, Kilner and Hall compared the performance of providers (n=82) conducting triage both with and without *aide-memoires.*[85] Unlike Chen, participants were non-medical professionals (UK police firearms officers) and had not received prior training in triage. Participants were given simple clinical details (*e.g. "18-year old female, large flap laceration to upper arm, respiratory rate 26, pulse 115)* of 30 patients (20 adult, 10 paediatric) and asked to triage them into the categories, Priority One, Two or Three. On completion, participants were then given a copy of the MIMMS Triage Sieve (and paediatric version) and instructed to repeat the process. Participants were given 15-minutes for both exercises, equating to 30-seconds per patient. The nature of the study meant that it was not possible to calculate the performance of the MIMMS Triage Sieve, as this was used *a priori* by the authors to define the 'gold standard' categorisations. However, this study does demonstrate that non-EMS providers are able to effectively triage using the MIMMS Triage Sieve *aide memoire* with no prior training (mean correct triage categories 24.41/30, range 15-30).[85] A number of terrorist related major incidents including the London 7/7 bombings and the Paris Bataclan attacks have occurred since this study was conducted. These have all highlighted that the incident scene is likely to be a hostile and unsafe environment, preventing access (certainly initially) by a conventional EMS response.[87] In these circumstances, it is very likely that the initial triage may be performed by non-EMS providers.[84,88]

Using the same paper triage exercise given to UK police firearms officers, Cuttance et al performed a similar study with a large group of EMS paramedics (n=292) to determine whether there was an improvement in triage accuracy with intervention (MIMMS Triage Sieve training, use of an *aide memoire*, or both), using no intervention as a control.[23] Triage accuracy was significantly ($p<0.001$) lower in the no intervention group (47%), compared to 77% with training and 90% with an *aide memoire;* both under and over-triage were greatest in the group triaging with no intervention. In common with the study by Kilner et al, there are limitations to this work, primarily that the outcome measurement is agreement with the authors' classifications (determined *a priori)*, rather than the MIMMS Triage Sieve's ability to detect Priority One patients on the

basis of their acuity and need for life-saving intervention. What the study does add, is that even for EMS paramedics the provision of an *aide memoire* allows for more accurate triage, which in a stressful environment such as a major incident, is essential.[23,85]

The use of actors in major incident simulation allows for greater fidelity and realism compared to paper-based triage exercises.[89] Utilising a combination of actors and mannequins to represent victims from a train explosion, Schenker et al determined the triage performance of EMS providers (n=40) using START. 130 simulated patients were involved in the incident, with 30 categorised as Priority One; START correctly identified 20 Priority One patients yielding a sensitivity of 67% and an under-triage rate of 33%.[70] Identical results were observed in a similar study by Ingrassia et al, where using a simulated building explosion, EMS providers (n=17) used START to triage 112 patients (15 Priority One).[89]

Navin et al used a simulated building collapse with 99 patients (combination of actors and patient mannequins), to assess the performance of EMS responders using the STM and START.[90] The two tools were compared using accuracy with triage categories designated *a priori* based on the START classification, and the overall time required to perform the triage process. The authors reported that the STM was more accurate than START (91.7% versus 71.0%), with START under-triaging 17 Priority One patients (out of 25). Although the speed to triage individual patients was quicker using START, the time taken to clear the scene was quicker with STM. The study is associated with limitations; firstly physiological measurements were not taken by the EMS responders – values were simply read out by the actors, thus limiting the ability to reliably comment on the speed of triage. Secondly, the outcome measurement was agreement with triage categorisations designated *a priori* and not the need for life-saving intervention.

During a major incident training course, Rehn et al utilised four bus crash scenarios to assess the performance of emergency services providers (including non-medical providers) using the MIMMS Triage Sieve.[4] Performance was assessed before and after training was given on the use of the MIMMS Triage Sieve, with accuracy determined by agreement with the triage categories that were allocated *a priori*. Whilst there is a lack of detailed performance characteristics, the authors report that before training (i.e. when no triage tool was used) participants demonstrated mean rates of under and over-triage of 12.2%; subsequently when the MIMMS Triage Sieve was used, both under and over-triage was zero. In addition to an overall improvement in accuracy, the authors report that the mean time taken to conduct the triage exercise was reduced when the MIMMS Triage Sieve was used (22 minutes versus 10 minutes). This study supports previous work in demonstrating that training in triage methods leads to an improvement in overall triage performance. However, as with other studies is associated with the limitations of not being a comparative analysis and performance being determined by agreement with *a priori* categorisations.[4,23,85]

Using simulation with patient mannequins, Wolf et al compared the performance of providers (EMS and non-EMS) using the ASAV with triage categories determined *a priori*.[47] Irrespective of the background of the

providers, the ASAV demonstrated both high sensitivity (87.4%) and specificity (91.0%) at identifying Priority One patients. Whilst under and over-triage rates of 9.7% and 6.4% respectively are reported, it is not clear how these are derived; with PPV not reported it is not possible to determine the over-triage rate (using the method described by Peng).[73] However, if 1-sensitivity is used to calculate under-triage, this would yield an under-triage rate of 12.6%, which although comparable to 9.7% is higher than that reported. Additionally, comparison was made to the performance of the modified START during a separate major incident simulation exercise (sensitivity 88.2%, specificity 93.9%), and found to be comparable.[47,91] There are limitations to the study, which the authors appropriately describe, notably the use of patient mannequins where the actual clinical condition of the patient cannot be replicated.[47] In addition, in keeping with a number of the studies previously described, the outcome measurement was agreement with previously assigned triage categorisations, not the need for a life-saving intervention. The authors have correctly limited the conclusions to it being a 'proof of concept' study of the ASAV and that it can be applied, but that there is a lack of evidence currently to support it assessing patients clinically.[47]

Virtual reality is an additional modality that has been used to analyse triage tool performance; despite high fidelity simulation products available for personal use (e.g. flight simulators), few studies have looked at its benefit for the major incident context.[71,92] Recently, Jain et al used virtual reality simulation to reproduce a historical train crash and compare the performance of EMS paramedic students using START and STM.[22] The primary aim of the study was to compare the total triage time for each tool, in keeping with Navin et al, START was found to be the quicker of the two tools (11 minutes 49 seconds versus 10 minutes 9 seconds), but this did not reach statistical significance ($p=0.07$).[90] Whilst the study was limited by a lack of defined outcome measurement (ISS, need for life-saving intervention, mortality) and a lack of performance characteristics (sensitivity and specificity) for either triage tool, it demonstrated the feasibility of virtual reality simulating the major incident environment.

SALT Triage

In response to a lack of evidence to support existing triage tools, the SALT triage method (**Figure 1.4)** was derived by a working group from the USA and introduced as an alternative to START.[93] As with existing triage tools, SALT categorises patients as Priority One, Two or Three, but does this through a series of subjective triage assessments (does the patient make purposeful movements? Is there a peripheral pulse? Is there any evidence of respiratory distress?).

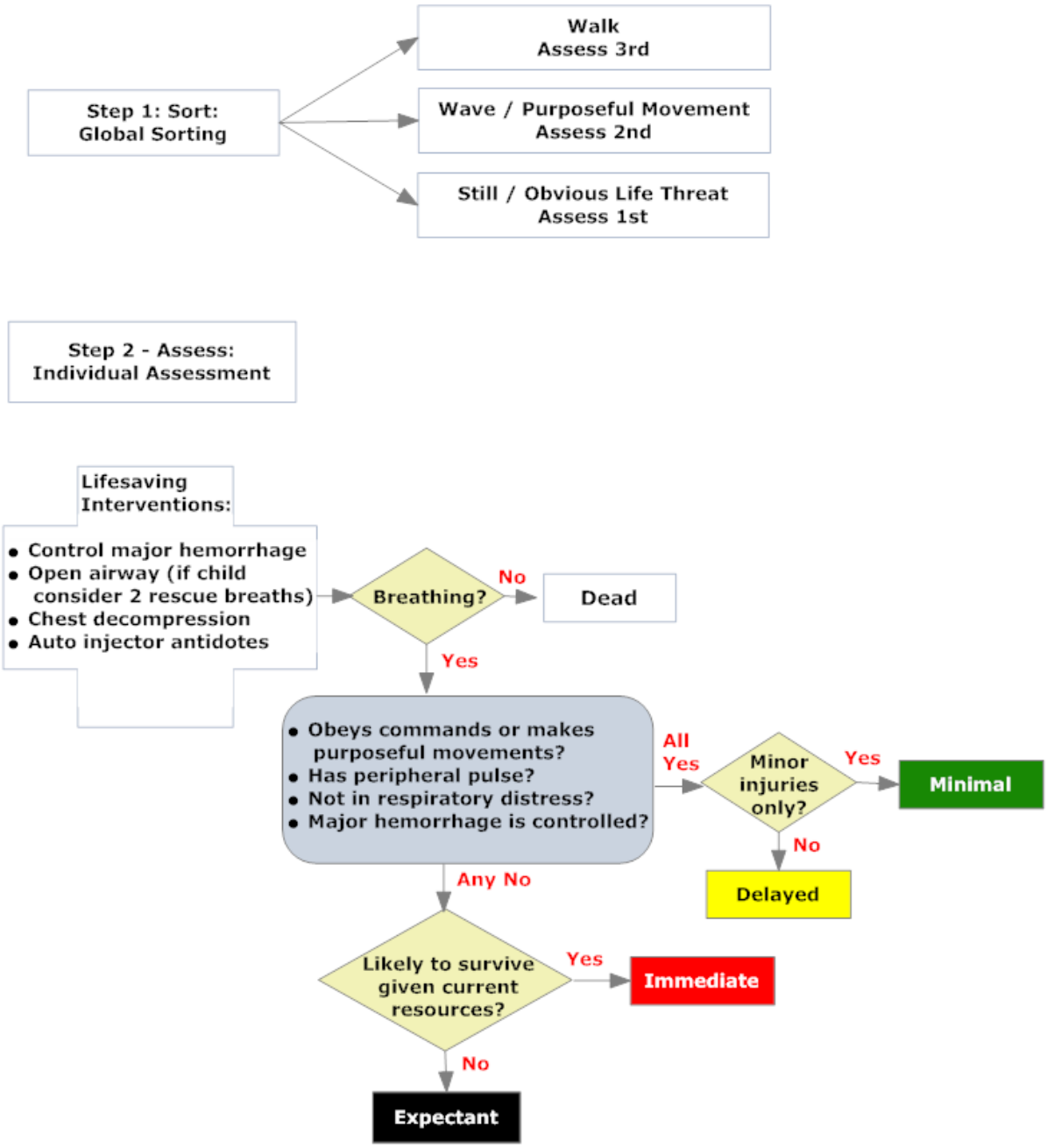


Figure 1.4. SALT triage tool.[93]

SALT is a novel triage tool, there are therefore a limited number of studies assessing its performance, all of which use simulation. The initial pilot study was conducted using a simulated plane crash scenario with 52 patients (16 Priority One (30.8%)).[94] Having received training, two EMS paramedics performed the triage assessments under timed conditions using SALT, demonstrating 100.0% sensitivity and 80.5% specificity, correlating with zero under-triage and 30.5% over-triage.[73,94] A limitation of this pilot study, which the authors duly acknowledge, is the outcome measurement, which is agreement with the triage category assigned *a priori* by the authors themselves using SALT rather than the need for life-saving intervention.[94]

Using a paper based triage exercise Deluhery et al compared the performance of EMS paramedics using SALT immediately following training and then four months later.[95] As with the pilot study the outcome assessment

was agreement with the authors' triage category and not the need for life-saving intervention.[94] For both tests, triage accuracy exceeded 80% with no statistical significance between them, demonstrating retention of knowledge and ability to use SALT four months after initial training. Overall sensitivities and specificities are not given for SALT, but individual accuracy for each patient is, with the paramedics reaching between 74-93% accuracy at identifying Priority One patients.

Whilst acknowledging that the aim of the study was to determine the ability of EMS paramedics to retain the knowledge to use SALT, there are limitations to the study, including the choice of outcome as previously discussed. Whereas the pilot study was conducted within a specified time period to simulate the potential time pressures of triage at a major incident, there was no time limit in this study.[94] The study also demonstrated a potential weakness of the SALT methodology with one patient being considered either Priority One or Two, and this is likely to be as a result of a lack of objective physiological assessment in the tool, which could lead to an increase in under or over-triage.[95] Similar levels of skill retention were demonstrated by Nilsson et al, who conducted triage assessments for non-EMS providers (firefighters); those who received training out-performed those who didn't, and when the study was repeated six months later (without refresher training), the firemen demonstrated that they had retained triage skills using SALT.[96]

Using virtual reality, Cone et al compared the performance of SALT with the triage algorithm from the Smart Incident Command System.[97] Creating a scenario involving a bus crash, EMS students (n=22) triaged 25 patients (10 Priority One) using SALT and then Smart three months later. Triage accuracy was significantly higher using Smart (93.0% versus 70.0%, $p<0.001$), with lower rates of under-triage (5.1% versus 23.2%, $p<0.05$) and over-triage (1.8% versus 6.8%, $p<0.001$). Additionally, using Smart was significantly faster, with a mean total triage time of 11 minutes 59 seconds compared to SALT which was almost double, at 21 minutes 3 seconds, ($p<0.001$). There are limitations associated with this study, which the authors describe including the outcome measurement not being need for life-saving intervention. In addition, whilst the Smart triage tool demonstrated improved performance, it has not been described elsewhere and appears to be a combination of the traditional START and original MIMMS Triage Sieve. Whilst the authors suggest that it is in use in the UK, there is no other supporting evidence for this, with NARU directing that major incident triage be conducted using the NARU sieve since 2015.[45] Lastly, the authors combined expectant patients with those recorded as Priority One, which represents an additional study weakness that has been previously described.

Additional studies using simulation methods, paper triage exercises and both prospective and retrospectively collected trauma data exist, including those relating to the performance of paediatric major incident triage tools and the adult Priority Three cohort.[53,66,98,99] As this thesis focuses on the adult population and identifying those in need of life-saving intervention, these studies have not been included in this literature review. In addition, studies comparing differing methods of triage tool implementation (e.g. using triage tags versus glow sticks) have not been included as these are not considered directly relevant to the research question being investigated.[100] In order to concentrate on studies exploring the performance of major incident triage tools,

those studies looking at the ability of the physiological parameters[101,102] to predict the requirement for major trauma centre care in the case of field triage have been excluded from this literature review.

Summary

In summary, the literature consists of a number of studies looking at the performance of various triage tools in multiple different environments; there is limited correlation between these studies, with a wide variety of performance demonstrated by each triage tool. A number of different outcomes are reported, including mortality, ISS, accuracy with triage categorisations allocated *a priori* and the need for life-saving intervention; with a lack of a standardised outcome, comparison between studies is difficult.[18,50-55] Indeed, there is also a lack of standardisation with how performance is reported, with overall accuracy, AUROC, Youden Index and sensitivity and specificity again making the comparison between studies more difficult.[12,15,18,20,55]

For a primary major incident triage tool, the need for life-saving intervention is the most important outcome, with sensitivity the most important metric. The evidence is limited to a small number of studies that compare more than one triage tool, and this is further reduced when the need for life-saving intervention is used as the outcome measurement. This thesis intends to bridge the gap in major incident triage research and to derive an evidence-based physiological triage tool that demonstrates improved performance characteristics at predicting need for life-saving intervention in the adult trauma population. This has not previously been undertaken, and this thesis aims to provide the much-needed evidence-base for major incident triage.

Chapter 2: What constitutes a priority one patient in a major incident?

Reference:

Vassallo J, Smith J E, Bruijns S, Wallis L A. Major Incident Triage: a consensus-based definition of the essential life-saving interventions during the definitive care phase of a major incident. Injury. 2016 Sep;47(9):1898-1902.

Declaration from author

The following co-authors contributed to the paper: Jason E Smith, Stevan R Bruijns and Lee A Wallis.

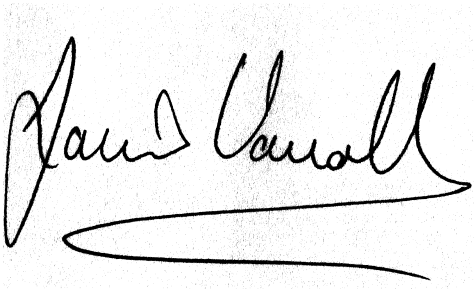
In the case of Chapter 2, contribution by authors to the work was as follows:

Nature of contribution

- JV, JES and LAW conceived the idea and designed the study. JV and SB drafted the work with all authors contributing to revise it critically for important intellectual content. All authors approved the final published version and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- **Extent of contribution:** JV: 80%; SB and JES together 15%; LAW: 5%

The following co-authors contributed to the work:

1. Prof. Lee A Wallis
2. Prof. Jason E Smith
3. Associate Prof. Stevan R Bruijns



Signed: James Vassallo

Declaration by co-authors

The undersigned hereby certify that:

1. The above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. There are no other author of the publication according these criteria;
5. Potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. The original data are stored at the following location and will be held for at least five years from date indicated below.

Location of stored data:

Survey data are stored online at www.surveymonkey.com, with raw data downloaded and stored on the authors (JV) encrypted account at the University of Birmingham, allocated through the Academic Department of Military Emergency Medicine.

31st January 2018

Prof. Jason E. Smith	Date

8th February 2018

Prof. Lee A. Wallis	Date

Main findings

- The Delphi panel considered 32 interventions to be life-saving.
- Interventions were considered to be life-saving if they were performed immediately or within an hour.

Motivation for conducting study

Major incidents occur worldwide on a regular basis and for healthcare providers are defined as an incident where the "*number, severity, or type of live casualties requires extraordinary resources"*.[3] Triage is the process of prioritising patients on the basis of their clinical acuity and is a key principle in the effective management of a major incident. Within the UK, both military and civilian major incident agencies utilise a two-stage approach to major incident triage, with an initial 'sieve' followed by a secondary 'sort'.[3] Both of these processes assign casualties to one of three categories:

Triage Category	Meaning
Priority One (P1)	Require immediate life-saving intervention
Priority Two (P2)	Require medical or surgical intervention within 2-4 hours
Priority Three (P3)	Treatment can be delayed >4 hours

Table 2.1: Definition of triage categories.[3]

Whilst the MIMMS course provides this description, there is no definition as to what constitutes a 'life-saving intervention'. In order to compare the performance of existing triage tools and indeed develop future triage tools, an appropriate benchmark is required with which to validate them against. In the past, trauma triage tools have been validated against the ISS, and their ability to identify the major trauma patient defined by an ISS >15.[32] The ISS is a retrospective measurement, being calculated following investigation and/or surgery and does not reflect a patient's clinical acuity or their resource needs; and so, within the major incident context, represents a flawed metric with which to compare triage tool performance.[57]

The concept of defining the Priority One patient in terms of requirement for a life-saving intervention was introduced in the early 2000's, with a modification of the Baxt field triage criteria (**Table 2.2**).[12,32] Subsequently, interventions defining the Priority One patient were refined for the paediatric population and the adult military patient.[18,57] Whilst a number of the interventions described by Horne for the adult military population will be transferable to the civilian population, they may not reflect current civilian practice (e.g. large volume crystalloid resuscitation).[18] Additionally, not all civilian interventions (such as interventional radiology) are deployable in all military environments and so were not included by Horne as life-saving interventions.[18] With research in this cohort of patients continuing, our approach to managing the seriously injured patient continues to develop. In order to derive and validate a new major incident triage tool it is appropriate to conduct an up to date study in which to provide a current definition of what constitutes a life-saving intervention.

1. Non-orthopaedic operative procedure within 6 hours of admission with positive operative findings (including thoracotomies, laparotomies, pericardial windows, craniotomies and burr-hole placement).
2. Fluid resuscitation of greater than 1000ml or transfusion to maintain a systolic blood pressure of more than 89mmHg.
3. Invasive central nervous system monitoring, with a positive head computed tomography scan (significant extradural, subdural or intraparenchymal haemorrhage) or documented raised intra-cranial pressure.
4. Procedure to maintain a patent airway or requirement for assisted ventilation.
5. Decompression of a tension pneumothorax.

Table 2.2: Modified-Baxt criteria.[12]

Aim

The aim of this study was to determine what constitutes a life-saving intervention in the context of the adult trauma patient during a major incident.

Objectives

1. Obtain expert consensus as to what constitutes a life-saving intervention at a major incident.
2. Determine the time period in which an intervention is considered life-saving.

A copy of the published paper follows over the next five pages.

Injury, Int. J. Care Injured xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Injury

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

Major incident triage: A consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident

James Vassallo[a,b,*], Jason E. Smith[c,d], Stevan R. Bruijns[a], Lee A. Wallis[a]

[a] Division of Emergency Medicine, University of Cape Town, Cape Town, South Africa
[b] Institute of Naval Medicine, Alverstoke, Gosport, UK
[c] Emergency Department, Derriford Hospital, Plymouth, UK
[d] Academic Department of Military Emergency Medicine, Royal Centre for Defence Medicine (Research & Academia), Medical Directorate, Joint Medical Command, Birmingham, UK

ARTICLE INFO

Keywords:
Major incidents
Triage
Delphi study
Major incident management
Life saving interventions

ABSTRACT

Introduction: Triage is a key principle in the effective management of major incidents. The process currently relies on algorithms assigning patients to specific triage categories; there is, however, little guidance as to what these categories represent. Previously, these algorithms were validated against injury severity scores, but it is accepted now that the need for life-saving intervention is a more important outcome. However, the definition of a life-saving intervention is unclear. The aim of this study was to define what constitutes a life-saving intervention, in order to facilitate the definition of an adult priority one patient during the definitive care phase of a major incident.

Methods: We conducted a modified Delphi study, using a panel of subject matter experts drawn from the United Kingdom and Republic of South Africa with a background in Emergency Care or Major Incident Management. The study was conducted using an online survey tool, over three rounds between July and December 2013. A four point Likert scale was used to seek consensus for 50 possible interventions, with a consensus level set at 70%.

Results: 24 participants completed all three rounds of the Delphi, with 32 life-saving interventions reaching consensus.

Conclusions: This study provides a consensus definition of what constitutes a life-saving intervention in the context of an adult, priority one patient during the definitive care phase of a major incident. The definition will contribute to further research into major incident triage, specifically in terms of validation of an adult major incident triage tool.

Introduction

Major incidents occur on a regular basis across the world and range from natural disasters to transport incidents and terrorist activities [1]. However, it was not until the early 1990s that formal training in major incident management became available, giving guidance to participants on the principles of effective management [2] Triage, the process of sorting patients and categorising them on the basis of clinical acuity, is a key principle and the first clinical management priority at a major incident.

By no means a new concept, triage has been in existence since the Napoleonic wars, and is not unique to major incidents [3]; indeed, it is carried out daily in a variety of clinical emergency environments [4–7]. The Major Incident Medical Management and Support (MIMMS) course recommends a two-stage approach to triage. The first, the Triage Sieve (TSi), is conducted by the initial responders finding the casualty at the incident scene. It is a rapid initial assessment only, and enables an overview of all casualties which can guide treatment priorities [2].

The Triage Sort (TSo) is a more detailed second assessment of the casualty and is conducted by more experienced medical personnel as patients arrive at the Casualty Clearing Station (CCS), a safe environment some distance from the scene, where more time and resources are available to medical staff [2]. Both the TSi and TSo allocate a patient to one of three categories, but there is

* Corresponding author at: Underwater Medicine Division, Institute of Naval Medicine, Alverstoke, Gosport, PO12 2DL, UK.
E-mail address: vassallo@doctors.org.uk (J. Vassallo).

http://dx.doi.org/10.1016/j.injury.2016.06.022
0020-1383/

limited guidance as to what the categories correspond to clinically [2,8]. Once casualties have been prioritised using the TSo at the Casualty Clearing Station, treatment can be initiated, depending on patient flow from the incident and the medical resources available.

On arrival at hospital, the patient will be re-triaged, again using the TSo, further guiding treatment priorities. Triage is a dynamic process, reflecting the nature of the patient's response to injury and subsequent treatment.

As would be expected, the TSi/TSo are not the only algorithms used in major incidents; both the US and Australia have developed their own [8,9]. However, all share the common principle of assigning patients to one of three categories. The three categories in guidance currently provided are:

- Priority 1, Immediate: Require immediate life-saving intervention (LSI)
- Priority 2, Urgent: Require medical or surgical intervention within 2–4 h
- Priority 3, Delayed: Treatment can be delayed > 4 h

The concept of a 'life-saving intervention' has evolved over time; in 1990, Baxt was the first to offer a resource-based definition to identify the major trauma patient [10]. Subsequently and specifically for the retrospective analysis of major incident triage algorithms, Garner produced a set of LSIs to define the priority one patient and validate existing algorithms [8]. The identification of those most in need of a life-saving intervention is now accepted as the purpose of major incident triage algorithms and they must be validated against this standard (rather than against the injury severity score (ISS) or other injury scores as has previously been done) [11]. The ISS, while it may be used to predict probability of survival, demonstrates a clear lack of correlation with the requirement for life-saving intervention and is itself not a tool for triage [10].

Consensus exists on what constitutes a LSI in a paediatric population [11] but comparatively little work has been done for an adult population. Building on a previously published list, Horne conducted an adapted Delphi that identified 34 LSIs for use in an adult military trauma population (Appendix A in Supplementary material) [8,12]. Although currently the only work of its kind, there is limited detail as to the Delphi methodology used, instead focusing on the derivation of a novel triage tool. Additionally, its intention was to reflect military and not civilian trauma care – with all participants currently deployed "to ensure that it reflected the most current military trauma practice." [12].

With marked differences in the injury mechanism between military and civilian populations as well as differences in available healthcare resources in the military setting, these life-saving interventions may not be wholly transferable to the civilian population [13]. In order to review and optimise current triage methods utilised at major incidents, there is a need to define the output of the triage process.

The aim of this study was to obtain consensus as to what constitutes a life-saving intervention during the definitive care phase of a civilian major incident. This in turn will allow us to define a triage priority one patient in the civilian setting. For the purposes of this study, a patient in the definitive care phase was one at an appropriate medical facility capable of providing advanced life-saving interventions with no limitation on available resources.

Methods

Using the framework set out by Boulkedid et al., a modified three round online Delphi study was conducted between July-December 2013. [14] This study received approval through the Human Research Ethics Committee of the University of Cape Town (reference 285/2013).

To maximise heterogeneity of the Delphi panel, participants were specialists in Emergency Care or Major Incident Management and drawn from the work locations of the authors: the United Kingdom and Republic of South Africa. The following initial screening criteria were used: held positions of authority within the sphere of emergency planning, involvement in Major Incident academic work, specialists in the management of major incidents, major trauma or the emergency care of patients, current MIMMS course faculty, Consultant Advisors, Defence Consultant Advisors or Defence Professors in specialities involved in deployed trauma care within the UK Defence Medical Services. Only those responding to the initial invitation were subsequently invited to take part in the Delphi study. Participation was fully anonymised throughout the study period, with no additional participants included after the first round commenced. Following the final round, consent was sought from participants to publish their names.

In keeping with prior studies within the literature, consensus was set *a priori* at 70% [15], with a four point Likert scale used to deter neutrality, ranging from strongly agree to strongly disagree. All rounds were distributed online using SurveyMonkey ® (SurveyMonkey Inc. Palo Alto, California, USA). Round one consisted of 51 interventions that included the 41 life-saving interventions described by Horne (Appendix A, Table 1; Horne, in Supplementary material). The other ten were related to timing (Appendix B, Table 3 in Supplementary material). During the first round, participants were given the opportunity to suggest additional interventions they considered to be life-saving of which all were included in the second round (Appendix C, Table 4 in Supplementary material). Email feedback was provided to all participants individually following each round. This included participant's individual responses from the preceding round and also group results. Interventions reaching positive or negative consensus (70%) were removed from subsequent rounds. Interventions reaching positive consensus after three rounds were considered to be LSIs, to be used to define Priority One patients.

Data were collected using SurveyMonkey ® (SurveyMonkey Inc. Palo Alto, California, USA) software and analysed using a Microsoft Excel ® spreadsheet.

Results

Of 74 potential experts identified, 30 responded and consented to take part in the first round; 24 completed all three rounds (UK 13 and SA 11) with the majority (20) from Emergency Medicine (Fig. 1).

Following three rounds 32 (64%) interventions reached positive consensus and were considered life-saving interventions (Table 1). Of the rest, 6 (12%) reached negative consensus and 12 (24%) failed to reach consensus. Fig. 2 demonstrates the flow of life-saving interventions throughout the Delphi. Detailed analysis of each round and subsequent flow is provided at Appendix D and E in Supplementary material.

Over three rounds only 6 of 10 time statements reached consensus status. The 2 positive statements were "following an injury, a LSI is one that is required immediately" and "following an injury, a LSI is one that is required within one hour". Four statements reached negative consensus (life-saving intervention required within 6,8.12 or 24 h).

Discussion

This study has determined a consensus opinion of life-saving interventions to be performed during the definitive care phase of a

Please cite this article in press as: J. Vassallo, et al., Major incident triage: A consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident, Injury (2016), http://dx.doi.org/10.1016/j.injury.2016.06.022

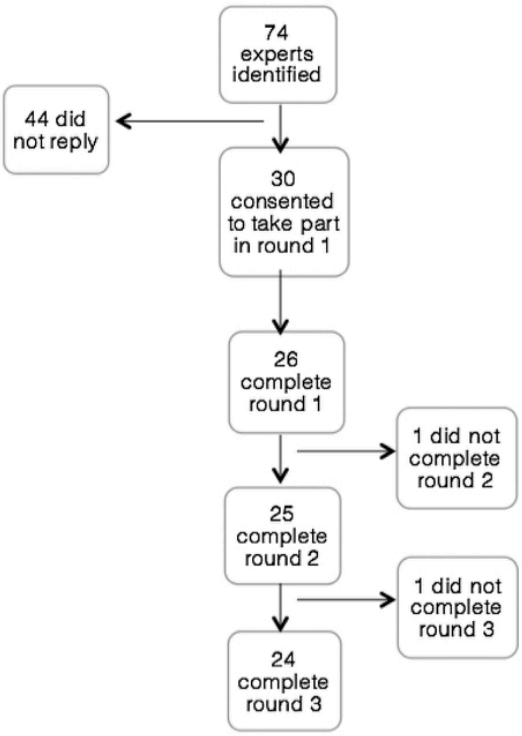


Fig. 1. Participation Flow Diagram.

Table 1
Results of the Delphi Process – Life-Saving Interventions.

	Intervention
1	Intubation for actual airway obstruction
2	Intubation for impending airway obstruction
3	Surgical airway for airway obstruction
4	Surgical airway for impending airway obstruction
5	Needle thoracocentesis
6	Finger thoracostomy
7	Tube thoracostomy
8	Application of a chest seal (commercial/improvised)
9	Positive Pressure Ventilation for ventilatory inadequacy
10	Application of a tourniquet for haemorrhage control
11	Use of haemostatic agents for haemorrhage control
12	Insertion of an intra-osseous device for resuscitation purposes
13	Receiving uncross-matched blood
14	Receiving $\geq$4 units of blood/blood products
15	Administration of tranexamic acid
16	Laparotomy for trauma
17	Thoracotomy for trauma
18	Pericardial window for trauma
19	Surgery to gain proximal vascular control
20	Interventional radiology for haemorrhage control
21	Application of a pelvic binder
22	ALS/ACLS protocols for a patient in a *peri*-arrest situation
23	ALS/ACLS protocols for a patient in cardiac arrest
24	Neurosurgery for the evacuation of an intra-cranial haematoma
25	Craniotomy
26	Burr Hole Insertion
27	Spinal nursing for a C1-3 fracture
28	Administration of a seizure-terminating medication
29	Active rewarming for initial core temp $<32^\circ$ celcius
30	Passive rewarming for initial core temp $<32^\circ$ celcius
31	Correction of low blood glucose
32	Administration of chemical antidotes

civilian major incident. Despite life-saving interventions being recognized as a more appropriate outcome than injury scores since 1990, the literature is very limited with regard to LSIs. [8,10–12] Within a paediatric cohort, Wallis identified 18 LSIs which, with the exception of three (related to simple airway adjuncts and supraglottic airway devices), all reached positive consensus in our study [11]. A second study identifying 32 LSIs used an adult military cohort [12]; 23 reached positive consensus in our study. With Horne's interventions largely forming the first round of our Delphi, the similarity between the two studies is unsurprising. However, a number of interventions, including crystalloid resuscitation and inotrope administration, were removed having reached negative consensus. Certain differences between the two can be explained by the context of the former study, representing LSIs within an operational military setting. Interventional radiology for haemorrhage control reached positive consensus in our study, and whilst it exists in some UK centres, it is not a UK military deployable specialty and therefore not included by Horne [12]. Although the literature has described the use of interventional radiology for haemorrhage control since 1973 [16,17], LSI studies subsequent to this (1990 and 2000) have failed to include it [8,10–12].

There were only two time statements reaching positive consensus in our study, with interventions required either immediately or within one hour to be life-saving. This relates well to existing literature; non-orthopaedic surgery was required within one hour for the paediatric patient and the suggestion that adult patients able to wait longer than 2 h were unlikely to be critical [11,12]. This study has developed previous work and identified 32 life-saving interventions for the adult patient, ranging from the administration of uncross-matched blood to specific surgical procedures. Where previously studies have described life-saving interventions more generically, we have been discriminating in our approach and described specific interventions; for example fluid resuscitation is specified by fluid type and neurosurgical procedures and injuries are listed individually. We feel that producing a more exhaustive list of life-saving interventions adds strength to our study, and also enables subsequent major incident triage research to be conducted more reliably, without author bias or ambiguity, on data obtained from trauma registries.

The use of ALS/ACLS for both peri-arrest and cardiac arrest patients reached positive consensus with an overwhelming majority showing agreement (91% and 87% respectively) on the initial round of the study. Although we expect that its inclusion as a life-saving intervention will attract some criticism, it should be remembered that medical casualties may result from a major incident, such as in stadia crush incidents, multiple drownings or lightning strikes. The ability to provide life-saving interventions will depend on the location in which they are being performed, the resources available (scene/CCS/hospital) and the demand on those resources. For the purposes of this study the interventions were being performed hypothetically during the definitive care phase of a major incident, in an appropriate medical facility with no limitation on resources. While this might be considered a limitation in the context of the study, it has allowed for consensus opinion to what can be considered as 'gold-standard' life-saving interventions, irrespective of resources and demand. In addition to ALS/ACLS, a number of other medical interventions including the correction of hypoglycaemia and hypothermia all received positive consensus in our study. In accordance with published guidance on reporting Delphi methodology, all statements reaching positive consensus have been reported [14].

For a number of interventions, variation was observed in the overall response following the second and third rounds. Although not possible to fully quantify, this is not unexpected as the Delphi

Please cite this article in press as: J. Vassallo, et al., Major incident triage: A consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident, Injury (2016), http://dx.doi.org/10.1016/j.injury.2016.06.022

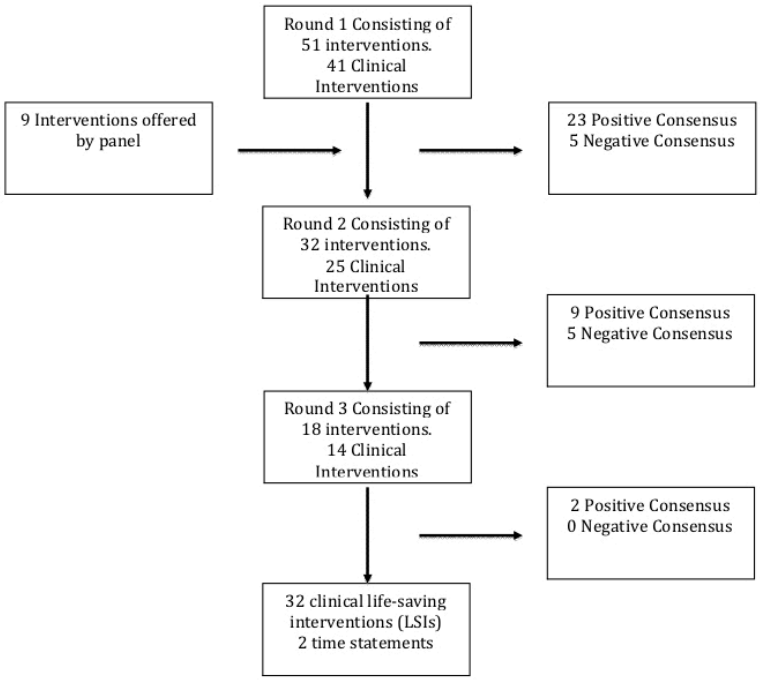


Fig. 2. Flow of interventions each round.

method is a multi-stage iterative process [20]. Following each round participants received both their individual responses and the group mean responses from the previous round. This is to allow them to review their position on statements in comparison to the group position and may account for some of the variability seen. Human factors may additionally explain some of the variation; if between rounds an intervention in dispute for a participant proved life-saving in clinical practice, then this will likely influence the individual's responses.

Delphi methodology is a well established means of obtaining expert opinion to quantify variables in a systematic fashion [19,20]. Whilst it has been frequently employed for a variety of topics, including major incident management, it is not without its limitations including, but not limited to the selection of participants and the execution of the process [11,20,21]. Previous Delphi studies have documented a median of 17 (IQR 11–31) participants with limited anonymity; our sample consisted of 24 participants completing all three rounds, all of whom were anonymised throughout the duration of the study [14].

We employed the Delphi method for our study as the outcome is best identified by those with a combined knowledge of clinical care and major incident management, and requires a multi-disciplinary approach [11,18]. Although it is acknowledged that past experience may influence decisions and represent participation bias, the anonymous nature of the Delphi reduces this bias when compared to other consensus methods and increases the strength of the study [20].

The definition of expertise is subjective and the identification of potential participants is reliant on the researchers being familiar with suitable individuals [22]. In order to increase the heterogeneity of the panel, participants with experience in major incident management were invited from a variety of backgrounds.

Whilst the outcome of the Delphi represents a consensus opinion, it is recognized that a limitation exists through restricting participation to individuals from the UK and South Africa, countries with a developed major incident response. We acknowledge that whilst the interventions are likely to be considered life-saving worldwide irrespective of participant location, consensus might be expected to change if the response was considered in a resource-poor setting. In this setting, a number of interventions may be considered inappropriate, namely interventional radiology, neurosurgery and thoracotomy. Additionally, where there is no developed response, the capability to provide a pre-hospital medical response and therefore perform life-saving interventions prior to arrival in hospital will be limited.

A key limitation of our study is the attempt to quantify the time period in which an intervention is considered life-saving; we have assumed that there will be no clinical deterioration following initial resuscitation. In the context of clinical deterioration, any of the interventions described would be considered life-saving, irrespective of when they were performed; supported by the statement "no time limit" failing to reach consensus. Additionally, we have not stated when the time period begins, leading to potential ambiguity. In practice, three possible starting points can be identified, immediately following injury, on arrival of Emergency Medical Services (EMS), or on arrival in hospital. Although adopting time of injury as the 'start' point would clearly be the optimum measure, it is not without limitation; the time from injury to EMS notification will largely be unmeasurable. Within our study, only interventions performed within one hour reached positive consensus; in an urban setting and even with a developed EMS system, this is likely to be challenging to achieve for all patients. Although a clear limitation, the delay from arrival of EMS to hospital arrival (median 87 min) [23], adopting hospital arrival as the 'start' point allows for a unifying measurable standard;

Please cite this article in press as: J. Vassallo, et al., Major incident triage: A consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident, Injury (2016), http://dx.doi.org/10.1016/j.injury.2016.06.022

irrespective of the injury location and resources available [23]. For this reason, we recommend that this is the adopted measure.

Conclusion

This Delphi study has demonstrated consensus on what constitutes a life-saving intervention during the definitive care phase of a civilian major incident. A panel of experts drawn from two countries considered 32 interventions, performed within one hour, to be life-saving. This may be used to facilitate the definition of a priority one patient. Although similar work has been done previously for a paediatric population, this is the first time such work has been done for an adult, civilian population. This bridges a gap in the literature and can now be used to conduct further research into major incident triage with the specific intention of developing and validating an adult major incident triage tool.

Conflict of interest

The authors declare that they have no conflicts of interest. JV and JES are serving members of the UK Armed Forces.

Acknowledgements

The following took part in the Delphi and consented for their names to be published. The authors would like to thank them for their participation: Dr I d'Andrea, Prof J Benger, Dr S Bruijns, Prof S Carley, Dr K Challen, Dr F Cloete, Dr A Crede, Dr H Geduld, Dr T Hardcastle, Prof T Harris, Lt Col S Horne, Dr T Hurst, Dr J Keep, Dr S Lahri, Prof F Lecky, Dr S Le Roux, Prof K Mackway-Jones, Dr R Maharaj, Col R Russell, Dr P Shirley, Dr M Tunnicliff, Dr K Vallabh, Dr M Wells.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.injury.2016.06.022.

References

[1] Challen K, Walter D. Major incident triage: comparative validation using data from 7th July bombings. Injury 2013;44(5):629–33.
[2] Advanced Life Support Group. Major Incident medical management and support: the practical approach. 3rd edition London, England: BMJ Publishing; 2011. p. 1–7.
[3] Horne S, Vassallo J. Triage in the Defence Medical Services. J R Army Med Corps 2015;161(2):90–3.
[4] Bunn F, Byrne G, Kendall S. Telephone consultation and triage: effects on health care use and patient satisfaction. Cochrane Database Syst Rev 2004;3, doi:http://dx.doi.org/10.1002/14651858.CD004180.pub2 Art. No.: CD004180.
[5] Cooke MW, Jinks S. Does the Manchester triage system detect the critically ill? J Accid Emerg Med 1999;16(3):179–81.
[6] Potter D, Kehoe A, Smith JE. The sensitivity of pre-hospital and in-hospital tools for the identification of major trauma patients presenting to a major trauma centre. J R Nav Med Serv 2013;99(1):16–9.
[7] Eastwood K, Morgans A, Smith K, et al. Secondary Triage in prehospital emergency ambulance services: a systematic review. Emerg Med J 2015;32(6):486–92.
[8] Garner A, Lee A, Harrison K, Schultz CH. Comparative analysis of multiple-casualty incident triage algorithms. Ann Emerg Med 2001;38(5):541–8.
[9] Benson M, Koenig KL, Schultz CH. Disaster triage: START, then SAVE- a new method of dynamic triage for victims of a catastrophic earthquake. Prehosp Disaster Med 1996;11(2):117–24.
[10] Baxt WG, Upenieks V. The lack of full correlation between the Injury Severity Score and the resource needs of injured patients. Ann Emerg Med. 1990;19(12):1396–400.
[11] Wallis L, Carley S, Hodgetts CT. A procedure based alternative to the injury severity score for major incident triage of children: results of a Delphi consensus process. Emerg Med J 2006;23(4):291–5.
[12] Horne S, Vassallo J, Read J, Ball S. UK triage–an improved tool for an evolving threat. Injury 2013;44(1):23–8.
[13] Ramasamy A, Harrisson S, Lasrado I, Stewart MP. A review of casualties during the Iraqi insurgency 2006?a British field hospital experience. Injury 2009;40(5):493–7.
[14] Boulkedid R, Abdoul H, Loustau M, Sibony O, Alberti C. Using and reporting the Delphi method for selecting healthcare quality indicators: a systematic review. PLoS One 2011;6(6):e20476.
[15] Sumsion T. The delphi technique: an adaptive research tool. Br J Occup Ther 1998;61(4):153–6.
[16] Ring EJ, Athanasoulis C, Waltman AC, Margolies MN, Baum S. Arteriographic management of haemorrhage following pelvic fracture. Radiology 1973;109(1):65–70.
[17] Bauer JR, Ray CE. Transcatheter arterial embolization in the trauma patient: a review. Semin Intervent Radiol 2004;21(1):11–22.
[18] Hasson F, Keeney S, McKenna H. Research guidelines for the Delphi survey technique. J Adv Nurs 2000;32:1008–15.
[19] Pill J. The Delphi method: substance, context, a critique and an annotated bibliography. Socio Econ Plan Sci 1971;5:57–71.
[20] Fink A, Kosecoff J, Chassin M, Brook RH. Consensus methods: characteristics and guidelines for use. Am J Public Health 1984;74(9):979–83.
[21] Carley SD, Mackway-Jones K, Donnan S. Delphi study into planning for care of children in major incidents. Arch Dis Child 1999;80:406–9.
[22] Crawford IWF, Mackway-Jones K, Russell DR, Carley SD. Delphi based consensus study into planning for chemical incidents. Emerg Med J 2004;21(1):24–8.
[23] Stordahl H, Passas E, Hopland A, Nielsen EW. Nine out of ten trauma calls to a Norwegian hospital are avoidable: a retrospective analysis. BMC Emerg Med 2015;3(1):15.

Please cite this article in press as: J. Vassallo, et al., Major incident triage: A consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident, Injury (2016), http://dx.doi.org/10.1016/j.injury.2016.06.022

Discussion of study

Supplementary methods

Consensus methodology is frequently used in the healthcare setting and is a means of gathering agreement on potentially controversial or ambiguous topics. Three common consensus methods exist; the nominal group process, the consensus development panel and the Delphi process.[103] A modified Delphi process was used in this study to determine consensus as to what constitutes a life-saving intervention for the adult patient in the major incident setting.

The Delphi process was first described by the RAND corporation in the 1950s for conducting military research; using a panel of seven experts in a variety of fields, they determined the specific requirements for military operations.[104] It has frequently been used in a medical setting, with numerous examples in the Emergency Medicine literature, encompassing a wide range of subjects from prioritisation of curriculum content in speciality training through to determining transfer criteria for abdominal aortic aneurysms.[105,106]

Where both the nominal group process and consensus development panel involve face to face contact, a key principle of Delphi methodology is the requirement for participant anonymity. This conveys two distinct advantages; firstly it removes any geographical barriers to meeting, thus allowing for greater participant involvement, and secondly, participants in face to face meetings may face participation bias, and have their opinions influenced by other participants. By removing physical meetings, this participation bias is reduced, and allows for a more genuine representation of the individual participant.[107]

The principles of a Delphi process involve selecting a panel of experts, then through a series of rounds seeking consensus opinion on the subject in question. Following each round, feedback is provided to the participants, allowing them to review their responses in the subsequent round. This is continued for either a pre-determined number of rounds or until a pre-defined level of consensus has been reached.

Participant Selection

The expert panel was drawn from the work locations of the authors: the UK and Republic of South Africa. Seventy-four potential participants were identified by the authors (JV, JES and LAW) and an email invitation was sent to these to invite them to participate in the study. The criteria for participant selection were:

1. Held positions of authority within the sphere of emergency planning
2. Involvement in Major Incident academic work
3. Specialists in the management of major incidents, major trauma or emergency care of patients
4. Current MIMMS course faculty
5. Consultant Advisors, Defence Consultant Advisors or Defence Professors in specialities involved in deployed trauma care with the UK Defence Medical Services (DMS)

Only those responding to the initial invitation were included in the study, and no additional participants were included during subsequent rounds.

Round One

Traditionally the first round of a Delphi involves asking the panel open, descriptive questions around a topic with the aim of producing a questionnaire with which consensus can subsequently be sought. One of the difficulties associated with Delphi methodology is participation fatigue, where participants fail to complete subsequent rounds of the Delphi process. In order to mitigate and reduce the potential for this effect, a modified approach was taken, with the initial round consisting of a set of previously defined list of life-saving interventions which had been derived by a group of eight UK DMS consultants deployed in an operational military setting (**Table 2.3**).[18]

Airway

1. Intubation for low GCS or airway obstruction (actual or impending).
2. Surgical airway.
3. Oral or nasal airway for impaired ventilation with GCS < 13.

Breathing

4. Any kind of thoracostomy (needle, finger, tube).
5. Positive pressure ventilation for ventilatory inadequacy.

Circulation

6. Tourniquet or haemostatic agents applied to control bleeding.
7. Central line or intraosseous access for resuscitation.
8. > 4 units blood products, > 4 litres crystalloids or inotropes given.
9. Proximal amputations.
10. Fasciotomies for actual/suspected compartment syndrome.
11. Laparotomy or thoracotomy/pericardial window.
12. Ex-fix to pelvis or open femur fracture for haemorrhage control.
13. Surgical proximal vascular control.
14. Peri-arrest rhythm or cardiac arrest requiring Advanced (Cardiac) Life Support.

Disability

15. Immediate neurosurgery.
16. Spinal nursing for proven unstable cervical spine fracture.

Environment

17. Active re-warming for initial temperature less than 32° Celsius.
18. Chemical antidotes (organophosphates, carbon monoxide, cyanide).

Table 2.3: Life-saving interventions defined by Horne et al.[18]

Using a four-point Likert scale (Strongly Agree, Agree, Disagree, Strongly Disagree) participants reported the level of agreement with each intervention they considered to be life-saving. In keeping with other examples of Delphi studies in the literature, consensus was set *a priori* at 70% - statements reaching consensus were removed from subsequent rounds.[106,108,109] In addition to the list shown in **Table 2.3**, participants were given the opportunity to include additional interventions that they considered to be life-saving. Nine additional interventions were offered (**Table 2.4**) and were automatically included in round two for participants to review.

1. Application of a pelvic binder.
2. Administration of tranexamic acid.
3. Correction of low blood glucose levels.
4. Administration of seizure-terminating medications.
5. Administration of thrombolysis/use of percutaneous coronary intervention.
6. Application of a chest seal.
7. Craniotomy/burr hole insertion.
8. Acute haemofiltration.
9. Decompressive craniectomy.

Table 2.4: Additional life-saving interventions offered by Delphi panel following round one.

Timing of interventions

Baxt et al stated that one criteria for defining the major trauma patient was non-orthopaedic operative intervention within the first 24 hours of injury.[110] When subsequently applied to the major incident context, Garner reduced the time period for non-orthopaedic operative intervention to the initial six hours.[12] Whilst MIMMS states that the Priority One patient requires a life-saving intervention 'immediately', there is no time period to quantify 'immediately' and so one may speculate that it is likely to represent intervention within the initial two hours; as beyond two hours patients are categorised as Priority Two.[3] As an extension to the Delphi process, consensus was sought to determine the time period in which an intervention was considered to be life-saving. Again, using a four-point Likert scale, and with consensus set at 70%, participants were asked to state their agreement with the time periods in **Table 2.5**.

1. A life-saving intervention is one that is required immediately.
2. A life-saving intervention is one that is required within one hour.
3. A life-saving intervention is one that is required within two hours.
4. A life-saving intervention is one that is required within three hours.
5. A life-saving intervention is one that is required within four hours.
6. A life-saving intervention is one that is required within six hours.
7. A life-saving intervention is one that is required within eight hours.
8. A life-saving intervention is one that is required within twelve hours.
9. A life-saving intervention is one that is required within twenty-four hours.
10. There is no time limit for an intervention to be considered life-saving.

Table 2.5: Timing of life-saving interventions.

Conduct of the study

In keeping with a systematic review of Delphi framework described by Boulkedid, the Delphi process was conducted online over three rounds using SurveyMonkey® (SurveyMonkey Inc. Palo Alto, California, USA) with data being exported to and analysed in Microsoft Excel® by the author (JV).[111] Both individual and collective feedback was provided to participants before subsequent rounds commenced. Each online round remained active for approximately one month, with the study taking place between July and December 2013. Participants were sent a reminder during the round in order to ensure maximal participation.

Supplementary results

Of the 74 potential participants identified, only 30 (40.5%) responded to the invitation email and agreed to take part in the study. Of these, 24 completed all three rounds giving an 80.0% completion rate (**Figure 2.1**). Whilst 40.5% participation is low, the final number of participants exceeds the median number (n=17, IQR 11-31) of participants reported in a systematic review of the Delphi process by Boulkedid et al.[111] The majority of participants were specialists in Emergency Medicine (n=21), with Anaesthesia (n=2) and Surgery (n=1) making up the remainder.

Over the three rounds a total of 50 interventions were reviewed by the Delphi panel, with 32 (64.0%) reaching positive consensus and being considered life-saving. Six (12%) were considered to not be life-saving and were therefore removed from the process. 12 (24%) interventions failed to reach consensus. Of ten statements relating to timing of life-saving interventions, two reached positive consensus (interventions should be performed immediately and within one hour) and four reached negative consensus (interventions are considered life-saving up to six, eight, twelve or twenty-four hours) - see **Figures 2.2, 2.3** and **Table 2.1**.

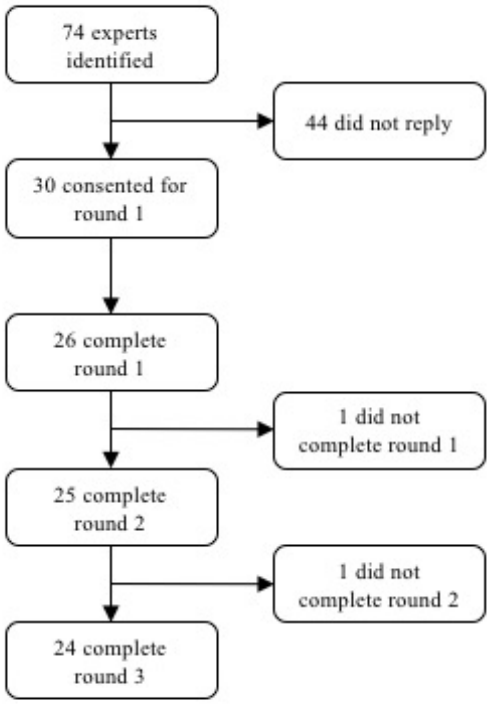


Figure 2.1: Delphi participation flow diagram.[24]

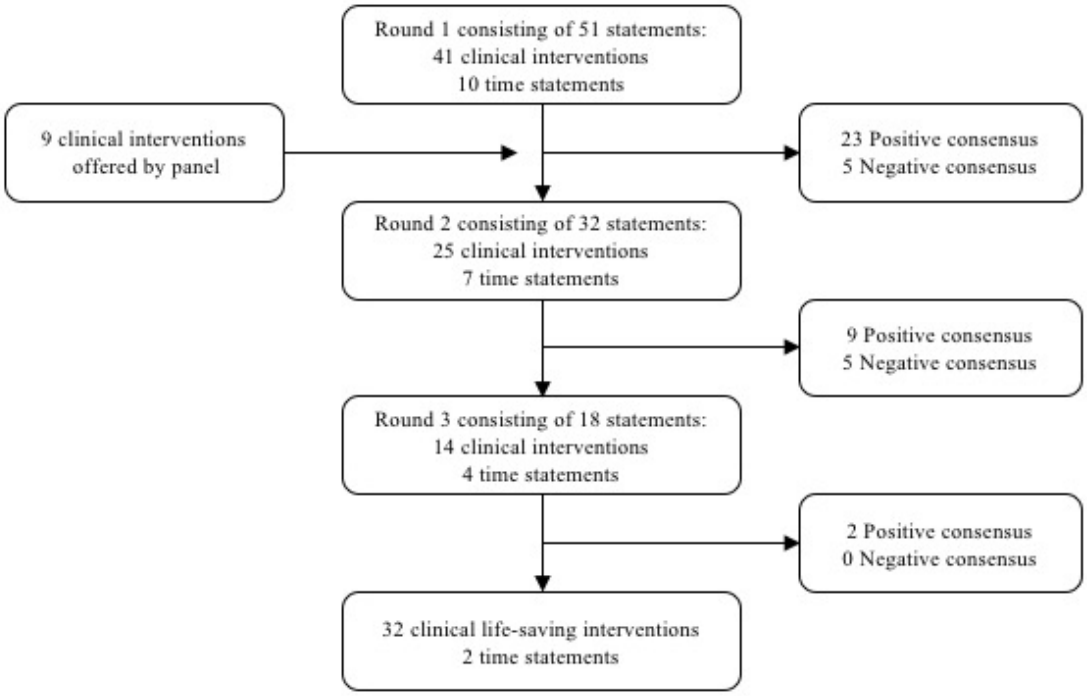


Figure 2.2: Flow of interventions during each round of the Delphi process.[24]

	Round 1			Round 2			Round 3		
Intervention	***% Positive***	***% Negative***	***Outcome***	***% Positive***	***% Negative***	***Outcome***	***%Positive***	***% Negative***	***Outcome***
Intubation for a reduced GCS is a life-saving intervention.	***52%***	***48%***		***52%***	***48%***		***58%***	***42%***	
Intubation for actual airway obstruction is a life-saving intervention.	***92%***	***8%***	*Removed*						
Intubation for impending airway obstruction is a life-saving intervention.	***76%***	***24%***	*Removed*						
The insertion of a supra-glottic airway device for a reduced GCS is a life-saving intervention.	***36%***	***64%***		***36%***	***64%***		***42%***	***58%***	
A surgical airway for a reduced GCS is a life-saving intervention.	***24%***	***76%***	*Removed*						
A surgical airway for actual airway obstruction is a life-saving intervention.	***96%***	***4%***	*Removed*						
A surgical airway for impending airway obstruction is a life-saving intervention.	***52%***	***48%***		***76%***	***24%***				
The insertion of an OPA in a patient with impaired ventilation and a GCS <13 is a life-saving intervention.	***40%***	***60%***		***40%***	***60%***		***43%***	***57%***	
The insertion of a NPA in a patient with impaired ventilation and a GCS <13 is a life-saving intervention.	***40%***	***60%***		***36%***	***64%***		***33%***	***67%***	
Needle thoracocentesis is a life-saving intervention.	***84%***	***16%***	*Removed*						
Finger thoracostomy is a life-saving intervention.	***92%***	***8%***	*Removed*						
Tube thoracostomy is a life-saving intervention.	***64%***	***36%***		***72%***	***28%***	*Removed*			
Application of a chest seal (commercial/improvised) is a life-saving intervention.				***76%***	***24%***	*Removed*			
PPV for ventilator inadequacy is a life-saving intervention.	***96%***	***4%***	*Removed*						
The Application of a tourniquet to control haemorrhage is a life-saving intervention.	***96%***	***4%***	*Removed*						
The use of haemostatic agents to control haemorrhage is a life-saving intervention.	***79%***	***21%***	*Removed*						
The insertion of a central line for resuscitation purposes is a life-saving intervention.	***25%***	***75%***	*Removed*						
The insertion of an intra-osseous device for resuscitation purposes is a life-saving intervention.	***87%***	***13%***	*Removed*						
Receiving uncross-matched blood is a life-saving intervention.	***96%***	***4%***	*Removed*						
Receiving ≥4 units of blood/blood products is a life-saving intervention.	***83%***	***17%***	*Removed*						
Receiving ≥ 4 or more litres of crystalloid is a life-saving intervention.	***29%***	***71%***	*Removed*						
The use of inotropes is a life-saving intervention.	***63%***	***37%***		***44%***	***56%***		***42%***	***58%***	
Administration of tranexamic acid is a life-saving intervention.				***60%***	***40%***		***70%***	***30%***	*Removed*
Application of a pelvic binder is a life-saving intervention.				***88%***	***12%***	*Removed*			
Thrombolysis or PCI is a life-saving intervention.				***80%***	***20%***	*Removed*			
A proximal amputation is a life-saving intervention.	***56%***	***44%***		***48%***	***52%***		***63%***	***37%***	
A fasciotomy for suspected compartment syndrome is a life-saving intervention.	***43%***	***57%***		***24%***	***76%***	*Removed*			
A fasciotomy for actual compartment syndrome is a life-saving intervention.	***62%***	***38%***		***60%***	***40%***		***58%***	***42%***	
A laparotomy in the context of trauma is a life-saving intervention.	***96%***	***4%***	*Removed*						
A thoracotomy in the context of trauma is a life-saving intervention.	***96%***	***4%***	*Removed*						

The application of EX-FIX to a pelvic fracture for haemorrhage control is a life-saving intervention.	***56%***	***44%***		***44%***	***56%***		***46%***	***54%***	
The application of EX-FIX to a femoral fracture for haemorrhage control is a life-saving intervention.	***46%***	***54%***		***46%***	***56%***		***42%***	***58%***	
The use of ALS/ACLS protocols/management for a patient in a peri-arrest rhythm is a life-saving intervention.	***91%***	***9%***	*Removed*						
The use of ALS/ACLS protocols/management for a patient in a cardiac-arrest rhythm is a life-saving intervention.	***87%***	***13%***	*Removed*						
The use of interventional radiology to control haemorrhage is a life-saving intervention.	***79%***	***21%***	*Removed*						
The insertion of a intra-cranial pressure monitoring device is a life-saving intervention.	***17%***	***83%***	*Removed*						
Neurosurgery for the evacuation of a intra-cranial haematoma is a life-saving intervention.	***96%***	***4%***	*Removed*						
Spinal nursing for a C1-3 fracture is a life-saving intervention.	***75%***	***25%***	*Removed*						
Spinal Nursing for a C4-7 fracture is a life-saving intervention.	***62%***	***38%***		***60%***	***40%***		***58%***	***42%***	
Spinal nursing for a bilateral facet fracture of the cervical vertebra is a life-saving intervention.	***48%***	***52%***		***60%***	***40%***		***58%***	***42%***	
Craniotomy/Burr Holes are a life-saving intervention.				***87%***	***13%***	*Removed*			
A decompressive craniectomy for diffuse axonal injury is a life-saving intervention.				***20%***	***80%***	*Removed*			
Active rewarming for an initial core temp < 32 degrees celcius is a life-saving intervention.	***83%***	***17%***	*Removed*						
Passive rewarming for an initial core temp < 32 degrees celcius is a life-saving intervention.	***50%***	***50%***		***70%***	***30%***	*Removed*			
The administration of chemical antidotes is a life-saving intervention.	***96%***	***4%***	*Removed*						
The administration of seizure terminating medication is a life-saving intervention.				***80%***	***20%***	*Removed*			
The correction of low blood glucose is a life-saving intervention.				***92%***	***8%***	*Removed*			
Acute haemofiltration is a life-saving intervention.				***63%***	***37%***		***67%***	***33%***	
Timing of interventions									
A life-saving intervention is one that is required immediately.	***92%***	***8%***	*Removed*						
A life-saving intervention is one that is required within one hour.	***75%***	***25%***	*Removed*						
A life-saving intervention is one that is required within two hours.	***58%***	***42%***		***64%***	***36%***		***61%***	***39%***	
A life-saving intervention is one that is required within three hours.	***50%***	***50%***		***36%***	***64%***		***39%***	***61%***	
A life-saving intervention is one that is required within four hours.	***46%***	***54%***		***32%***	***68%***		***39%***	***61%***	
A life-saving intervention is one that is required within six hours.	***38%***	***62%***		***24%***	***76%***	*Removed*			
A life-saving intervention is one that is required within eight hours.	***33%***	***67%***		***12%***	***88%***	*Removed*			
A life-saving intervention is one that is required within twelve hours.	***33%***	***67%***		***16%***	***84%***	*Removed*			
A life-saving intervention is one that is required within twenty-four hours.	***29%***	***71%***	*Removed*						
There is no time limit for an intervention to be considered life-saving.	***46%***	***54%***		***60%***	***40%***		***67%***	***33%***	

Table 2.6: Results of Delphi process.

GCS - Glasgow Coma Scale, OPA – Oropharyngeal airway, NPA – Nasopharyngeal airway, PCI – percutaneous intervention, EX-FIX – external fixator device, ALS – advanced life support, ACLS – advanced cardiac life support

	Intervention
1	Intubation for actual airway obstruction
2	Intubation for impending airway obstruction
3	Surgical airway for airway obstruction
4	Surgical airway for impending airway obstruction
5	Needle thoracocentesis
6	Finger thoracostomy
7	Tube thoracostomy
8	Application of a chest seal (commercial/improvised)
9	Positive Pressure Ventilation for ventilatory inadequacy
10	Application of a tourniquet for haemorrhage control
11	Use of haemostatic agents for haemorrhage control
12	Insertion of an intra-osseous device for resuscitation purposes
13	Receiving uncross-matched blood
14	Receiving ≥ 4 units of blood/blood products
15	Administration of tranexamic acid
16	Laparotomy for trauma
17	Thoracotomy for trauma
18	Pericardial window for trauma
19	Surgery to gain proximal vascular control
20	Interventional radiology for haemorrhage control
21	Application of a pelvic binder
22	ALS/ACLS protocols for a patient in a *peri*-arrest situation
23	ALS/ACLS protocols for a patient in cardiac arrest
24	Neurosurgery for the evacuation of an intra-cranial haematoma
25	Craniotomy
26	Burr Hole Insertion
27	Spinal nursing for a C1-3 fracture
28	Administration of a seizure-terminating medication
29	Active rewarming for initial core temp $<32^\circ$ celcius
30	Passive rewarming for initial core temp $<32^\circ$ celcius
31	Correction of low blood glucose
32	Administration of chemical antidotes

Figure 2.3: Clinical interventions considered life-saving.[24]

For interventions not reaching consensus (either positive or negative), the median and interquartile ranges (IQR) were calculated to further analyse the data (**Table 2.7**). To do this the Likert scale was converted to a numerical scale (1 – Strongly Agree, 2 – Agree, 3 – Disagree, 4 – Strongly Disagree). Measuring for central tendency is an alternative method described for determining consensus in Delphi studies and when a reduced Likert scale is used, such as in our study, an IQR of one or less is suggestive of consensus.[104] When the results were analysed, with the exception of two interventions (oropharyngeal (OPA) and nasopharyngeal airway (NPA) insertion), all other clinical interventions reached consensus (six positive and four negative). Although the IQR was two, indicating consensus hadn't been reached, the median for both OPA and NPA insertion was three, indicating that the panel had a tendency to disagree that these were life-saving interventions.

When measures of central tendency were calculated for the time statements, consensus was reached that a life-saving intervention is required within two hours and no longer. For the statement "there is no time limit for an intervention to be considered life-saving", the median score indicated agreement, but this did not reach consensus.

Intervention	Median (IQR)
Intubation for a reduced GCS is a life-saving intervention.	2 (1)
The insertion of a supra-glottic airway device for a reduced GCS is a life-saving intervention.	3 (1)
The insertion of an OPA in a patient with impaired ventilation and a GCS <13 is a life-saving intervention.	3 (2)
The insertion of a NPA in a patient with impaired ventilation and a GCS <13 is a life-saving intervention.	3 (2)
The use of inotropes is a life-saving intervention.	3 (1)
A proximal amputation is a life-saving intervention.	2 (1)
A fasciotomy for actual compartment syndrome is considered a life-saving intervention.	2 (1)
The application of an EX-FIX to a pelvic fracture for haemorrhage control is a life-saving intervention.	3 (1)
The application of an EX-FIX to a femoral fracture for haemorrhage control is a life-saving intervention.	3 (1)
Spinal nursing for a C4-7 fracture is a life-saving intervention.	2 (1)
Spinal nursing for a bilateral facet fracture of the cervical vertebra is a life-saving intervention.	2 (1)
Acute haemofiltration is a life-saving intervention.	2 (1)
Timing of interventions	
A life-saving intervention is one that is required within two hours.	2 (1)
A life-saving intervention is one that is required within three hours.	3 (1)
A life-saving intervention is one that is required within four hours.	3 (1)
There is no time limit for an intervention to be considered life-saving.	2 (2)

Table 2.7: Measures of central tendency for interventions not reaching consensus.

After this study was published, Lerner et al produced a set of criteria with which to evaluate mass casualty incidents, of which there is considerable overlap with this study.[56] The work by Lerner et al defined the immediate or Priority One category of patients as requiring one of nine groups of interventions within varying time periods (**Table 2.8**).

1. Neurological, vascular or haemorrhage-control surgery to the head, neck, or torso performed within 4 hours of hospital arrival.
2. Limb-conserving surgery performed within 4 hours of arrival at a hospital on a limb that was found to be pulseless distal to the injury prior to surgery.
3. Escharotomy performed on a patient with burns within 2 hours of arrival at a hospital.
4. Chest tube placed within 2 hours of arrival at a hospital.
5. An advanced airway intervention (e.g. intubation, laryngeal mask airway, surgical airway) performed in the pre-hospital setting or within 4 hours of arrival at a hospital.
6. Intravenous vasopressors administered within 2 hours of arrival at a hospital.
7. Arrived in the ED with uncontrolled haemorrhage.
8. Chemical exposure requiring additional treatment with antidotes in the ED or in the hospital within 4 hours of arrival that was provided to correct symptoms and not solely for patient comfort and/or the relief of minor symptoms (e.g. rhinorrhoea).
9. Patient who required EMS initiation of cardiopulmonary resuscitation (i.e. had a cardiac arrest) during transport, in the ED, or within 4 hours of arrival at a hospital.

Table 2.8: Definition of the 'immediate' patient, Lerner at al.[56]

When the two studies are compared, there are a number of similarities, but equally a number of differences, such as the use of vasopressors or laryngeal mask airways, both of which failed to reach consensus, with a median score disagreeing that they should be considered life-saving. There are a number of limitations to this study, and these include a small number of participants (n=13), with only 11 completing all three rounds. Additionally, the panel interviewed was from a single country (USA), with less heterogeneity than the panel involved in this study.

Supplementary limitations

As discussed in the paper, whilst this study was conducted and reported in line with suggestions from a previous systematic review on Delphi methodology there are still a number of limitations.[111] The identification of an expert panel is a subjective assessment and one that was made by the authors (JV, JES and LAW), which itself is a limitation. Although attempts were made to include clinicians from a variety of specialities to increase panel heterogeneity, the overwhelming majority were emergency medicine specialists. Whilst emergency medicine specialists may be present at a major incident, they are unlikely to form the majority of the initial response, with this role being provided by EMS, and it is acknowledged that an additional limitation of this study is a lack of representation from non-physician EMS responders.

Worldwide, irrespective of the patient's location, all the interventions would be considered life-saving, but the ability to provide them will be multi-factorial. For example, within the UK DMS, interventional radiology is not currently a deployed specialty so as an intervention, this could not be provided. However, in this setting, an advanced EMS is available, with senior physicians capable of performing multiple interventions from **Figure 2.3**, including pre-hospital thoracotomy, delivering anaesthesia and initiating resuscitation with blood products. In resource-poor settings, where there may not be such a developed EMS, few interventions are likely to be possible prior to arrival in hospital. Equally, within the hospital setting it may not be appropriate to perform particular interventions, if the resources are unavailable to support the subsequent requirement for ongoing care.

Identifying the time period in which an intervention is considered to be life-saving proved difficult, with consensus reached for interventions performed immediately and within one hour only. The nature in which the statements were phrased may have led to potential ambiguity for the panel, as it was not specified from what point those time periods began. In the paper, three possible start points are discussed, each with its own associated limitations. Whilst the ideal start point would be from time of injury, it is possible that this may not be known, especially in the context of a major incident occurring in a rural or developing area. Additionally, should an incident occur in a rural area, there may well be a delay in activating EMS, which will then further delay their arrival. Even in settings with a developed EMS, the median time from EMS arrival to hospital arrival is 87 minutes, clearly exceeding the one hour time period reaching consensus.[112] Although there is likely to be an accumulation of these time delays, adopting hospital arrival as the starting time point is recommended as it allows for a unifying measurable standard, irrespective of injury location and EMS resources available.

The study made the assumption that there would be no clinical deterioration following resuscitation; clearly in the event of deterioration, irrespective of the time at which this occurs, the interventions performed would be considered life-saving. This is supported by the statement "there is no time limit for an intervention to be considered life-saving" not reaching consensus either by percentage agreement or by IQR, but with the median response to 'agree' with the statement. Additionally, when reviewing the comments from the panel, it was felt that in the context of clinical deterioration the interventions performed would be life-saving irrespective of the time period.

The life-saving interventions in **Figure 2.3** represent the gold-standard definition of the Priority One patient, i.e. a Priority One patient will be expected to need at least one of these 32 interventions. Within a developed healthcare setting, it would be expected that these interventions would be able to be provided to all patients on an individual basis. Due to the nature of major incidents, it is likely that the earliest opportunity that the majority of these interventions can be performed (with the exception of external haemorrhage control) will be in the Casualty Clearing Station (CCS); a permissive environment set up away from the initial scene and staffed by more experienced clinicians. However, the ability to provide these interventions at the CCS or hospital relies on a developed major incident plan, and for the CCS it will specifically require experienced clinicians with the appropriate equipment to be deployed forward of the hospital. It is acknowledged that in the context of overwhelmed healthcare resources, both at the CCS and at hospital it may not be possible or indeed appropriate to provide all the interventions in **Figure 2.3**. However, the purpose of this study was to develop the gold-standard criteria for defining the Priority One patient, which with the appropriate resources these interventions are able to be provided.

Chapter conclusion

A key issue in triage research is the lack of a standardised outcome with which to validate or indeed develop triage tools. By using a modified Delphi process, 32 interventions have been identified as life-saving in the context of a major incident. The next stage of this project (**chapter 3**) is to determine the optimum method with which to identify these patients.

Chapter 3: Identifying the optimum physiology to predict the need for life-saving intervention and deriving the Modified Physiological Triage Tool.

Reference:

Vassallo J, Beavis J, Smith J E, Wallis L A. Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT). Injury. 2017 May;48(5):992-999.

Declaration from author

The following co-authors contributed to the paper: John Beavis, Jason E Smith, Lee A Wallis.

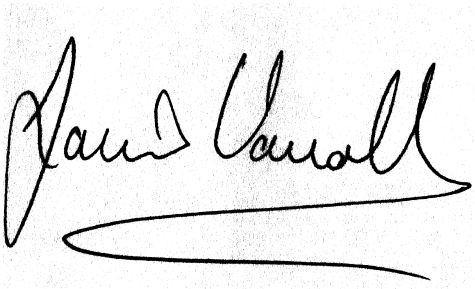
In the case of Chapter 3, contribution by authors to the work was as follows:

Nature of contribution

- JV, JES and LAW conceived the idea. JV and JB designed the study. JV drafted the work with all authors contributing to revise it critically for important intellectual content. All authors approved the final published version and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- **Extent of contribution:** JV: 75%; JB 10%, JES 10%; LAW: 5%

The following co-authors contributed to the work:

1. Prof. Lee A Wallis
2. Prof. Jason E Smith
3. Dr John Beavis



Signed: James Vassallo

Declaration by co-authors

The undersigned hereby certify that:

1. The above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. There are no other author of the publication according these criteria;
5. Potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. The original data are stored at the following location and will be held for at least five years from date indicated below

Location of stored data:

Data were stored on the authors (JV) encrypted account at the University of Birmingham, allocated through the Academic Department of Military Emergency Medicine.

31st January 2018

Prof. Jason E. Smith	Date

8th February 2018

Prof. Lee A. Wallis	Date

Main findings:

- A heart rate ≥100, respiratory rate <12 or ≥22 and a GCS <14 represent the optimum physiological thresholds for predicting need for life-saving intervention.
- The Modified Physiological Triage Tool demonstrated the greatest sensitivity at predicting need for life-saving intervention with the lowest rates of under-triage when compared to existing methods of triage.
- Existing triage tools have the lowest rates of over-triage, with greater specificity than the Modified Physiological Triage Tool.

Motivation for conducting study

Worldwide a number of methods exist for the purposes of primary major incident triage, each using an assessment of the patient's physiology to determine their triage category. In countries using MIMMS for training, the MIMMS Triage Sieve is used; the exception to this is the UK, where following the 2005 London 7/7 bombings, the MIMMS Triage Sieve was replaced by the NARU Sieve.[3,45] Additional methods include START and Careflight, employed in America and Australia respectively.[11,12] Within the DMS, the Military Sieve is used, with analogous physiological assessments to the NARU Sieve.[46] While they are depicted separately in **Table 3.1** for the purposes of analyses in this and subsequent chapters, they have been described as one.

Triage Tool	1st Assessment	2nd Assessment	3rd Assessment	4th Assessment	5th Assessment
NARU Sieve	Catastrophic haemorrhage?	Walking?	Unconscious?	Breathing? <10 RR >30	HR >120 or CRT >2 secs
MIMMS Triage Sieve	Walking?	Breathing? <10 RR ≥30	HR >120 or CRT >2 secs		
Military Sieve	Walking?	Catastrophic limb haemorrhage?	Breathing? <10 RR >30	HR >120	Unconscious?
START	Walking?	Breathing? RR ≥30	Palpable Pulse?	Obeys commands?	Catastrophic haemorrhage?
Careflight	Walking?	Obeys commands?	Breathing?	Palpable radial pulse?	

Table 3.1: Comparison of existing triage tools.

HR – Heart Rate, RR – Respiratory Rate, CRT – Capillary Refill Time

In the early 2000's work by Garner et al using trauma registry data demonstrated that whilst both START and Careflight had sensitivities and specificities of over 80% at predicting the need for life-saving interventions (modified-Baxt criteria, **Table 2.2**), the MIMMS Triage Sieve had a reported sensitivity and specificity of only 45 and 88% respectively.[12]

Following the London 7/7 bombings in 2005, and using data from patients seen at the Royal London Hospital (n=203, 50.2% incident population), Challen performed a retrospective cohort study, comparing the performance of the MIMMS Triage Sieve, START and Careflight against life-saving interventions (modified-

Baxt criteria, **Table 2.2**). The results differed considerably from Garner's study, with all three triage tools having only 50% sensitivity, but with 100% specificity. Whilst Challen's study has the advantage of being conducted on data from an actual major incident, it is unfortunately limited by low numbers of genuine Priority One patients (n=8) with data only available to analyse for half of these (n=4). This is not unique to the London 7/7 bombings, with Kahn et al reporting only two patients requiring a life-saving intervention following a train crash in the US (total n=148).[17]

Over a decade later, and again using trauma registry data, Horne et al compared the performance of the MIMMS Triage Sieve with the Military Sieve, as used by the DMS. Using a more extensive list of life-saving interventions to define the Priority One patient **(Table 2.3)**, they found a significant improvement in sensitivity with the Military Sieve (59% versus 53%, $p<0.001$) at predicting the Priority One patient.[18] As a follow on from this study, the authors (including JV) conducted a prospective study comparing the performance of potential modifications to the Military Sieve (Modified Military Sieve). Within the prospective military environment, the Modified Military Sieve outperformed existing methods with a sensitivity of 68% (Military Sieve 63%, MIMMS Triage Sieve 50%, START 52% and Careflight 45%).[19]

These studies demonstrate that existing primary major incident triage tools have limited accuracy when identifying those patients in need of life-saving intervention, but that with simple modifications, the performance can be improved with only modest reductions in specificity.

Aim

The aim of this study was to derive a novel physiological triage tool that demonstrates improved performance characteristics at predicting the need for life-saving interventions when compared to existing triage tools.

Objectives

1. Identify the optimum thresholds of heart rate, respiratory rate and Glasgow Coma Scale at predicting need for life-saving intervention.
2. Combining the optimum thresholds from objective one, define the Modified Physiological Triage Tool.
3. Perform a comparative analysis of the Modified Physiological Triage Tool with existing methods of primary major incident triage.

A copy of the published paper follows over the next eight pages.

Injury, Int. J. Care Injured xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Injury

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

Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT)

James Vassallo[a,b,*], John Beavis[c], Jason E. Smith[d], Lee A. Wallis[a]

[a] Division of Emergency Medicine, University of Cape Town, Cape Town, South Africa
[b] Institute of Naval Medicine, Gosport PO12 2DL, United Kingdom
[c] Faculty of Science and Technology, Bournemouth University, Bournemouth, United Kingdom
[d] Academic Department of Military Emergency Medicine, Royal Centre for Defence Medicine (Research & Academia), Medical Directorate, Joint Medical Command, Birmingham, United Kingdom

ARTICLE INFO

Keywords:
Triage
Major incidents
Life-saving intervention
Physiological predictors

ABSTRACT

Background: Triage is a key principle in the effective management at a major incident. There are at least three different triage systems in use worldwide and previous attempts to validate them, have revealed limited sensitivity. Within a civilian adult population, there has been no work to develop an improved system.

Methods: A retrospective database review of the UK Joint Theatre Trauma Registry was performed for all adult patients (>18 years) presenting to a deployed Military Treatment Facility between 2006 and 2013. Patients were defined as Priority One if they had received one or more life-saving interventions from a previously defined list.

Using first recorded hospital physiological data (HR/RR/GCS), binary logistic regression models were used to derive optimum physiological ranges to predict need for life-saving intervention. This allowed for the derivation of the Modified Physiological Triage Tool–MPTT ($GCS \geq 14$, $HR \geq 100$, $12 < RR \geq 22$). A comparison of the MPTT and existing triage tools was then performed using sensitivities and specificities with 95% confidence intervals. Differences in performance were assessed for statistical significance using a McNemar test with Bonferroni correction.

Results: Of 6095 patients, 3654 (60.0%) had complete data and were included in the study, with 1738 (47.6%) identified as priority one. Existing triage tools had a maximum sensitivity of 50.9% (Modified Military Sieve) and specificity of 98.4% (Careflight). The MPTT (sensitivity 69.9%, 95% CI 0.677-0.720, specificity 65.3%, 95% CI 0.632-0.675) showed an absolute increase in sensitivity over existing tools ranging from 19.0% (Modified Military Sieve) to 45.1% (Triage Sieve). There was a statistically significant difference between the performance ($p < 0.001$) between the MPTT and the Modified Military Sieve.

Discussion & conclusion: The performance characteristics of the MPTT exceed existing major incident triage systems, whilst maintaining an appropriate rate of over-triage and minimising under-triage within the context of predicting the need for a life-saving intervention in a military setting. Further work is required to both prospectively validate this system and to identify its performance within a civilian environment, prior to recommending its use in the major incident setting.

Introduction

Triage is a key principle in the effective management of major incidents and, in line with the principles taught by the Major Incident Medical Management and Support course, is the first clinical priority, ahead of casualty treatment [1]. Stemming from the French verb *trier*, meaning to sort, its origins can be traced back to the 14th Century where it was used to describe sorting coffee beans and wool. As a clinical 'sorting' process, Baron Larrey, Napoleon's surgeon, is frequently credited with introducing the first system around 1792; *"Those who are dangerously wounded should receive the first attention, without regard to rank or distinction"* [2,3]. Today, within the clinical context, it is regarded as the process of *"sorting patients and categorising them on the basis of clinical acuity"* [4].

* Corresponding author at: Institute of Naval Medicine, Gosport, PO12 2DL, United Kingdom.
E-mail addresses: vassallo@doctors.org.uk (J. Vassallo), jbeavis@bournemouth.ac.uk (J. Beavis), jasonesmith@nhs.net (J.E. Smith), lee.wallis@bvr.co.za (L.A. Wallis).

http://dx.doi.org/10.1016/j.injury.2017.01.038
0020-1383/

Triage is a dynamic process, and at a major incident it will be repeated several times as the patient transitions through the respective phases of medical care [1]. Equally, the physiological state of the patient may improve following intervention, or deteriorate in response to injury progression; having a dynamic triage process, where the patient can undergo repeated assessment, allows for this to be recognised and the patient category can be amended as required. A key tenet of initial major incident triage is that it can be performed rapidly, and the results should be reproducible irrespective of user.

A number of triage methods exist (Triage Sieve, START, Careflight) [1,5], each assigning patients to one of three priority categories. The initial discriminator of these tools is the ability to walk; patients able to walk are allocated the lowest acuity category (P3 or delayed). Those unable to walk then undergo an assessment of basic physiology (Heart Rate, Respiratory Rate, Blood Pressure and Conscious Level) to assign patients to either P1 or P2 categories (immediate or urgent) [1,5]. Although mechanism of injury and anatomical injury are used for individual field triage, within a major incident setting, these are too time-consuming and require additional user training [6].

The most severely injured patients (priority one) are those requiring life-saving interventions, the definition of which has evolved over time since it was first used for individual trauma patients [5,7]. Definitions exist for the paediatric and military patient, but until recently there has not been an accepted, consensus definition of what constitutes a civilian priority one adult patient at a major incident [4,8,9].

To date, there has been no prospective validation of the major incident triage tools during a major incident; this is unlikely to be possible in the future due to both ethical and logistical constraints. Research is therefore limited to either the retrospective review of major incidents or the analysis of trauma registry data. There have been a limited number of reviews comparing the performance of existing triage tools.

An early trauma registry review demonstrated similar performance of START and Careflight (sensitivity 84% and 82%, specificity 91% and 86% respectively) with the Triage Sieve performing poorly at predicting the need for life-saving intervention (sensitivity 45%, specificity 88%) [5]. By contrast, a retrospective comparison of the same triage tools following the London 7th July bombings demonstrated equally poor sensitivities (50%) for all triage tools, albeit all with 100% specificity [10]. However, despite using the same life-saving intervention definition and it being a major incident, only 2% (n = 4) patients included were considered priority one, in contrast to a registry review with 12% (n = 135) [5]. With only a single study validating modifications to an existing triage tool, the Modified Military Sieve, there has been no work to date to derive an optimum physiological triage tool [11].

With lack of evidence to support existing major incident triage tools, this study aims to derive a triage tool, using observed physiological measurements, that shows an improved performance at predicting the need for life-saving intervention in a military population when compared to existing methods.

Methods

A retrospective database review of the UK Joint Theatre Trauma Registry was conducted for all adult trauma patients (≥18 years) presenting to the Emergency Department at Camp Bastion, Afghanistan between 2006 and 2013. The medical facilities provided at Camp Bastion have been extensively described elsewhere [12,13].

Data on all seriously injured patients (including UK military, coalition forces, detainees, and local civilians) treated by UK Defence Medical Services in these facilities are collected by Trauma Nurse Coordinators within the deployed clinical team and returned to the UK Joint Theatre Trauma Registry (JTTR). Defence Analytical Services and Advice maintain the JTTR at the Royal Centre for Defence Medicine in Birmingham, UK. Data are collected from clinical notes, trauma charts and in the case of death, post mortem findings. The JTTR holds continuous data on this cohort from 2003, coinciding with the start of hostilities in Iraq. Returns are electronic (where deployed IT systems allow), with hard copy accompanying UK military patients evacuated to Royal Centre for Defence Medicine for definitive care [14].

The default entry criterion for UK JTTR is a casualty who triggers trauma team activation in a deployed field hospital or Primary Casualty Receiving Facility afloat. The entry criteria were expanded in 2007 to include all trauma patients returned to Royal Centre for Defence Medicine for definitive treatment, irrespective of whether a trauma team response was mandated. Anonymised data were supplied from the JTTR database, and according to institutional agreement ethical approval was not required [14].

Only patients with complete recordings of their physiological parameters on arrival at hospital were included in the study (SBP, HR, GCS, RR). Due to the nature of the JTTR and its inclusion criteria, patients in the study were assumed to be non-ambulant. In order to examine for potential selection bias through the deletion of incomplete records, analysis was performed for age, gender and mechanism of injury for the included and excluded groups. Outliers were defined as a physiological parameter with a Z score of 3 standard deviations (HR > 170 beats per minute, SBP > 206 mmHg and RR > 45 breaths per minute). In order to prevent bias and reducing statistical power, outliers were removed prior to the analysis [15]. Patients were defined as priority one if they received any one intervention from a previously derived list (Fig. 1). The JTTR does not record presence of a radial pulse as a variable, therefore for the purposes of prioritisation using START and Careflight, a surrogate systolic blood pressure of 90 mmHg was taken to represent the presence of a radial pulse and absence of hypotension [16,17].

The primary outcome of the study was to derive the optimum ranges of each physiological parameter in isolation at predicting the need for life-saving intervention. The secondary outcome was to compare the performance of the Modified Physiological Triage Tool (MPTT), the combination of these independently derived parameters, with existing major incident triage tools.

Separate bivariate logistical regression models were developed for each physiological parameter in isolation to determine the need for life-saving intervention. For heart rate and respiratory rate, regressions were estimated separately for values above and below the median (HR-89, RR-18). The performance of each model was reported in terms of the significance of the parameters (B0 and B1), the explanatory power (Nagelkerke's pseudo-R2) and goodness of fit (Hosmer-Lemeshow's χ^2). The probability of outcome equation Probability (event Y) = $1/(1 + e^{-(B0+X*B1)})$ was used to determine the optimum threshold for predicting need for life-saving intervention for each physiological parameter in isolation.

For the comparative analysis, performance was evaluated using sensitivity, specificity, under-triage (1-sensitivity) and over-triage (1-Positive Predictive Value) with 95% confidence intervals calculated for all major incident triage tools. For tools with similar performance, a McNemar test with a Bonferroni correction was applied, allowing for the evaluation of any statistically significant difference between the tools [18]. Data processing and analysis were conducted using a combination of Statistical Package for the Social Sciences (SPSS) Version 23.0 (SPSS Inc., Chicago, Illinois, USA), STATA Version 12.0 (StataCorp, College Station, Texas, USA) and Microsoft Excel Version 14.5.8 [19,20].

As part of a larger programme of work, this study received ethical approval by the Human Research Ethics Committee of the

Please cite this article in press as: J. Vassallo, et al., Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT), Injury (2017), http://dx.doi.org/10.1016/j.injury.2017.01.038

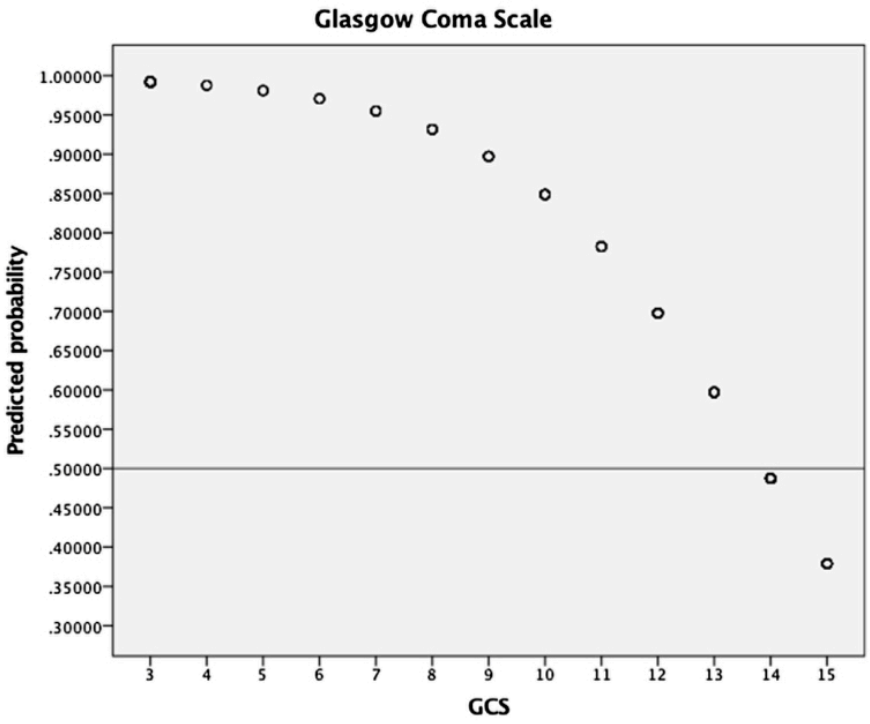


Fig. 1. GCS parameter estimates.

University of Cape Town (reference 285/2013), the primary institution of the lead author.

Results

During the study period 6095 adult patients were included in the database. 3701 (60.7%) had complete physiological data (SBP, HR, GCS and RR) with 47 excluded as outliers (SBP > 206 n = 9, RR > 45 n = 28, HR > 170, n = 12). 3654 were included in the final data analysis (60.0%) with a median age of 24 years (IQR 21–29 years); 3593 (98.3%) were male. Both independent *t*-test and Pearson Chi Square tests were non significant for age ($p = 0.811$) and gender ($p = 0.472$) respectively when comparing the complete and incomplete physiological data groups. Statistical significance was observed for mechanism of injury between the two groups ($p < 0.05$); however, observationally the relative frequencies were similar for both explosive (57.5% vs 55.1%) and GSW (30.6% vs 34.3%) mechanisms of injury.

During the study period there were 75 (2.1%) fatalities. Injury secondary to explosive devices and gunshot wounds combined accounted for the majority of cases (n = 3264, 89.3%). Injured personnel had a mean of 2 body regions affected (range 0–8) with the highest proportion affecting the lower extremities (36.0%), followed by upper extremities (16.2%) and thorax (10.8%). Injury Severity Score (ISS) was recorded for the majority of patients (n = 3649, 99.8%), with median and mean ISS of 5 and 11.4 respectively.

1738 (47.6%) patients received a life-saving intervention and were considered Priority One, with the majority receiving a single intervention (n = 629, 36.2%), range 0 to 12. 5380 life-saving interventions were performed during the study period with tourniquet use the most frequent (n = 724, 13.5%). No patients received chemical antidotes, therapeutic rewarming or correction of low blood glucose. Additionally, no patients received interventional radiology for haemorrhage control as it is not currently a deployed medical capability of the UK Defence Medical Services.

Glasgow coma scale

The regression model demonstrated significance ($p < 0.001$, $\chi^2 = 768.42$), explaining approximately 25% of the variation in the outcome variable (Nagelkerke $R^2 = 0.255$). The model fit was satisfactory (Hosmer and Lemeshow statistic $\chi^2 = 0.441$, df = 2, $p = 0.506$). Using a probability of outcome equation, the value of

Table 1
List of life-saving interventions [4].

1	Intubation for actual or impending airway obstruction.
2	Surgical airway for actual or impending airway obstruction.
3	Thoracostomy (needle/finger/tube).
4	Application of a chest seal (commercial/improvised).
5	Positive pressure ventilation for ventilatory inadequacy.
6	Application of a tourniquet for haemorrhage control.
7	Use of haemostatic agents for haemorrhage control.
8	Insertion of an intra-osseous device for resuscitation purposes.
9	Receiving uncross-matched blood.
10	Receiving ≥ 4 units of blood/blood products.
11	Administration of tranexamic acid.
12	Laparotomy for trauma.
13	Thoracotomy or pericardial window for trauma.
14	Surgery to gain proximal vascular control.
15	Interventional radiology for haemorrhage control.
16	Application of a pelvic binder.
17	ALS/ALS for a patient in a peri-arrest/cardiac arrest situation.
18	Neurosurgery for the evacuation of an intra-cranial haematoma.
19	Craniotomy/Burr hole insertion.
20	Spinal nursing for a C1-3 fracture.
21	Administration of a seizure-terminating medication.
22	Active/passive rewarming for initial core temp <32 °C.
23	Correction of low blood glucose.
24	Administration of chemical antidotes.

Please cite this article in press as: J. Vassallo, et al., Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT), Injury (2017), http://dx.doi.org/10.1016/j.injury.2017.01.038

GCS<14 was derived as the optimum level for predicting the need for life-saving intervention. Probability values for all physiological parameters are provided in tabulated form in Tables 1–3 , web only appendices.

Respiratory rate

Both regression models (RR ≤ 18 and RR > 18) demonstrated significance, $\chi^2 = 21.4$ and 75.2, d.f = 1, $p < 0.001$ respectively, with poor fit (Hosmer and Lemeshow statistic $\chi^2 = 27.8$ and 13.5, d.f = 6 and $p < 0.05$ respectively for RR ≤ 18 and RR > 18). Optimum levels of respiratory rate (upper and lower) were defined as RR < 12 and RR ≥ 22 having been derived using probability of outcome equations. (Figs. 1 and 2, web only appendices).

Table 2
Characteristics of study population.

No of patients	3654
Gender (n (%))	3593 (98.3%)
Male	61 (1.7%)
Female	
ISS (Median (IQR))	5 (2–16)
Age (years) (Median (IQR))	24 (21–29)
Fatalities (n (%))	75 (2.1%)
Mechanism of injury (n (%))	8 (0.2%)
Assault	32 (1.0%)
Burns	47 (1.3%)
Crush	2012 (55.1%)
Explosive	47 (1.3%)
Fall <5 m	20 (0.5%)
Fall >5 m	1252 (34.3%)
GSW	158 (4.3%)
MVC	58 (1.6%)
Other	16 (0.4%)
Stabbing	4 (0.1%)
Unknown	
Injury pattern (n (%))	236 (6.5%)
Abdomen	61 (1.7%)
External	361 (9.9%)
Face	458 (12.5%)
Head	1317 (36.0%)
Lower extremities	63 (1.7%)
Neck	22 (0.6%)
Other	142 (3.9%)
Spine	396 (10.8%)
Thorax	593 (16.2%)
Upper extremities	
Priority One (N (%))	1738 (47.6%)
Priority One	1855 (52.4%)
Not Priority One	
LSI frequency (Median (IQR), %P1)	0 (0–2)
1	629 (36.2%)
2	293 (16.9%)
3	218 (12.5%)
4	155 (8.9%)
5	128 (7.4%)
6	122 (7.0%)
7	93 (5.4%)
8	57 (3.3%)
9	26 (1.5%)
10	11 (0.6%)
11	4 (0.2%)
12	2 (0.1%)
LSI by type (n (% total LSI))	643 (12.0%)
Intubation & Surgical Airway	534 (9.9%)
Thoracostomy & Chest Seal	699 (13.0%)
Positive Pressure Ventilation	724 (13.5%)
Combat Tourniquet	172 (3.2%)
Haemostatic Dressing	329 (6.1%)
Intraosseous access	1039 (19.3%)
Blood (Cross/Uncross-matched)	503 (9.3%)
Tranexamic Acid	432 (8.0%)
Laparotomy	52 (1.0%)
Thoracotomy & Pericardial Window	68 (1.3%)
Proximal Vascular Control	34 (0.6%)
Pelvic Binder	58 (1.1%)
ACLS Protocols	22 (0.4%)
Neurosurgery/Spinal Nursing	71 (1.3%)
Seizure termination/Low BM correction	

Heart rate

Only the HR > 89 model demonstrated significance, $\chi^2 = 179.6$, d.f = 1 and $p < 0.001$ with a good fit (Hosmer and Lemeshow statistic $\chi^2 = 8.8$, d.f. 8 and $p = 0.358$). Using the probability of outcome equation, a HR threshold of ≥100 was determined as the optimum level at predicting need for life-saving intervention. (Fig. 3, web only appendix).

Comparative analysis

The MPTT, defined as GCS < 14, RR < 12, RR ≥ 22, HR ≥ 100, demonstrated the greatest sensitivity of all existing triage tools (69.9%, 95% CI 67.7–72.0%), with an absolute increase in sensitivity of 19.0% over the Modified Military Sieve and the lowest rate of under-triage (30.1%). Statistically significant differences were recorded between both the MPTT and Modified Military Sieve ($\chi^2 = 746$, $p < 0.001$) and the MPTT and Military Sieve ($\chi^2 = 998$, $p < 0.001$). Fig. 3 summarises the performance accuracy of the triage tools in their ability to predict the need for life-saving intervention.

Discussion

This study has successfully derived the first evidence-based triage tool with improved sensitivity and acceptable specificity when compared to existing tools such as START, Careflight and the Military Sieve. This was achieved using a cohort of military patients.

There is a paucity of literature surrounding both the creation and use of existing major incident triage tools. No previous study has attempted to derive a tool based on physiological data. Having adapted the criteria defining a major trauma patient to reflect major incident practice, one study performed a comparative analysis to demonstrate the performance of existing tools and using logistical regression methods, identified the strengths and weaknesses of the current thresholds for each physiological component [5]. The performance of both START and Careflight differed largely from that observed subsequently; [9,21] the use of a lower SBP surrogate to represent palpable radial pulse (80 mmHg) may explain some of the differences in sensitivity observed [5,10,11].

Following the 7th July bombings in London, all tools (START, Triage Sieve and Careflight) were shown to have the same performance at identifying priority one patients (50% sensitivity and 100% specificity) [21]. Despite being performed on a major incident dataset, data were only available for 50% of the small number of priority one patients, from one hospital (n = 4). Additionally, a SBP of 110 mmHg was used represent the presence of a palpable pulse when categorising patients using START and Careflight. Although a wide range of systolic blood pressures correlating with palpable pulse have been used in previous studies, this estimate is higher than most and a surrogate of 90 mmHg as was used in this study, may be more appropriate with its correlation with increased mortality following both penetrating and blunt trauma [22,23].

Within a military setting, simple modifications have been proposed to the heart rate and respiratory rate components of the military sieve, demonstrating an improvement in its performance characteristics [9]. During a subsequent prospective validation and comparative analysis, the modified military sieve was

Please cite this article in press as: J. Vassallo, et al., Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT), Injury (2017), http://dx.doi.org/10.1016/j.injury.2017.01.038

Table 3
Sensitivity analysis.

Model	Sensitivity (95% CIs)	Specificity (95% CIs)	Under-triage (1-sens)	Over-triage (1-ppv)
MPTT[1]	69.9% (67.7–72.0%)	65.3% (63.2–67.5%)	30.1%	35.2%
Military Sieve	43.8% (41.5–46.2%)	93.6% (92.4–94.6%)	56.2%	13.8%
Modified Military Sieve	50.9% (48.6–53.3%)	87.5% (85.9–88.9%)	49.1%	21.2%
Triage Sieve	24.8% (22.8–26.9%)	94.7% (93.6–95.7%)	75.2%	18.8%
START	38.7% (36.5–41.1%)	96.9% (96.0–97.6%)	61.3%	8.1%
Careflight	33.5% (31.3–35.8%)	98.4% (97.7–98.9%)	66.5%	5.0%

MPTT: $12 < RR \geq 22$, $HR \geq 100$, $GCS < 14$, Military Sieve: $10 <$ RR>30, HR > 120, $GCS < 13$, Modified Military Sieve: $12 <$ RR > 24, $40 <$ H > 120, $GCS < 13$, Triage Sieve: $10 <$ RR > 30, HR > 120, START: $RR \geq 30$, $SBP < 90$, $GCS < 13$, Careflight: $SBP < 90$, $GCS < 13$

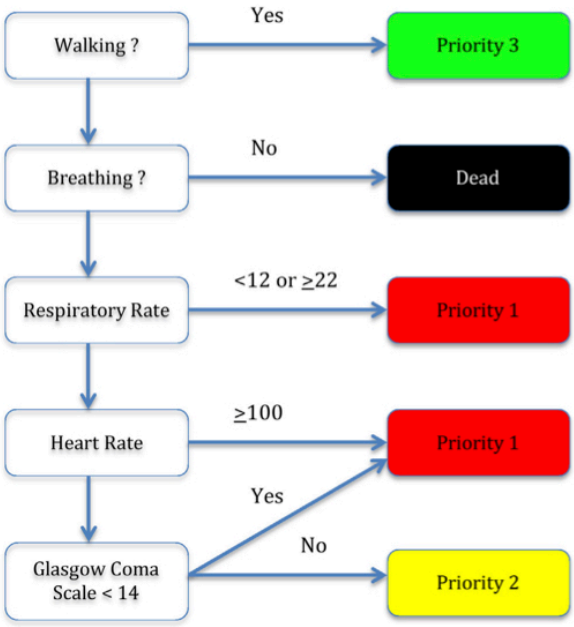


Fig. 2. MPTT algorithm.

demonstrated to have a statistically significant increase in performance when compared to existing methods [11] (Table 4).

This study has successfully created the Modified Physiological Triage Tool and is the first study where physiological thresholds within triage tools have been derived using logistical regression to individually predict need for life-saving intervention. Whilst ISS was measured within our population, we chose specifically to measure triage tool performance against need for life-saving intervention. Numerous studies have previously demonstrated a lack of correlation between ISS and need for life-saving intervention. Fundamentally, the ISS is a retrospectively calculated score which measures injury severity and does not describe the clinical acuity of the patient. The high frequency of P1 patients (47.6%) reflects the injury burden within our cohort. Within a major incident setting the authors believe that this is a more appropriate measure [4,7,8,10].

The MPTT showed the greatest sensitivity (69.9%, 95% CI 67.7–72.0%) at predicting the need for life-saving intervention. With the lowest rate of under-triage, the MPTT demonstrates far better performance clinically and statistically than existing tools, with an absolute increase in sensitivity of 19.0% over the Modified Military Sieve (50.9%, 95% CI 48.6–53.3%). However, this increased sensitivity comes with a reduction in specificity and the highest rate of over-triage (35.2%).

Currently there is no guidance to stipulate the recommended accuracy of major incident triage, however for field triage to a Major Trauma Centre, the recommendations are that over and under-triage are limited to 35% and 5% respectively [24]. The rate of under-triage by the modified physiological triage tool is clearly high, but it is the lowest of all existing major incident triage tools, maintaining a tolerated level of over-triage.

The effect sizes of the individual components of the modified physiological triage tool are in themselves small, with only a maximum of 13% variation accounted for by both HR and GCS (Nagelkerke's R^2). With the nature of the modified physiological triage tool's derivation, the performance we have demonstrated is likely to represent the optimum for simple physiological parameters as is contained within major incident triage tools. Without including additional measured variables (such as mechanism of injury or anatomical injury), these rates of over and under-triage are unlikely to be improved, as this would render the triage tool unsuitable for the 'quick-look' primary triage that is required initially at the scene of a major incident.

A key principle of major incident triage is that it must be able to be performed rapidly, reliably and with reproducible results, irrespective of the seniority or background of the individual performing it. The modified physiological triage tool has been derived with these principles in mind and is no more complicated than existing tools, yet demonstrates increased performance at predicting the need for life-saving intervention, whilst minimising rates of under-triage and having an acceptable rate of over-triage.

Limitations

There are a number of limitations to our study, the first being the use of a military trauma registry to derive a major incident triage tool.

Patients who were uninjured or sustained minor injuries following an incident are not included in the JTTR. Specificities within the analysis must therefore be interpreted with caution as the inclusion criteria will prevent all 'true negative' patients from

[1] Sensitivity analysis performed using the same dataset in which the MPTT was derived.

Please cite this article in press as: J. Vassallo, et al., Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT), Injury (2017), http://dx.doi.org/10.1016/j.injury.2017.01.038

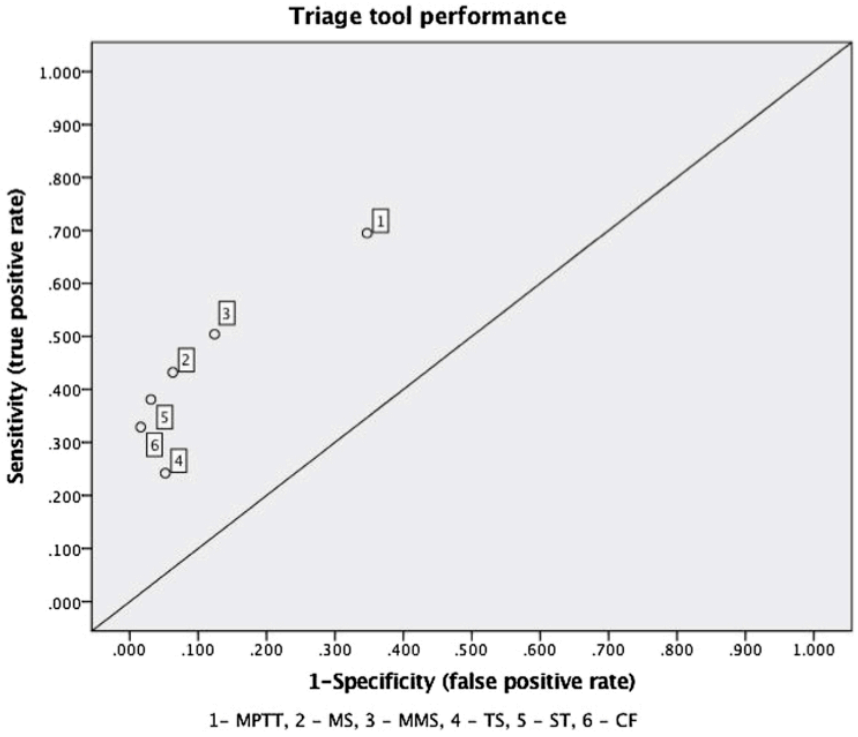


Fig. 3. Triage tool performance.

Table 4
Comparative analysis by study [5,9,10].

	Current Study	Garner	Challen	Horne
Triage Sieve – Sensitivity	25% (23–27%)	45% (37–54%)	50%	50% (43–57%)
Triage Sieve – Specificity	95% (94–96%)	88% (86–90%)	100%	89% (84–94%)
START – Sensitivity	39% (37–41%)	84% (76–89%)	50%	52% (45–59%)
START – Specificity	97% (96–98%)	91% (89–93%)	100%	90% (85–95%)
Careflight – Sensitivity	34% (31–36%)	82% (75–88%)	50%	45% (38–52%)
Careflight – Specificity	98% (98–99%)	86% (94–97%)	100%	92% (87–97%)

Triage Sieve: $10 < RR > 30$, $HR > 120$, START: $RR \geq 30$, $SBP < 90$, $GCS < 13$, Careflight: $SBP < 90$, $GCS < 13$.

being included within the JTTR. The population of patients from a major incident population will include a large number of patients sustaining only minor injuries, representing the ambulant P3 or delayed category. Whilst trauma registries have been and continue to be used as surrogates for major incident research, they are unlikely to be entirely representative of the population in question because of this, instead focusing on the non-ambulant patients of higher acuity [5].

Our dataset demonstrates a high proportion of priority one patients (n = 1755, 47.8%), most of whom suffered blast and ballistic injury (n = 3268, 89.0%) [25]. Over the last decade several high profile terrorist atrocities have occurred across Europe, including a number of marauding terrorist firearm attacks, using high velocity weapons and improvised explosive devices akin to that seen in the military setting [26]. Whilst the MPTT has demonstrated good performance at predicting need for life-saving intervention within our cohort, and may be likely to do so in the context of terrorist atrocities on civilians, its performance may not easily translate to a civilian major incident if the mechanism of injury is predominantly blunt trauma [25].

Closely linked with the mechanism of injury experienced on the battlefield is the relatively low age (median 24 years, mean 26.2 years) and the low frequency of females injured within our dataset (n = 60, 1.6%). Within a UK civilian trauma context it has been acknowledged that the mean age of patients has increased over the last three decades and in 2013 was 53.8 years [25]. We also recognise that our cohort of predominantly young males are likely to have limited medical comorbidities when compared to the population as a whole, and therefore the physiology with which we have derived the MPTT is likely to not be fully representative of the whole population. Whilst this is not specific to the major incident environment, it is likely that it will be relevant and these factors are acknowledged as limitations to our study and must be explored before the MPTT can be recommended for use in a civilian context.

Evaluating the performance of the MPTT on the same dataset in which it was derived introduces the potential for bias with respect to its performance. It has previously been suggested that in these circumstances, the derived diagnostic test (in this case the MPTT) can have an exaggerated test performance and that when evaluated using an alternative, independent dataset performs less

Please cite this article in press as: J. Vassallo, et al., Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT), Injury (2017), http://dx.doi.org/10.1016/j.injury.2017.01.038

Table 5
Surrogates used within the study.

Intervention	Surrogate Variable
ALS/ACLS Protocols	CPR, Epinephrine, Atropine, Amiodarone, "Resus Drugs"
Intubation for actual/impending airway obstruction	Endotracheal tube AND rapid sequence induction
Pelvic binder	Limb traction AND coded pelvic injury (856161, 856162, 856171, 856172)
Positive pressure ventilation	Mechanical ventilation
Proximal vascular control	Arterial ligation, shunt, cross clamping
Spinal nursing	Proven spinal fracture C1-C3

well [27]. Analysis using additional independent datasets are therefore required to support the MPTT's improved performance.

Whilst our analysis has been performed on a large sample (n = 3673), it is acknowledged that a number of patients were removed due to incomplete physiological data (n = 2394, 39.3% of total dataset). The list-wise deletion method of incomplete data can be considered as a form of selection bias, but analysis on the deleted dataset revealed no statistically significant difference between age and gender of the two groups. Although significance was seen with mechanism of injury between the two groups, observationally the proportions were near identical. Despite our results demonstrating both considerable effect sizes and significance, we are unable to comment whether with a more complete data set these results would have been different. Incomplete data entry is a limitation of retrospective database reviews, and the JTTR is no different. The nature of military operations and the pressured environment that clinicians are working in, is likely to explain some of this missing data [11]. The major incident setting is no different, and the difficulties in maintaining contemporaneous medical records during a major incident have been described previously [21,28]. The extent of missing data in our study (39.3%) is directly comparable to that observed following the 7th July bombings (approximately 38.0%).

We acknowledge that the use of in-hospital physiology is a limitation of our study. A change in physiology may well be observed in patients receiving interventions prior to their arrival at hospital. Whilst data is available on the JTTR at point of wounding, only 25% cases for the study period in question had complete data. Due to the austere nature of military operations, data completion is unsurprisingly poor, and this has previously been described elsewhere [29]. For this practical reason physiology was used on arrival at hospital, where complete data was available for 61%.

In keeping with the literature on mortality following trauma, a surrogate systolic blood pressure measurement of 90 mmHg was used to represent the presence of a radial pulse for purposes of classification using START and Careflight [22,23]. We acknowledge that the use of surrogates (Table 5) is a limitation of our study, but one that is shared with other major incident triage publications and due to the nature of the JTTR is unavoidable [5,10,30].

Conclusions

In summary, we present the modified physiological triage tool, the first example of a statistically derived physiological triage tool for use in the military major incident setting. Our findings show that the modified physiological triage tool demonstrates good performance at predicting need for life-saving intervention within a military setting. It is superior to all existing major incident triage tools with respect to its rates of under-triage, and has an acceptable level of over-triage. Further work is needed to validate this tool on civilian trauma registry data and will be required prior to changes to existing civilian major incident doctrine. Ideally, the modified physiological triage tool should be specifically tested in the major incident environment in order to assess its performance.

Conflicts of interest

We can confirm that there are no conflicts of interests to declare. Two of the authors (JV and JES) are serving members of the United Kingdom Royal Navy.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.injury.2017.01.038.

References

[1] Advanced Life Support Group. Major Incident Medical Management and Support: The Practical Approach. London: BMJ Books; 2002.
[2] Trauma.org. United Kingdom. Cited 30 May 2016. Available on http://www.trauma.org.
[3] Burris D, Welling D, Rich N. Dominique Jean Larrey and the principles of humanity in warfare. J Am Coll Surg 2004;198(5):831–5.
[4] Vassallo J, Smith JE, Bruijns S, Wallis LA. Major incident triage: a consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident. Injury 2016;47(9):1898–902.
[5] Garner A, Lee A, Harrison K, Schultz C. Comparative analysis of multiple-casualty incident triage algorithms. Ann Emerg Med 2001;38(5):541–8.
[6] Sasser S, Hunt R, Faul M, et al. Guidelines for field triage of injured patients. Recommendations of the national expert panel on field triage. MMWR Recomm Rep 2009;58(RR-1):1–35.
[7] Baxt WG, Upenieks V. The lack of full correlation between the injury severity score and the resource needs of injured patients. Ann Emerg Med 1990;19:1396–400.
[8] Wallis L, Carley S, Hodgetts CT. A procedure based alternative to the injury severity score for major incident triage of children: results of a Delphi consensus process. Emerg Med J 2006;23(4):291–5.
[9] Horne S, Vassallo J, Read J. UK Triage – a new tool for an evolving threat. Injury 2013;44(1):23–8.
[10] Challen KHE. Comparative Validation of Major Incident Triage Systems. MRes Thesis. University of Manchester; 2008.
[11] Vassallo J, Horne S, Ball S, Whitley J. UK Triage –the validation of a new tool for an evolving threat. Injury 2014;45(12):2071–5.
[12] Henning D, Smith JE, Patch D, Lambert A. A comparison of civilian (National Confidential Enquiry into Patient Outcome and Death) trauma standards with current practice in a deployed field hospital in Afghanistan. Emerg Med J 2011;28(4):310–2.
[13] Vassallo D. A short history of Camp Bastion Hospital: the two hospitals and unit deployments. J R Army Med Corps 2015;161:79–83.
[14] Smith JE. The epidemiology of blast lung injury during recent military conflicts: a retrospective database review of cases presenting to deployed military hospitals, 2003–2009. Philos Trans R Soc B 2011;366:291–4.
[15] Field A. Discover Statistics Using SPSS. 3rd edn London: SAGE Publications; 2009.
[16] Edelman DA, White MT, Tyburski JG, Wilson RF. Post-traumatic hypotension: should systolic blood pressure of 90–109 mmHg be included? Shock 2007;27(2):134–8.
[17] Rossaint R, Bouillon B, Cerny V, et al. Management of bleeding following major trauma: an updated European guideline. Crit Care 2010;14:R52.
[18] Hazra A, Gogtay N. Biostatistics series module 4: comparing groups –categorical variables. Indian J Dermatol 2016;61:385–92.
[19] IBM Corp. Released 2013. IBM SPSS Statistics for Macintosh, Version 23.0. Armonk, NY:IBM Corp.
[20] StataCorp. 2011. *Stata Statistical Software: Release 12*. College Station, TX : StataCorp LP.
[21] Challen K, Walter D. Major incident triage: comparative validation using data from 7th july bombings. Injury 2013;44(5):629–33.
[22] Hasler RM, Nüesch E, Jüni P, Bouamra O, Exadaktylos A, Lecky F. Systolic blood pressure below 110 mmHg is associated with increased mortality in

Please cite this article in press as: J. Vassallo, et al., Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT), Injury (2017), http://dx.doi.org/10.1016/j.injury.2017.01.038

penetrating major trauma patients: multicentre cohort study. Resuscitation 2012;83(4):476–81.
[23] Hasler RM, Nüesch E, Jüni P, Bouamra O, Exadaktylos A, Lecky F. Systolic blood pressure below 110 mmHg is associated with increased mortality in blunt major trauma patients: multicentre cohort study. Resuscitation 2011;82(9):1202–7.
[24] American College of Surgeons. Resources for the Optimal Care of the Injured Patient 2014. Chicago, IL: American College of Surgeons; 2014.
[25] Kehoe A, Smith JE, Edwards A, Yates D, Lecky F. The changing face of major trauma in the UK. Emerg Med J 2015;32:911–5.
[26] Hirsch M, Carli P, Nizard R, Riou B, Baroudjian B, Baubet T, et al. The medical response to multisite terrorist attacks in Paris. Lancet 2015;386(10012):2535–8.
[27] University of York 2009. Diagnostic Tests. In Systematic Reviews. Available on: https://www.york.ac.uk/crd/SysRev/!SSL!/WebHelp/TITLEPAGE.htm. Cited 9th January 2017.
[28] London Assembly. Report of the 7th July Review Committee. June 2006.
[29] Robinson JB, Smith MP, Gross KR, Sauer SW, Geracci JJ, Day CD, et al. Battlefield documentation of tactical combat casualty care in Afghanistan. US Army Med Dep J 2016;2–16:87–94.
[30] Price CL, Brace-McDonnell SJ, Stallard N, Bleetman A, Maconochie I, Perkins GD. Performance characteristics of five triage tools for major incidents involving traumatic injuries to children. Injury 2016;47:988–9920.

Please cite this article in press as: J. Vassallo, et al., Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT), Injury (2017), http://dx.doi.org/10.1016/j.injury.2017.01.038

Discussion of study

Supplementary methods

Whilst it may seem logical to conduct the derivation of a novel major incident triage tool using data taken from an actual incident, this is not without limitation. Despite occurring worldwide on a regular basis, the frequency of major incidents is unpredictable, making prospective research extremely difficult. Additionally, in retrospective studies describing actual incidents, the numbers of patients requiring life-saving interventions are typically low;[15,17] any tool designed to identify need for life-saving intervention being derived using these datasets will therefore have questionable generalisability to future incidents. By using trauma registries as a surrogate source of patients, this limitation is removed– greater numbers of patients receive life-saving interventions, from a variety of injury mechanisms, allowing for the more reliable derivation of a triage tool.

However, the use of trauma registries and databases for analyses is not without difficulty; errors occurring during the data entry and sampling process will potentially affect the reliability of the results obtained. The Joint Theatre Trauma Registry (JTTR), recording anonymised data from injury on deployed military operations through to evacuation to RCDM, Birmingham, UK, is no different; over the eight-year study period large proportions of missing data were encountered. For data recorded at point of injury, complete physiological data were only available for 17.2% cases (n=1051), increasing to 60.7% (n=3701) for the ED at Camp Bastion. It is unsurprising that large quantities of data are missing from point of injury – it is a military dataset recording injuries occurring on active military operations in Afghanistan – frequently those injured will remain in a hostile environment where the priority is to provide optimal tactical care, rather than documentation.[46,113] Due to the relative frequencies of missing data, analysis was performed using first recorded hospital physiology only. In addition, this is in keeping with **chapter 2** where for standardisation, the time period required for an intervention should begin on arrival in hospital. A comparison of pre-hospital versus hospital physiology was conducted using median and IQR **(Table 3.4)**.

In addition to the frequency of missing data described, erroneous and nonsense physiological values were observed, e.g. RR 247 breaths per minute (bpm) and SBP 13485 mmHg. Such results are considered outliers and would introduce error into analysis, and so an assessment of the data was undertaken to identify potential outliers and according to convention, to remove them.[114,115] For each physiological parameter (heart rate (HR), respiratory rate (RR), systolic blood pressure (SBP)), individual values were converted into Z scores using the formula:

Z score = (Value – parameter mean) / *parameter standard deviation.*

Outliers were defined as those values with a Z score more than three standard deviations away from the mean, correlating to a value greater than positive (or negative) 3.29. This dictates that the extreme 0.1% values are considered outliers and are therefore removed.[114] Box and whisker plots are provided for each physiological parameter, both with and without the removal of outliers **(Figure 3.1).**

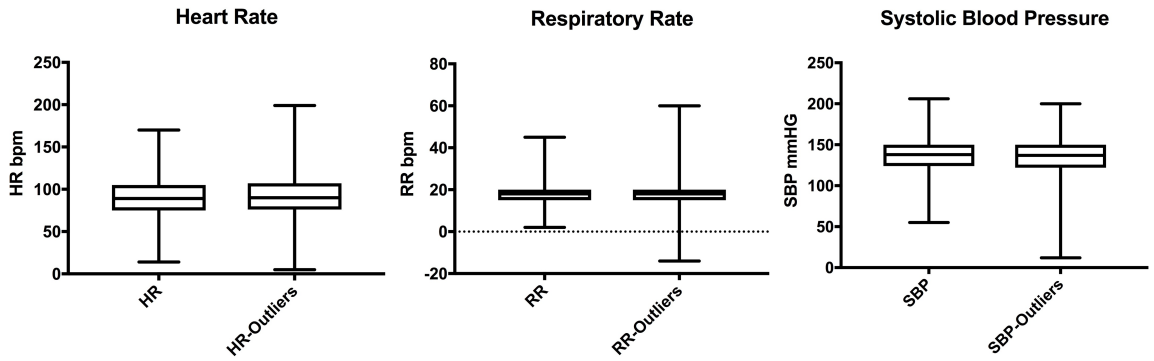


Figure 3.1 Box and whisker plot for physiological parameters (including and excluding outliers).

In **chapter 2** the Delphi panel considered that interventions were life-saving if they were performed within one hour. Due to the nature of how the JTTR data is recorded, it is not possible to determine the specific time that interventions are performed; interventions were simply recorded as occurring at either point of injury (Role 1), evacuation, in hospital (Role 3) or at RCDM (Role 4). The exception to this were surgical operations, where surgical start time was recorded in accordance with the WHO Surgical Safety Checklist. For the purposes of this study, only interventions performed at Role 1, during evacuation or Role 3 were included; interventions and procedures performed at RCDM were deemed to be beyond the initial resuscitation phase and were therefore excluded.

Not all interventions in **Figure 2.3** are recorded within the JTTR database, and therefore surrogates were employed to represent the closest intervention (**Table 3.2).** For the application of a pelvic binder, a combination of intervention and injury diagnosis using AIS codes were used. Only AIS codes associated with the anatomical diagnosis of an unstable pelvic injury were included:

- 856161 Pelvic ring fracture, incomplete disruption of posterior arch; partially or vertically stable.
- 856162 Pelvic ring fracture, incomplete disruption of posterior arch; partially or vertically stable open.
- 856171 Pelvis substantial deformation and displacement with associated vascular disruption; with major retroperitoneal haematoma; fracture (NFS as to blood loss).
- 856172 Pelvis substantial deformation and displacement with associated vascular disruption; with major retroperitoneal haematoma; fracture blood loss > 20% by volume.

Intervention	Surrogate Variable
ALS/ACLS Protocols	CPR, Epinephrine, Atropine, Amiodarone, "Resus Drugs"
Intubation for actual/impending airway obstruction	Endotracheal tube AND rapid sequence induction
Pelvic binder	Limb traction AND coded pelvic injury (856161, 856162, 856171, 856172)
Positive pressure ventilation	Mechanical ventilation
Proximal vascular control	Arterial ligation, shunt, cross clamping
Spinal nursing	Proven spinal fracture C1-C3

Table 3.2: Surrogate variables used for JTTR analysis.

ALS/ACLS – Advanced Life Support / Advanced Cardiac Life Support, CPR – Cardiopulmonary resuscitation, JTTR- Joint Theatre Trauma Registry

Existing major incident triage tools classify Priority One patients if any single physiological parameter meets or exceeds the defined threshold, irrespective of all other parameters. In order to maintain this independence, separate bivariate analyses were performed for each parameter, instead of a single combined multivariate logistical analysis. Separate bivariate logistical regression models were developed for each physiological parameter to determine the binary outcome variable (need for life-saving intervention). It was expected that an increase and decrease at the upper and lower ranges respectively for both HR and RR would relate positively to the outcome probability. Therefore, regressions for both were estimated separately for values above and below the median level (HR-89bpm, RR-18bpm). Models were fitted by Maximum Likelihood estimation, and the performance of each model reported in terms of the significance of the parameters (B0 and B1), the explanatory power (Nagelkerke's pseudo-R2), goodness of fit (Hosmer-Lemeshow's X^2) and the percentage improvement in classification success (i.e. the classification success achieved by the model compared to the classification success achieved by assigning all cases the outcome of the most probable class). The logistic regression equation Probability (event Y) $=1/(1+e^{-(B0 + X*B1)})$ was applied to determine the median effective level (Prob(Y)=0.5) for each parameter. The combination of these individual parameters formed the novel physiological triage tool "Modified Physiological Triage Tool – MPTT".

In order to conduct the subsequent comparative analysis with existing triage tools, surrogates were required for START, Careflight and the Military Sieve. With both START and Careflight using the presence of a palpable pulse as a triage assessment, a surrogate measure was required, as this is not included as a recorded variable on the JTTR. Described within the publication, a surrogate SBP measurement of 90mmHg was used to represent the presence of a palpable pulse. There is a considerable variety in opinion within the literature as to what SBP level correlates with the presence of a palpable pulse; traditionally earlier Advanced Trauma Life Support (ATLS) teaching stipulated that a radial pulse would be felt at SBP levels greater than 80mmHg. However, studies have shown that in a number of hypotensive patients (measured both by non-invasive and invasive means), presence of a radial pulse remains at levels below 80mmHg.[116,117] In support of this, recent European guidelines for the management of haemorrhagic trauma patients infer that the presence of a radial pulse correlates with a SBP of 70mmHg.[118] Whilst there is likely to be individual variation between patients, a conservative threshold of 90mmHg was chosen to represent the presence of a palpable pulse. This threshold was chosen for two reasons; firstly, as a conservative assessment, very few patients (if any) would NOT have

a palpable pulse at this level, making it a reliable measurement and secondly, because of increased mortality following blunt and penetrating trauma associated with SBP less than 90mmHg.[119,120]

The Military Sieve includes an assessment of conscious level, but this is simply 'conscious' versus 'unconscious' and there is no further description available within the Clinical Guidelines for Operations.[46] Both START and Careflight assess the conscious level by determining if the patient 'obeys commands', corresponding to an isolated GCS Motor Score of 6. The JTTR database records the complete GCS score and not the individual (Eye, Verbal, Motor) components, therefore it is not possible to specifically determine whether a patient 'obeys commands'. For the purposes of the comparative analysis, a GCS < 13 was used to represent both 'unconscious' and 'obeys commands'; this is consistent with what has previously been described with studies looking at the Military Sieve and comparing its performance with the MIMMS Triage Sieve.[18]

The published paper includes the Modified Military Sieve in the comparative analysis; this was a theoretical model derived by the author (JV) prior to commencing this programme of work. The Modified Military Sieve was developed using an alternative retrospective JTTR dataset, (different to that used in this study) by modifying the existing parameters of the Military Sieve and determining which yielded the optimum sensitivity and specificity for predicting need for life-saving intervention (**Table 2.3).** Whilst the Modified Military Sieve is described in the publication, it has not been adopted for use by the DMS.[18] The comparative analysis was performed using sensitivity and specificity with the calculation of under-triage (1-sensitivity) and over-triage (1-positive predictive value). When comparing the triage tools, a McNemar Chi-squared test was used to determine significance. As testing was repeated multiple times, a Bonferroni correction was applied to reduce the chance of a Type I error, which in the context of this study would be incorrectly rejecting the true null hypothesis that the MPTT and Triage Tool "X" have equal performance.[121,122]

Supplementary results

Of 6095 cases recorded on the database, only 3654 (60.0%) were included in the final analysis (**Figure 3.2**). Following the removal of cases with incomplete physiological data, a further 47 cases were excluded as outliers (**Table 3.3**).

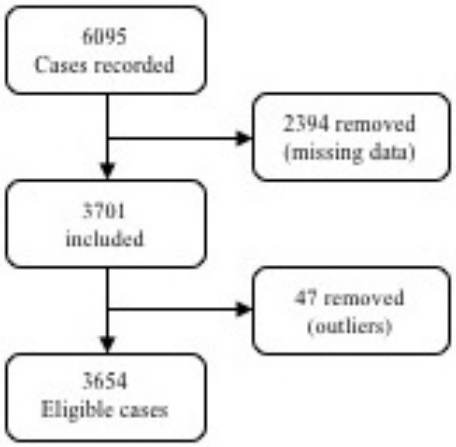


Figure 3.2: JTTR participation flow diagram.[123]

	Number	Percentage
Complete data recorded	3701	
Outliers (z > 3)	47	1.3%
Respiratory rate (>45bpm)	28	0.75%
Heart rate (>170bpm)	12	0.32%
Systolic blood pressure (>206mmHg)	9	0.24%

Table 3.3: Frequency of outliers.

Bpm- breaths per minute

Characteristics of the study population are described in **Table 2** of the published paper. Injured personnel had a mean of two body regions affected (range 0-8) with a preponderance of extremity injuries (lower 36.0%, upper 16.2%). Approximately half the study population (n=1755, 47.8%) received at least one life-saving intervention from **Figure 2.3** (range 1-12 interventions). Of patients receiving an intervention, the majority (36.2%) received a single intervention and the application of a tourniquet was the most frequent intervention.

Due to the number of missing cases and incomplete physiology recorded at point of injury (Role 1), analysis was performed using first recorded hospital physiology (at Role 3). This may represent a limitation as it is possible for an improvement in a patient's recorded physiology in those receiving interventions prior to arrival at hospital. In order to explore this effect, a comparison was undertaken of pre-hospital versus first recorded hospital physiology **(Table 3.4)**.

	Point of injury (Role 1)	First recorded hospital (Role 3)
GCS	15 (12-15)	15 (14-15)
Heart Rate (bpm)	89 (76-105)	89 (75-105)
Respiratory Rate (bpm)	19 (16-24)	18 (15-20)
Systolic Blood Pressure (mmHg)	126 (113-139)	138 (124-138)

Table 3.4: Comparison of pre-hospital versus first recorded hospital physiology (median (IQR)).

Bpm- breaths per minute, GCS – Glasgow Coma Scale, IQR – interquartile range

With the exception of SBP, the median values are comparable between point of injury and arrival in hospital. When the IQR are compared, a lower GCS first quartile and greater RR third quartile is observed at point of injury. SBP measurements at point of injury are within normal ranges, and although the median SBP is 12mmHg lower than on arrival in hospital, the values, including the first quarter, do not fall below the threshold considered to be consistent with shock or hypotension.[124]

Glasgow Coma Scale

The logistic regression model for GCS demonstrated statistical significance for identifying the need for life-saving intervention ($p<0.001$, $\chi^2 = 768.42$), with approximately 25% of the variation in the outcome variable being described by the GCS (Nagelkerke $R^2 = 0.255$). The model fit was satisfactory (Hosmer and Lemeshow statistic $\chi^2 = 0.441$, d.f.=2, p=0.506). Using the probability of outcome equation the value of GCS <14 was derived as the optimum level for predicting the need for life-saving intervention. Probability values for each GCS threshold are shown in **Table 3.5** below, and in graphical form in **Figure 1** of the published paper.

GCS Value	Predicted probability of outcome
3	0.992
4	0.987
5	0.980
6	0.970
7	0.954
8	0.930
9	0.895
10	0.846
11	0.779
12	0.694
13	0.594
14	0.485
15	0.378

Table 3.5: Predicted probability of outcome for GCS thresholds.

Respiratory Rate

The dataset was split by the median (RR $\leq$18, n=2313 and RR >18, n=1360) and logistic regression models were developed for both lower and upper ranges. Population pyramids for both RR and HR are shown below in **Figures 3.3 and 3.5.** Both models demonstrated significance, χ^2=21.4 and 75.2, d.f.=1, $p<0.001$ respectively, with poor fit (Hosmer and Lemeshow statistic $\chi^2 = 27.8$ and 13.5, d.f.=6 and $p<0.05$ respectively for RR $\leq$18 and RR >18). Approximately 1% (lower) and 7% (upper) of variation in the outcome variable could be explained by the model (Nagelkerke $R^2 = 0.012$ and 0.072). Probability values for RR thresholds are

shown in **Table 3.6** and in graphical form in **Figure 3.4.** Optimum levels of respiratory rate (upper and lower) were defined as RR <12 and RR ≥22 having been derived using a probability of outcome equation.

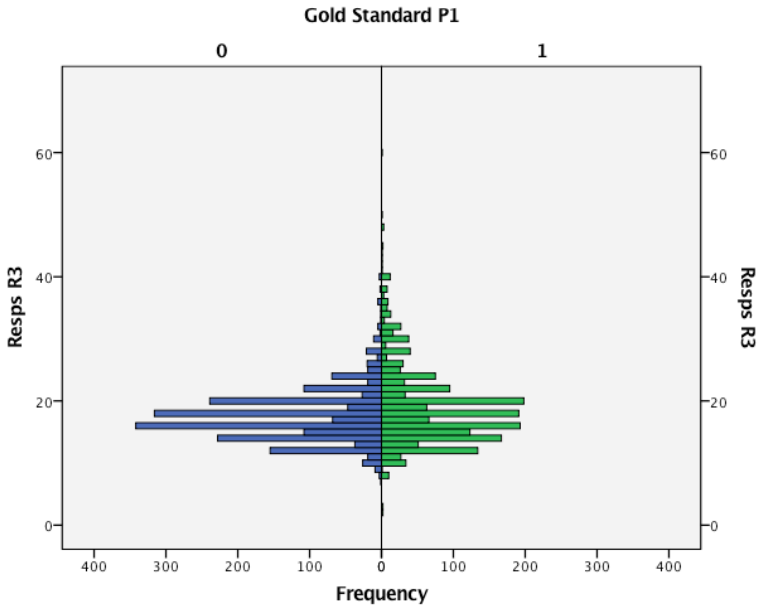


Figure 3.3: Population pyramid for respiratory rate.

RR Value (low)	Predicted probability of outcome	RR Value (high)	Predicted probability of outcome
5	0.629	15	0.344
6	0.610	16	0.368
7	0.591	17	0.393
8	0.571	18	0.418
9	0.551	19	0.444
10	0.531	20	0.471
11	0.511	21	0.497
12	0.491	22	0.524
13	0.471	23	0.550
14	0.450	24	0.576
15	0.430	25	0.602

Table 3.6: Predicted probability of outcome for respiratory rate thresholds.

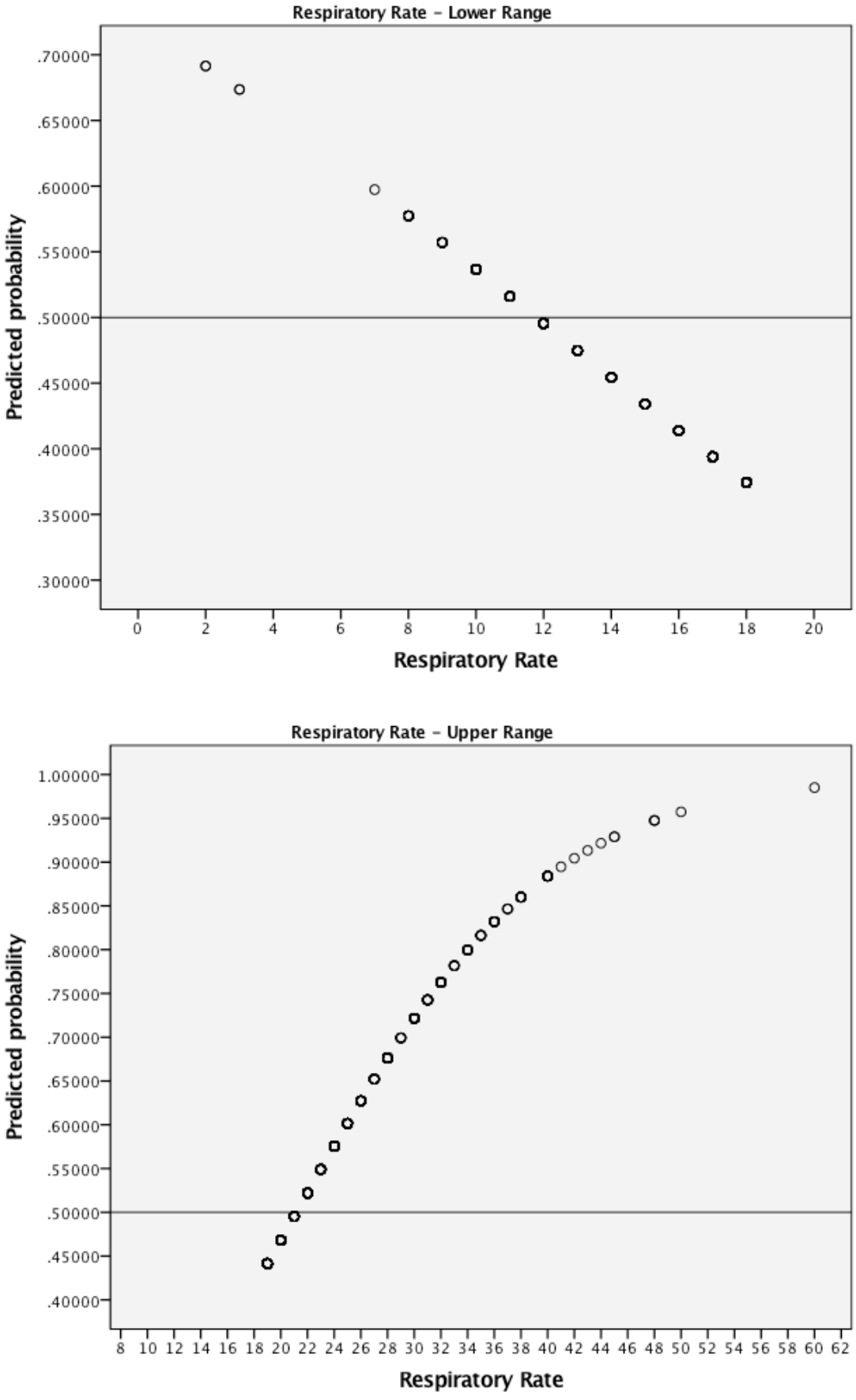


Figure 3.4: Parameter estimates for respiratory rate.

Heart Rate

As with the RR, the dataset was split by the median (HR ≤89, n=1878 and HR >89, n=1795, **Figure 3.5**) with logistic regression models developed for both ranges. Only the upper range (HR >89) demonstrated significance, χ^2= 179.6, d.f.=1 and p<0.001 with a good fit (Hosmer and Lemeshow statistic χ^2 = 8.8, d.f.=8 and p=0.358). Approximately 13% of the variation in outcome variable could be explained by the upper model (Nagelkerke R^2 = 0.129). Probability values for HR thresholds are shown in **Table 3.7** and in graphical form in **Figure 3.6.** Using the probability of outcome equation, the optimum level of heart rate was defined as HR ≥100.

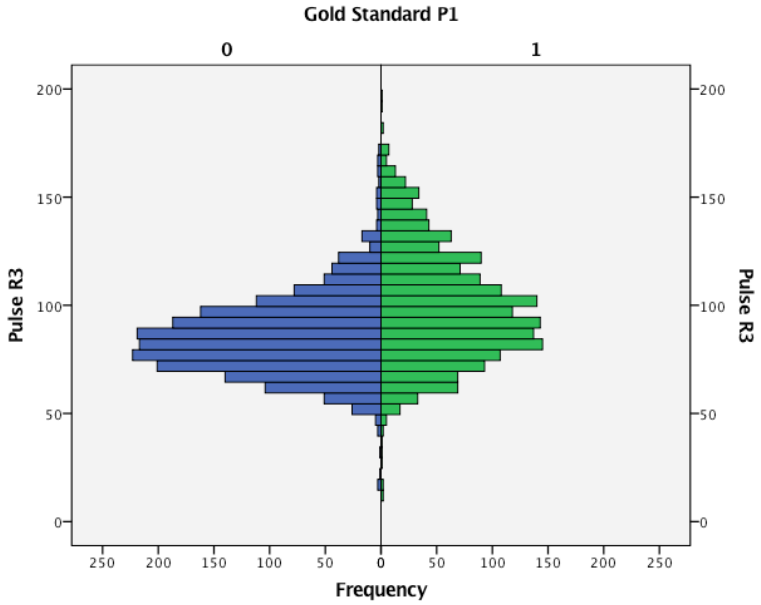


Figure 3.5: Population pyramid for heart rate.

HR Value	Predicted probability of outcome	HR Value	Predicted probability of outcome
90	0.405	99	0.496
91	0.415	100	0.506
92	0.425	101	0.516
93	0.435	102	0.527
94	0.445	103	0.537
95	0.455	104	0.547
96	0.465	105	0.557
97	0.476		
98	0.486		

Table 3.7: Predicted probability of outcome for heart rate thresholds.

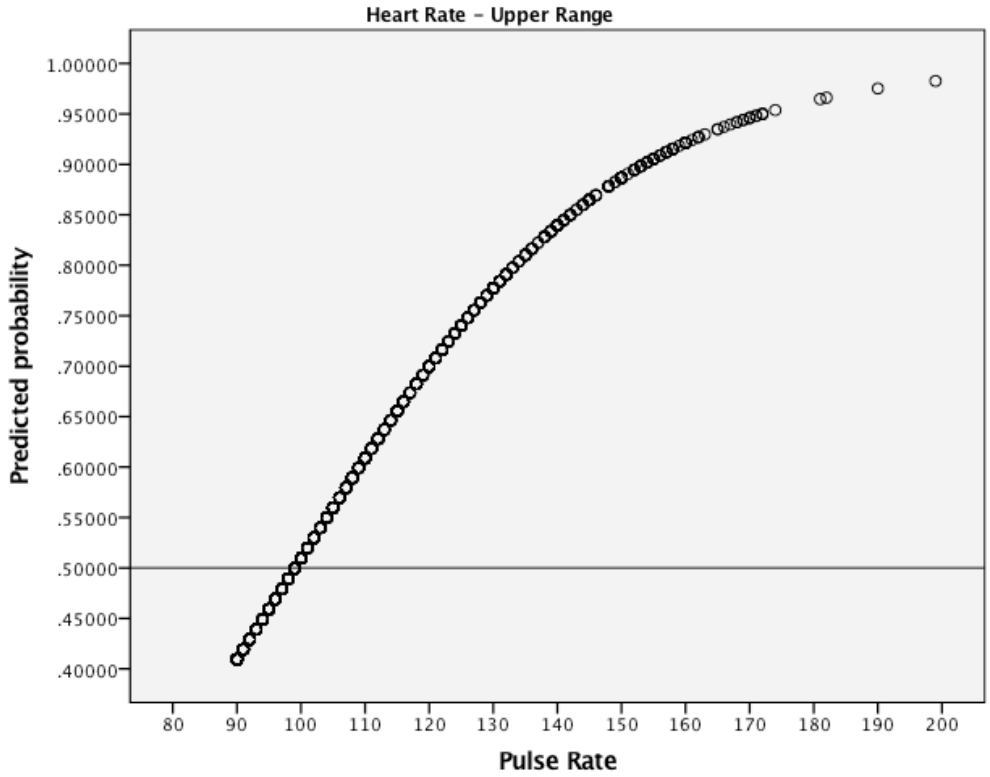


Figure 3.6: Parameter estimates for heart rate.

Comparative Analysis

The combination of the individual physiological thresholds (GCS <14, 12< RR ≥22 and HR ≥100) was used to define the MPTT (**Figure 3.7)**. In a comparative analysis with existing triage tools, the MPTT demonstrated the greatest sensitivity, corresponding with the lowest rates of under-triage (**Table 3.8)**. However, the increase in sensitivity comes at the expense of the lowest specificity and the highest rates of over-triage. A McNemar test with Bonferroni correction (α=0.05/5=0.01) was used to determine if a statistically significant difference existed between the MPTT, the Military/NARU Sieve and the MIMMS Triage Sieve. For all comparisons, the null hypotheses that the MPTT and respective triage tools had equal performance was rejected.

MPTT versus MIMMS Triage Sieve - χ^2=1,350, p <0.001

MPTT versus Military/NARU Sieve - χ^2=998, p <0.001

Where in a previous study the Modified Military Sieve had demonstrated good performance at predicting need for life-saving intervention (Sensitivity: 71.2% (68.2-74.1)), Specificity: 79.3% (75.9-82.7)), within this analysis, the observed performance was considerably lower (Sensitivity: 50.9% (48.6-53.3), Specificity: 87.5% (85.9-88.9)).[18]

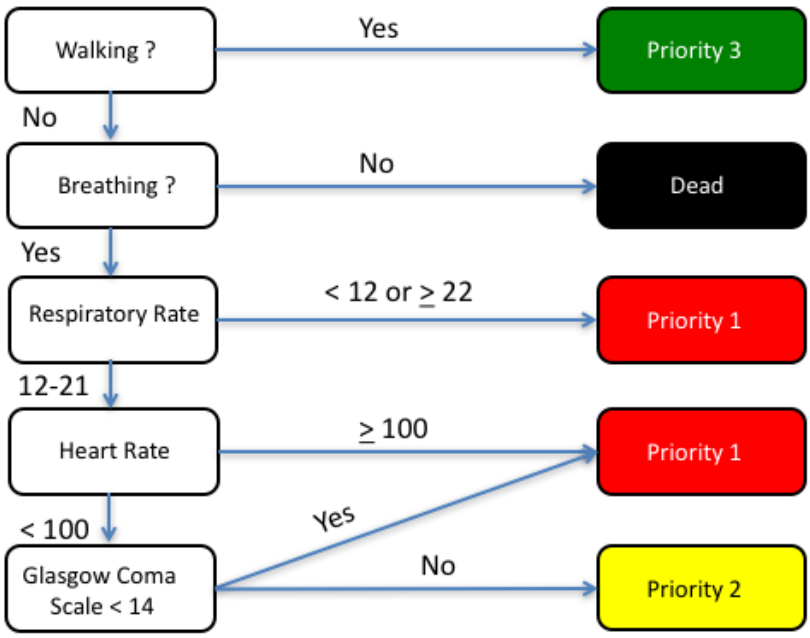


Figure 3.7: Modified Physiological Triage Tool (MPTT).[123]

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT	69.5% (67.3-71.6)	65.3% (63.2-67.4)	30.5% (28.4-32.7)	35.4% (33.3-37.6)
MIMMS Triage Sieve	24.2% (22.3-26.3)	94.8% (93.8-95.7)	75.8% (73.7-77.7)	19.1% (17.4-20.9)
Military/NARU Sieve	43.2% (41.0-45.6)	93.7% (92.5-94.7)	56.8% (54.4-59.1)	13.8% (12.4-15.4)
START	38.1% (35.8-40.4)	96.9% (96.1-97.6)	61.9% (59.6-64.2)	8.2% (7.1-9.5)
Careflight	32.9% (30.7-35.2)	98.4% (97.8-98.9)	67.1% (64.8-69.3)	5.0% (4.1-6.0)

Table 3.8: Comparative performance of the MPTT with existing triage tools.[123]

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value, MPTT: Modified Physiological Triage Tool

The ideal triage tool would have both maximal sensitivity and specificity, with minimal under and over-triage, but as with all diagnostic tests an increase in sensitivity tends to result in a decrease in specificity, therefore one should be prioritised (sensitivity versus specificity or under-triage versus over-triage) over the other. Limited guidance exists as to how accurate triage tools should be – with the American College of Surgeons directing that both under and over-triage should be kept to a minimum. However, within the same document, clear guidance is given for the field triage process, where they recommend that under and over-triage be kept to below 5% and 35% respectively.[16]

The field triage process differs considerably to primary major incident triage; it is a more detailed assessment of the individual trauma patient, using a combination of different methods (physiological assessment, anatomical injury assessment and assessment of the mechanism of injury) in order to determine whether or not the patient requires care at a Major Trauma Centre. It is not practical to suggest that this be performed during primary major incident triage for a number of reasons including the time required to complete the process, the

availability of experienced clinicians to perform it and the likely requirement to expose the patient to assess for injuries.

Whilst the two processes are different, with the field triage process being more detailed, it is the only quantitative measure that exists for assessing triage performance. Clearly the under-triage rate of the MPTT exceeds the 5% recommended threshold, but it is the lowest by a considerable amount (absolute reduction of 26.8% compared to the Military/NARU Sieve), whilst maintaining a rate of over-triage (35.4%) comparable to the recommended 35% threshold.[16]

Where minor discrepancy exists between **Table 3.8** and the published table 3, this is due to a combination of rounding of decimal places involved in the calculations and a different statistical program being used (GraphPad Prism instead of SPSS)**.**

Assessment of over and under-triage

Throughout all the studies described in this thesis under-triage and over-triage have been calculated using 1-sensitivity and 1-PPV respectively. Additional methods of calculating both exist, including 1-negative predictive value for under-triage and 1-specificity for over-triage and these are provided in **Table 3.9**. In these studies, 1-PPV was chosen to assess over-triage as it is the more appropriate measure due to it addressing the principal concern of over-triage i.e. resource utilisation for minimally injured patients. Additionally, it is the measure adopted in the USA for calculating over-triage using the Cribari matrix.[16,73]

However, in contrast, the Cribari matrix calculates under-triage as 1-negative predictive value instead of 1-sensitivity. By using 1-sensitivity, the denominator used in the calculation is all patients in need of life-saving intervention, which is more appropriate, as these are the patients who are most at risk from not being identified.[31,73,125]

	MPTT	**MIMMS Triage Sieve**	**Military/NARU Sieve**	**START**	**Careflight**
This study					
Under-triage ***(1-sensitivity)***	30.5% (28.4-32.7)	75.8% (73.7-77.7)	56.8% (54.4-59.1)	61.9% (59.6-64.2)	67.1% (64.8-69.3)
Over-triage ***(1-PPV)***	35.4% (33.3-37.6)	19.1% (17.4-20.9)	13.8% (12.4-15.4)	8.2% (7.05-9.51)	5.0% (4.1-6.0)
Alternative methods					
Under-triage ***(1-NPV)***	29.7% (27.6-31.9)	42.0% (39.7-44.4)	35.5% (33.3-37.8)	36.7% (34.5-39.0)	38.2% (35.9-40.5)
Over-triage ***(1-specificity)***	34.7% (32.6-36.8)	5.2% (4.3-6.3)	6.3% (5.3-7.5)	3.1% (2.4-4.0)	1.6% (1.1-2.2)

Table 3.9: Comparison of alternative methods of calculating under and over-triage.

PPV; Positive Predictive Value, NPV; Negative Predictive Value

Supplementary limitations

As discussed in the publication, there are a number of limitations associated with this study, including performing a comparative analysis of the MPTT on the same dataset in which it was derived. Whilst the use of a trauma registry with which to derive the MPTT conveys the benefit of a greater number of injured patients when compared to the retrospective review of a number of major incidents, it is acknowledged as a limitation, as the derivation is taking place in a different environment to that it is designed to function in.[15,17]

Linked with the use of trauma registries is the limitation of inclusion criteria for entry onto the trauma registry; in the case of this study, prior to 2007 the inclusion criteria were patients receiving a trauma team activation. This introduces a selection bias into the analysis as the entire population is not being analysed; whilst sensitivities calculated will be accurate (true positives as these will fulfil inclusion criteria), the specificities (true negatives) need to be interpreted with caution, as not all 'negative' patients will have been included in the analysis as they did not meet the inclusion criteria. Following 2007, when the inclusion criteria were broadened to include all patients who were repatriated to RCDM, irrespective of whether they received a trauma team activation for their care, this selection bias will have reduced to an extent.

Another limitation of using trauma registries is the reliance on the data inputted and where variables are not recorded, surrogates are required in order to conduct the analysis. The initial step of the MPTT and other triage tools is the assessment of whether the patient is able to walk; the JTTR does not record whether the patient is ambulatory or not, and for the purposes of this study it has been assumed that all patients were non-ambulatory, which represents an additional limitation.

The use of a surrogate GCS to represent 'unconscious' and 'obeys commands' is an additional limitation. In keeping with previous studies, GCS <13 was used to represent 'unconscious' for the Military/NARU Sieve as it is unlikely that a patient with a GCS $\geq$13 would be considered 'unconscious', even if assessed by an inexperienced provider. The use of GCS <13 to represent 'obeys commands' in the START and Careflight algorithms, may fail to identify all patients who are unable to 'obey commands'. As it is an isolated assessment of the motor component of the GCS, a patient only requires a motor score of five or less to be categorised as does not 'obey commands'. It is possible for patients to not 'obey commands' but to have a GCS score of 13 or 14, and these patients will not be captured by the surrogate measure used; as with the assessment of 'unconscious', it is unlikely that an inexperienced provider would categorise a patient as being able to 'obey commands' at a GCS $\geq$13.

Chapter conclusion

Using a retrospective military population, the MPTT has been derived and successfully outperforms existing methods of primary major incident triage at identifying those patients in need of a life-saving intervention. The MPTT yields the greatest sensitivity, corresponding to the lowest rates of under-triage; the priority of primary major incident triage is to minimise rates of under-triage and the MPTT fulfils these criteria. Although the MPTT has the greatest rate of over-triage, this is comparable to that recommended for individual field triage, and in this environment is considerably lower than that observed following the London 7/7 bombings.[16,61] Prior to recommending the MPTT as a replacement to existing methods in either the military or civilian major incident setting, additional validation is required and this is described in **chapters 4 and 5.**

Chapter 4: Assessing the performance of the Modified Physiological Triage Tool on a civilian population using a trauma registry

Reference:

Vassallo J, Smith JE, Bouamra O, Lecky F, Wallis LA. The civilian validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to primary major incident triage. Emerg Med J. 2017 Dec;34(12):810-815.

Declaration from author

The following co-authors contributed to the paper: Jason E Smith, Omar Bouamra, Fiona Lecky and Lee A Wallis.

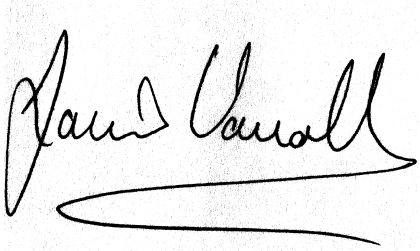
In the case of Chapter 4, contribution by authors to the work was as follows:

Nature of contribution

- JV, JES and LAW conceived the idea. JV, OB and FL designed the study. JV drafted the work with all authors contributing to revise it critically for important intellectual content. All authors approved the final published version and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- **Extent of contribution:** JV: 75%; OB and FL combined: 10%, JES: 10%; LAW: 5%

The following co-authors contributed to the work:

1. Prof. Lee A Wallis
2. Prof. Jason E Smith
3. Prof. Fiona Lecky
4. Dr Omar Bouamra



Signed: James Vassallo

Declaration by co-authors

The undersigned hereby certify that:

1. The above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. There are no other author of the publication according these criteria;
5. Potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. The original data are stored at the following location and will be held for at least five years from date indicated below

Location of stored data:

Data were stored on the authors (JV) encrypted account at the University of Birmingham, allocated through the Academic Department of Military Emergency Medicine.

31st January 2018

Prof. Jason E. Smith — Date

8th February 2018

Prof. Lee A. Wallis — Date

Main findings:

- Within the civilian trauma registry population, the Modified Physiological Triage Tool demonstrated the greatest sensitivity at predicting need for life-saving intervention with the lowest rates of under-triage, outperforming existing triage tools.
- In keeping with the derivation study, existing triage tools have greater specificity than the Modified Physiological Triage Tool, correlating with lower rates of over-triage.
- In this population, the rate of over-triage from the Modified Physiological Triage Tool is directly comparable to that observed following the London 7/7 bombings.

Motivation for conducting study

The MPTT was derived from a retrospective military cohort using logistic regression methodology and within this environment, it outperformed existing major incident triage tools at predicting need for life-saving intervention. The military environment differs considerably to the civilian setting, with a preponderance to blast and ballistic injuries, affecting mainly young males (median age 24, IQR 21-29 years). Before the MPTT can be recommended as an alternative to the NARU sieve, the existing method of UK civilian primary major incident triage, its performance needs to be determined in the civilian setting, where the population is older and with a different predominant mechanism of injury.[126]

Aim

The aim of this study was to perform a validation of the Modified Physiological Triage Tool in a civilian population.

Objectives

- Identify gold standard Priority One patients in terms of requirement for life-saving intervention.
- Determine the ability of the Modified Physiological Triage Tool at predicting the requirement for life-saving intervention.
- Undertake a comparative validation with existing triage tools.
- Perform a subgroup analysis on age, gender and injury type (blunt versus penetrating).

A copy of the published paper follows over the next six pages.

The civilian validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to primary major incident triage

James Vassallo,[1,2] Jason Smith,[3,4] Omar Bouamra,[5] Fiona Lecky,[5,6] Lee A Wallis[1]

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/emermed-2017-206647).

[1]Division of Emergency Medicine, University of Cape Town, Cape Town, South Africa
[2]Institute of Naval Medicine, Gosport, UK
[3]Department of Emergency, Derriford Hospital, Plymouth, UK
[4]Department of Military Emergency Medicine, Royal Centre for Defence Medicine (Research and Academia), Medical Directorate, Joint Medical Command, Birmingham, UK
[5]Trauma Audit and Research Network, Hope Hospital, Manchester, UK
[6]Health Services Research Section, School of Health and Related Research, University of Sheffield, Sheffield, UK

Correspondence to
Dr James Vassallo, Institute of Naval Medicine, Alverstoke, Gosport PO12 2DL, UK; vassallo@doctors.org.uk

Received 31 January 2017
Revised 11 July 2017
Accepted 22 July 2017

ABSTRACT

Introduction Triage is a key principle in the effective management of a major incident. Existing triage tools have demonstrated limited performance at predicting need for life-saving intervention (LSI). Derived on a military cohort, the Modified Physiological Triage Tool (MPTT) has demonstrated improved performance. Using a civilian trauma registry, this study aimed to validate the MPTT in a civilian environment.

Methods Retrospective database review of the Trauma Audit and Research Network (TARN) database for all adult patients (>18 years) between 2006 and 2014. Patients were defined as Priority One if they received one or more LSIs from a previously defined list. Only patients with complete physiological data were included. Patients were categorised by the MPTT and existing triage tools using first recorded hospital physiology. Performance characteristics were evaluated using sensitivity, specificity and area under receiver operating characteristic (AUROC).

Results During the study period, 218 985 adult patients were included in the TARN database. 127 233 (58.1%) had complete data: 55.6% male, aged 61.4 (IQR 43.1–80.0) years, Injury Severity Score 9 (IQR 9–16), 96.5% suffered blunt trauma and 24 791 (19.5%) were Priority One. The MPTT (sensitivity 57.6%, specificity 71.5%) outperformed all existing triage methods with a 44.7% absolute reduction in undertriage compared with existing UK civilian methods. AUROC comparison supported the use of the MPTT over other tools (p<0.001.)

Conclusion Within a civilian trauma registry population, the MPTT demonstrates improved performance at predicting need for LSI, with the lowest rates of undertriage and an appropriate level of overtriage. We suggest the MPTT be considered as an alternative to existing triage tools.

Key messages

What is already known on this subject?

- There is increasing evidence to suggest that existing primary major incident triage tools perform poorly at predicting the need for a life-saving intervention.
- Derived using logistic regression, the Modified Physiological Triage Tool (MPTT) demonstrated improved performance at predicting need for life-saving intervention with the lowest rates of undertriage and acceptable rates of overtriage within a military population. It is the first physiological triage tool to be derived specifically to predict need for life-saving intervention.

What this study adds?

- This study demonstrates that existing methods of primary major incident triage have unacceptably high rates of undertriage, with the Triage Sieve, the existing UK method of primary major incident triage performing the worst. The MPTT outperforms all existing triage tools with the lowest rates of undertriage, while maintaining an acceptable level of overtriage, comparable to that observed following the London 7/7 bombings.

INTRODUCTION

Major incidents occur worldwide on an almost daily basis, ranging from natural disasters to transport incidents to terrorist atrocities.[1] For the health services, they are defined as incidents requiring 'extraordinary resources' in order to manage the number or severity of casualties.[2] Over the last decade, we have seen an increase in terrorism-related incidents directed towards civilians worldwide, and notably the 2015 Paris marauding terrorist firearms attacks, which produced patterns of injuries in civilian casualties that are more akin to that seen in the military setting than had previously been observed.[3]

Triage is the process of determining a patient's clinical priority and is a key step for the effective management of major incidents. Its origins as a clinical sorting process date back to 1846, when Wilson, a Royal Naval Surgeon described sorting patients into groups corresponding to *slight*, *serious* or *fatal*.[4] A key tenet of major incident triage is that it must be rapid, reliable and reproducible, irrespective of the provider performing it.[2] Most methods of major incident triage use physiology to guide allocation to a particular triage category, with Priority One or Immediate being the most acute.[5] This process is used to either prioritise patient evacuation or to predict patient need for a life-saving intervention.[6 7]

There is limited evidence to support the use of the three commonly used civilian major incident triage tools (Triage Sieve,[2] START[8] and Careflight,[5] see table 1) with a number of studies demonstrating poor accuracy at predicting need for life-saving intervention.[5 9 10] Following the London 7/7 bombings, a study of the patients treated at the Royal London Hospital found that all three triage tools had an undertriage rate of 50%.[11]

To cite: Vassallo J, Smith J, Bouamra O, *et al*. *Emerg Med J* Published Online First: [*please include* Day Month Year]. doi:10.1136/emermed-2017-206647

Table 1 Comparison of existing triage tools[5 12]

Method	First assessment	Second assessment	Third assessment	Fourth assessment
START (USA)	Walking?	Breathing? Rate>29	Palpable pulse?*	Obeys commands?†
Careflight (Australia)	Walking?	Obeys commands?†	Breathing?	Palpable radial pulse?*
Triage Sieve (UK and International)	Walking?	Breathing? <10, Rate>30	HR>120	
Military Sieve (UK)	Walking?	Breathing? <10, rate>30	HR>120	Unconscious?†
Modified Physiological Triage Tool	Walking?	Breathing? <12, rate>22	HR>100	GCS<14

A patient is designated as Priority One if the patient is unable to walk and if any of the assessments conducted afterwards are positive.
*A systolic blood pressure measurement of 90 mm Hg was used as a surrogate measure to represent presence of a palpable pulse.
†A GCS<13 was used as a surrogate for unconsciousness or the inability to obey commands.

The Modified Physiological Triage Tool (MPTT) was derived on a military cohort, using logistic regression models for each individual physiological variable.[12]

Within a military population, the MPTT significantly outperformed existing triage tools at predicting need for life-saving intervention, with the lowest rate of undertriage (30.1%) while minimising rates of overtriage (35.2%).[12] However, this was a young population (median 24 years, IQR 21–29 years) sustaining predominantly blast injuries (55% were injured by explosion).

Despite outperforming existing triage tools in a military population, no studies have evaluated the performance of the MPTT in a civilian population. Before the MPTT can be suggested as a replacement to the Triage Sieve in a civilian major incident setting, an evaluation of its performance in this population needs to be undertaken.

Ideally, this should be in the major incident setting, under the circumstances in which the MPTT is expected to operate. However, owing to the unpredictable nature of major incidents, prospective research into the development of novel triage algorithms is impractical. Instead, we analyse major incidents retrospectively or use trauma databases as a source of injured patients; while the retrospective analysis of major incidents conveys the advantage of utilising a genuine scenario, previous attempts to use real major incidents have been hampered by small numbers of seriously injured patients. With small sample sizes, the ability to draw reliable conclusions on a triage tools' ability to predict need for life-saving intervention is therefore limited. By contrast, the use of a trauma database allows for the comparison of triage tools using large numbers of injured patients, testing their performance at predicting those in need of life-saving intervention following a variety of trauma mechanisms. We therefore aimed to validate the use of the MPTT on a civilian population using the UK Trauma Audit and Research Network (TARN) database.

METHODS

A retrospective database review was undertaken using the TARN database from 1 January 2006 to 31 December 2014. All adult (≥18 years) patients with trauma meeting TARN inclusion criteria presenting to hospitals in England and Wales were eligible (www.tarn.ac.uk).

Established in 1988, TARN is the largest trauma database in Europe collecting data on patients sustaining moderate to major traumatic injuries from all trauma receiving hospitals in the England and Wales. Data are submitted electronically by trained clerical staff from the receiving hospital to TARN and the data follow the patient pathway from injury to discharge. TARN eligibility includes patients with trauma admitted to hospital ≥3 days, critical care unit admission or who die in hospital.[13] Only direct admissions from scene of injury were included and patients with incomplete physiological data were excluded. Patients declared dead at scene and not conveyed to hospital are not included in the TARN database and therefore were not included in our analysis. Due to the nature of the TARN database and its inclusion criteria, patients were assumed to be non-ambulant.

In keeping with the derivation study, outliers, defined as HR >170 beats per minute, respiratory rate >45 breathes per minute and systolic blood pressure >206 mm Hg were removed.[12] Patients were defined as Priority One (P1) if they received one or more life-saving interventions from a previously defined list, derived through international consensus of experts involved in major incident management (see table S1 in the online supplementary file 1).[7] Using first recorded ED physiology, patients were categorised using existing triage tools (START, Careflight, Military Sieve, Triage Sieve).[5 8 14]

Not all life-saving interventions are recorded as variables on the TARN database, requiring surrogates to be used (see table S1 in the online supplementary file 1). These were determined prior to the database analysis and represent the closest approximation to the interventions required. Additionally, in keeping with previous work, a systolic blood pressure surrogate of 90 mm Hg was used to

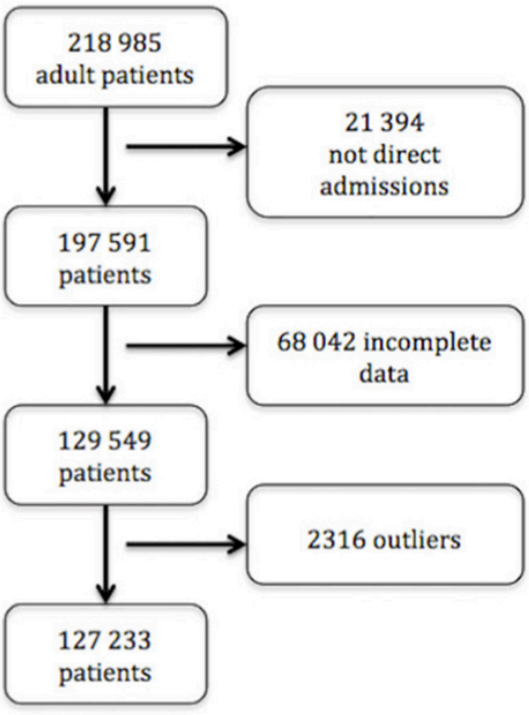


Figure 1 Study flow diagram.

Table 2 Characteristics of study population

Number of patients	127 233
Gender (n (%))	
Male	70 747 (55.6%)
Female	56 486 (44.4%)
Injury Severity Score (median (IQR))	9 (9–16)
Age (years) (median (IQR))	61.4 (43.1–80.0)
30-Day outcome (n (%))	
Alive	119 967 (94.3%)
Dead	7266 (5.7%)
Mode of injury (n (%))	
Blunt	122 802 (96.5%)
Penetrating	4431 (3.5%)
Mechanism of injury (n (%))	
RTC	27 915 (21.9%)
Crush	935 (0.7%)
Amputation (total+partial)	123 (0.1%)
Fall>2 m	18 141 (14.3%)
Fall<2 m	68 354 (53.7%)
Shooting	332 (0.3%)
Stabbing	2899 (2.3%)
Blast	77 (0.1%)
Blow(s)	5833 (4.6%)
Burns	105 (0.1%)
Other	2519 (2.0%)
Injury body region (n (%))	
Abdomen	8010 (4.2%)
Face	13 402 (7.1%)
Head	30 167 (15.9%)
Limb	73 755 (38.9%)
Spine	28 942 (15.3%)
Thorax	31 499 (16.6%)
Other	3731 (2.0%)
Priority One (N (%))	
Priority One	24 791 (19.5%)
Not Priority One	102 442 (80.5%)
Life-saving interventions (LSI) by type (n (% total LSI))	42 610
Intubation and ventilatory support	8813 (20.7%)
Blood administration (≥4 units)	2077 (4.9%) median 6 (IQR 4–11)
Thoracocentesis (needle/tube)	8158 (19.1%)
External haemorrhage control	235 (0.6%)
Intraosseous access	39 (0.1%)
Tranexamic acid	4246 (10.0%)
Laparotomy	2644 (6.2%)
Thoracotomy	1123 (2.6%)
Proximal vascular control	290 (0.7%)
Interventional radiology	200 (0.5%)
Pelvic binder	1166 (2.7%)
ACLS protocols	374 (0.9%)
Neurosurgery	1553 (3.5%)
Spinal nursing	3114 (7.3%)
Seizure termination	390 (0.9%)
Low BM correction	83 (0.2%)
Rewarming	471 (1.1%)

ACLS, advanced cardiovascular life support; LSI, life-saving intervention; RTC, road traffic crashes.

represent the presence of a radial pulse for the purposes of prioritisation using START and Careflight, as it is not a recorded variable on the TARN database.

Our primary outcome was a comparative analysis of the test performance of the MPTT with existing major incident triage tools at predicting need for life-saving intervention. Secondary outcomes were to evaluate the performance of the MPTT using a subgroup analysis split by gender, age and mode of injury. For all triage tools sensitivity, specificity, undertriage (1-sensitivity) and overtriage (1-positive predictive value) with 95% CIs were calculated.[15] Using a McNemar test, tools with similar performance characteristics were evaluated for any statistically significant difference in performance.[16]

SPSS V.23.0 (SPSS, Chicago, Illinois, USA) and STATA V.12.0 (StataCorp, College Station, Texas, USA) were used for data processing, multiple imputation and analysis.

Missing data

A comparison was made between the complete-data and missing-data patient groups to evaluate for a systematic difference with respect to age, Injury Severity Score (ISS), outcome and requirement for life-saving intervention. Performing a list-wise deletion on patients without complete data can introduce systematic errors. Missing data were investigated using multiple imputations under a missing at random assumption using chained equations.[17] A comparative analysis was performed on the imputed dataset. The imputation modelling strategy consisted of the following variables: ISS, age, 30-day outcome, gender, mechanism of injury and P1 status. The missing data method was utilised using the *ice* procedure in STATA with five sets of imputed data generated.

RESULTS

During the study period, 218 985 adult patients met TARN inclusion criteria with 127 233 included in our analysis (figure 1 breakdown). Median age was 61.4 years (IQR 43.1–80.0 years) with males accounting for 55.6% cases (n=70 747).

Overall, 30-day mortality was 5.7% (n=7266). Injury secondary to falls from low height (<2 m) accounted for the majority of cases (n=68 354; 53.7%) with limbs the most frequently injured body region (n=73 755; 38.9%). ISS was recorded for all patients, with a median and mean of 9 and 11.9, respectively. Additional study characteristics are presented in table 2. A 24 791 (19.5%) patients received one or more life-saving interventions and were considered Priority One. Intubation and ventilation were the most frequent life-saving intervention (n=8813, 20.7%).

A summary of triage tool performance is shown in table 3. The MPTT demonstrated the highest sensitivity of all existing triage tools (57.6%; 95% CIs 56.9% to 58.2%) with an absolute increase of 44.7% over the existing UK civilian Triage Sieve (12.9%; 95% CIs 12.5% to 13.4%). Full test characteristics are shown in table 4.

Using a McNemar test with Bonferroni correction ($\alpha=0.05/4=0.0125$), a statistically significant difference in performance was again observed between the MPTT and the Military Sieve ($\chi^2=30{,}405$, $p<0.001$) and the MPTT and the Triage Sieve ($\chi^2=36{,}804$, $p<0.001$).

Missing data

Statistical significance was observed for both age and gender ($p<0.001$) between the missing and complete data groups; however, observationally, the relative frequencies were similar for missing versus complete (55 vs 61 years and 62.2% vs 55.6% male).

Table 3 Triage tool summary of results

P1, n=24 791 (19.5%)									
MPTT		Military Sieve		Triage Sieve		START		Careflight	
P1	Not P1	P1	Not P1	P1	Not P1	P1	Not P1	P1	Not P1
14 270 (57.6%)	10 521 (42.4%)	6949 (28.0%)	17 842 (72.0%)	3208 (12.9%)	21 583 (87.1%)	7139 (28.8%)	17 652 (71.2%)	5852 (23.6%)	18 939 (76.4%)
Not P1, n=102 442 (80.5%)									
MPTT		Military Sieve		Triage Sieve		START		Careflight	
P1	Not P1	P1	Not P1	P1	Not P1	P1	Not P1	P1	Not P1
29 169 (28.5%)	73 273 (71.5%)	6083 (5.9%)	96 359 (94.1%)	3425 (3.3%)	99 017 (96.7%)	5833 (5.7%)	96 609 (94.3%)	4248 (4.1%)	98 194 (95.9%)

The 30-day mortality was significantly higher in the missing data group (10.1% vs 5.7%, p<0.001) and was associated with a greater proportion requiring life-saving intervention (34.7% vs 19.5%, p<0.001). A statistical significance (p<0.001) was observed in median ISS between the missing data group (10 (IQR 9–24)) and complete data group (9 (IQR 9–16)).

Performance was largely unchanged following multiple imputation to account for missing data under a missing at random analysis. The performance of the MPTT remained superior to existing triage tools with 60.2% sensitivity and 71.3% specificity. Full test characteristics following multiple imputation are provided in table S2 in the online supplementary file 2.

SUBGROUP ANALYSIS

Injury type

Patients sustaining penetrating trauma received a greater number of life-saving interventions when compared with blunt trauma (62.7% vs 17.9%). Rates of undertriage were lower for all triage tools with a penetrating mechanism, but this must be interpreted with caution due to the low numbers (3.5%). For blunt trauma, in keeping with the main data analysis, the MPTT was seen to have the lowest rate of undertriage, with the highest overtriage rate.

Age

The study population was split into age ranges 18–25 years, 26–49 years, 50–74 years and 75+ years in keeping with previous TARN publications.[13] Falls<2 m increased dramatically throughout the age ranges, accounting for 10% of injuries in the under 25s through to 85% in those over 75 years of age. For all triage tools, there was a trend of increasing undertriage and overtriage throughout all age groups, with the MPTT having the lowest rate of undertriage across all age groups, although at the expense of overtriage (see figure S1 in the online supplementary file 3: Relationship between triage tool performance and age range.)

Gender

Large differences in overtriage rates were observed for all triage tools, ranging from an additional 15.5% (MPTT) to 19.2% (Careflight). By comparison, undertriage rates were similar irrespective of gender for all triage tools.

LIMITATIONS

A key limitation of our work is the use of a retrospective trauma database in which to validate the MPTT, the injury pattern observed following a major incident may not reflect that on the database. Ideally, any validation should be conducted in the environment where the tool is to be used in practice. Owing to the unpredictable nature of major incidents, this is largely unpractical and frequently results in the use of trauma databases as a surrogate. We acknowledge that by conducting our study in this way, we are unable to recreate the environment in which the MPTT would be used in real life. However, by performing our analysis on the TARN trauma database, we are able to reliably test individual triage tools' performance at predicting the need for life-saving intervention on a large number of seriously injured patients.

While the proportion of patients not receiving a life-saving intervention in our study was 80.5%, the presence of inclusion criteria for the TARN database is likely to skew the study population towards those sustaining a higher mean severity of injury. Therefore, it can be expected that the actual population frequency of patients not receiving a life-saving intervention will be higher than observed in our study. We recognise this as a limitation of our study and therefore relative caution must be taken when interpreting the specificity of all triage tools in our comparison.

Thirdly, not all life-saving interventions are recorded as variables in the TARN database, requiring us to use a number of surrogates in order to conduct the study (see table S1 in the online supplementary file 1). These surrogates were chosen to represent the closest approximation to the life-saving interventions required. While our final study population is large (127 233 patients), we

Table 4 Test characteristics with 95% Confidence Intervals

Model	Sensitivity	Specificity	PPV	NPV	Undertriage (1-sensitivity)	Overtriage (1-PPV)
MPTT	57.6% (56.9-58.2%)	71.5% (71.2-71.8%)	32.9% (32.433.3%)	87.4% (87.287.7%)	42.4% (41.843.0%)	67.1% (66.567.7%)
Military Sieve	28.0% (27.528.6%)	94.1% (93.994.2%)	53.3% (52.554.2%)	84.4% (84.284.6%)	72.0% (71.472.6%)	46.7% (56.157.3%)
Triage Sieve	12.9% (12.513.4%)	96.7% (96.596.8%)	48.4% (47.2 49.6%)	82.1% (81.982.3%)	87.1% (86.787.5%)	51.6% (51.052.2%)
START	28.8% (28.229.4%)	94.3% (94.294.4%)	55.0% (54.255.9%)	84.6% (84.384.8%)	71.2% (70.671.8%)	45.0% (44.445.6%)
Careflight	23.6% (23.124.1%)	95.9% (95.796.0%)	57.9% (57.058.9%)	83.8% (83.684.0%)	76.4% (75.976.9%)	42.1% (41.542.7%)

MPTT: 12<RR≥22, HR>100, GCS<14; Military Sieve: 10<RR>30, HR>120, GCS<13; Triage Sieve: 10<RR>30, HR>120; START: RR>30, SBP<90, GCS<13; Careflight: SBP<90, GCS<13.
MPTT, Modified Physiological Triage Tool; NPV, negative predictive value; PPV, positive predictive value; SBP, systolic blood pressure.

acknowledge that an additional limitation is the exclusion of those with incomplete physiological data. While the demographics of the missing data population are comparable to the complete data set, we observed significant differences in outcome and need for life-saving intervention between the two groups. In order to explore and mitigate the effect of excluding missing data, we performed an additional performance analysis, employing multiple imputation for missing values. Little difference was observed between the two datasets with the MPTT continuing to demonstrate superior performance characteristics to existing triage tools.

DISCUSSION

There is a paucity of evidence examining the performance of existing adult major incident triage tools, with a number of contradictory studies in the literature.

Despite using retrospective major incident cohort's in which to perform their analyses, both Challen's and Kahn's studies are limited largely by the small numbers of genuine P1 patients (eight and two, respectively). Additionally, Kahn's study is limited by the evaluation of START in isolation and is not a triage tool comparison.[8 9] Similar to our study, both Garner and Cicero used trauma registries in which to perform a comparative analysis. Despite being a large study, the applicability of the work by Cicero is largely by the use of ISS and mortality as the outcome measure; the ISS is a retrospective measure of injury and bears little correlation to clinical acuity and the resource needs of a patient. This precludes direct comparison with our study.[12 18 19]

While the specificities reported by Garner are similar to those in the literature, the sensitivities differ considerably.[5] The definition of the P1 patient was the same for both Challen and Garner, whereas a more comprehensive definition, derived through consensus to represent current methods in trauma management was used for the purpose of this validation.[5 7 9] This is likely to explain the differences in sensitivity, with a comparison by study shown in the table 5.

There are a number of challenges associated with major incident research, not limited solely to the practical conduct of such studies. One such challenge is determining what is successful triage. In an ideal world, the methods we use for triage will correctly identify all patients with high levels of sensitivity and specificity, without incorrectly triaging patients to higher (overtriage) or lower (undertriage) categories. Studies to date have shown that with simple physiological triage this is not possible; with high sensitivity comes low specificity and so the performance of the optimum triage tool is a balance of accepting overtriage and undertriage. An additional challenge is how to define overtriage and undertriage. In keeping with previous studies measuring triage tool accuracy, we have used 1-positive predictive value and 1-sensitivity to calculate over and undertriage, respectively.[15 20 21] Alternative measures such as 1-specificity for overtriage[22] and 1-negative predictive value[21] for undertriage have been described elsewhere.

The MPTT, derived using individual logistical regression models for each physiological parameter, had the lowest rate of undertriage and approximately equal rates of overtriage and undertriage (35.2% vs 30.1%). The methodology behind its derivation is likely to suggest that this represents the limit of the capability of physiological triage at predicting need for life-saving intervention.[12]

Overall success of triage is not based solely on sensitivity or the identification of those in need of life-saving intervention. As with any diagnostic test, increasing triage tool sensitivity comes at the expense of lower specificity and there will be a number of patients who are incorrectly classified. A successful primary major incident triage tool needs to provide not only high sensitivity, but a compromise between those incorrectly classified (undertriage/overtriage). While the effects of undertriage are clearly apparent (failing to identify a patient in need of a life-saving intervention), overtriage in itself can be harmful as well. Previous studies have shown that a consequence of overtriage is the potential to overwhelm hospital resources, with a direct association between overtriage and critical mortality.[23 24] This is a key difference between major incidents and routine clinical practice, where a form of triage occurs for every patient in the ED (using systems such as the Manchester Triage System), but the key feature of these tools is to correctly identify those in need of urgent treatment (at the expense of overtriage).

Current guidance for major incident triage simply states that rates of undertriage and overtriage should be kept as low as possible.[25] By contrast, for the triage of individual patients to major trauma centres, a threshold of 35% overtriage and 5% undertriage is recommended.[25] Here, in addition to an assessment of physiological instability, the field triage process includes an anatomical and mechanistic assessment to aid in the decision-making. It is a more time-consuming process and is inappropriate for the purposes of primary major incident triage. While the rate of undertriage demonstrated by the MPTT is the lowest of all existing triage tools, it does come at the expense of increased overtriage. Although the highest of all triage tools (67.1%), the MPTT's overtriage rate is comparable to that encountered overall following the London 7/7 bombings (64%).[23] However, while this level of overtriage was tolerated following this incident, we acknowledge that this may not be transferable to all major incidents, especially in rural areas with limited surrounding healthcare facilities

Table 5 Comparative analysis by study with 95% Confidence Intervals[5 9 12 27]

	Current study	Derivation study	Garner	Challen	Horne
Triage Sieve Sensitivity/Specificity	13% (12–13%) 97% (96–97%)	25% (23–27%) 95% (94–96%)	45% (37–54%) 88% (86–90%)	50% 100%	50% (43–57%) 89% (84–94%)
START Sensitivity/Specificity	29% (28–29%) 94% (94–94%)	39% (37–41%) 97% (96–98%)	84% (76–89%) 91% (89–93%)	50% 100%	52% (45–59%) 90% (85–95%)
Careflight Sensitivity/Specificity	24% (23–24%) 96% (95–96%)	34% (31–36%) 98% (98–99%)	82% (75–88%) 86% (94–97%)	50% 100%	45% (38–52%) 92% (87–97%)
Military Sieve Sensitivity/Specificity	28% (28–29%) 94% (94–94%)	44% (42–46%) 94% (92–95%)			63% (57–70%) 82% (76–89%)
MPTT Sensitivity/Specificity	58% (57–58%) 72% (71–72%)	70% (68–72%) 65% (63–68%)			

MPTT, Modified Physiological Triage Tool.

and in those settings with a less developed emergency medical service response.[26]

The MPTT showed the highest sensitivity 57.6% (95% CI 56.9% to 58.2%) at predicting the need for life-saving intervention with an absolute increase of 44.7% over the existing Triage Sieve 12.9% (95% CI 12.5% to 13.4%). Throughout the subgroup analysis, the performance of the MPTT was superior to all existing triage tools in terms of minimising undertriage. A reduction in MPTT sensitivity is observed when compared with the derivation study (42.4% vs 35.1%). This is likely to be multifactorial, including the differing population age (median 62 years vs 24 years), the predominating mechanism of injury (falls <2m vs explosive) and the proportion of P1 patients (19.5% vs 47.6%).

In summary, we present a civilian validation of the MPTT, the first example of an evidence-based physiological triage tool for use in the major incident setting. Our findings demonstrate that the MPTT outperforms existing triage tools with respect to rates of undertriage, while maintaining an acceptable level of overtriage. We suggest that the MPTT should be considered as an alternative to existing systems for the purposes of major incident primary triage. Ideally, the MPTT should be tested in the major incident environment, but in the absence of this, simulation or computer modelling may represent an alternative.

Twitter @jamievassallo

Contributors JV, JES, FL and LAW conceived the study. JV conducted the analysis, supervised by JES. OB provided statistical advice and assisted with data analysis. JV drafted the manuscript and all authors contributed substantially to its revision. JV takes responsibility for the paper as a whole.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 Lennquist S. Medical response to major incidents and disasters. Lennquist S, ed. *Chapter 2: major incidents: examples and experiences*: Berlin Heidelberg, 2012.
2 Advanced Life Support Group. Major incident medical management and support. In: Carley S, Mackway-Jones K,eds. Oxford, UK: Blackwell Publishing Ltd, 2005.
3 Hirsch M, Carli P, Nizard R, *et al*. The medical response to multisite terrorist attacks in Paris. *Lancet* 2015;386:2535–8.
4 Wilson J. *Outlines of naval surgery*. Edinburgh: MacLachlan Stewart and Co, 1846:24–6.
5 Garner A, Lee A, Harrison K, *et al*. Comparative analysis of multiple-casualty incident triage algorithms. *Ann Emerg Med* 2001;38:541–8.
6 Jenkins JL, McCarthy ML, Sauer LM, *et al*. Mass-casualty triage: time for an evidence-based approach. *Prehosp Disaster Med* 2008;23:3–8.
7 Vassallo J, Smith JE, Bruijns SR, *et al*. Major incident triage: a consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident. *Injury* 2016;47:1898–902.
8 Kahn CA, Schultz CH, Miller KT, *et al*. Does START triage work? An outcomes assessment after a disaster. *Ann Emerg Med* 2009;54:424–30.
9 Challen K, Walter D. Major incident triage: comparative validation using data from 7th July bombings. *Injury* 2013;44:629–33.
10 Vassallo J, Horne S, Ball S, *et al*. UK triage the validation of a new tool to counter an evolving threat. *Injury* 2014;45:2071–5.
11 Challen KHE. *Comparative validation of major incident triage systems* MRes thesisUniversity of Mancheste 2008.
12 Vassallo J, Beavis J, Smith JE, *et al*. Major incident triage: derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT). *Injury* 2017;48:992–9.
13 Kehoe A, Smith JE, Edwards A, *et al*. The changing face of major trauma in the UK. *Emerg Med J* 2015;32:911–5.
14 Ministry of Defence. Clinical Guidelines for Operations (JSP 999). 2013 https://www.gov.uk/government/publications/jsp-999-clinical-guidelines-for-operations (accessed Sept 2017).
15 Lossius HM, Rehn M, Tjosevik KE, *et al*. Calculating trauma triage precision: effects of different definitions of major trauma. *J Trauma Manag Outcomes* 2012;6:9.
16 Hazra A, Gogtay N. Biostatistics series module 4: comparing groups – categorical variables. *Indian J Dermatol* 2016;61:385–9.
17 Royston P. Multiple Imputation of missing values: Update of ICE. *The Stata Journal* 2005;5:527–36.
18 Cross KP, Cicero MX. Head-to-head comparison of disaster triage methods in pediatric, adult, and geriatric patients. *Ann Emerg Med* 2013;61:668–76.
19 Baxt WG, Upenieks V. The lack of full correlation between the Injury Severity Score and the resource needs of injured patients. *Ann Emerg Med* 1990;19:1396–400.
20 Rehn M, Eken T, Krüger AJ, *et al*. Precision of field triage in patients brought to a trauma centre after introducing trauma team activation guidelines. *Scand J Trauma Resusc Emerg Med* 2009;17:1.
21 Peng J, Xiang H. Trauma undertriage and overtriage rates: are we using the wrong formulas? *Am J Emerg Med* 2016;34:2191–2.
22 Ardolino A, Cheung CR, Lawrence T, *et al*. The accuracy of existing prehospital triage tools for injured children in England: an analysis using emergency department data. *Emerg Med J* 2015;32:397–400.
23 Aylwin CJ, König TC, Brennan NW, *et al*. Reduction in critical mortality in urban mass casualty incidents: analysis of triage, surge, and resource use after the London bombings on July 7, 2005. *Lancet* 2006;368:2219–25.
24 Frykberg ER, Tepas JJ, bombings T. Lessons learned from Belfast to Beirut. *Ann Surg* 1988;208:569–76.
25 American College of Surgeons *Resources for optimal care of the injured patient*. Chicago, IL American College of Surgeons 2014.
26 Frykberg ER. Medical management of disasters and mass casualties from terrorist bombings: how can we cope? *J Trauma* 2002;53:201–12.
27 Horne S, Vassallo J, Read J, *et al*. UK triage – an improved tool for an evolving threat. *Injury* 2013;44:23–8.

Discussion of study

Supplementary methods

A retrospective review of the Trauma Audit and Research Network (TARN) database was conducted over a nine-year period (2006-2014). All adult patients (aged 18 or over) satisfying TARN inclusion criteria (**Appendix 1)** and who were direct admissions from the scene of injury were considered eligible for inclusion. Patients who are declared dead at scene or who are not conveyed to hospital are not included in the TARN database and therefore were not considered eligible for analysis. In order to maintain consistency with the derivation study, the same thresholds (HR >170bpm, RR >45bpm, SBP >206mmHg) were used to identify physiological outliers and these were then removed. Box and whisker plots are shown for each parameter (with and without outliers removed) in **Figure 4.1**. Due to the nature of the TARN database, patients included were assumed to be non-ambulant.

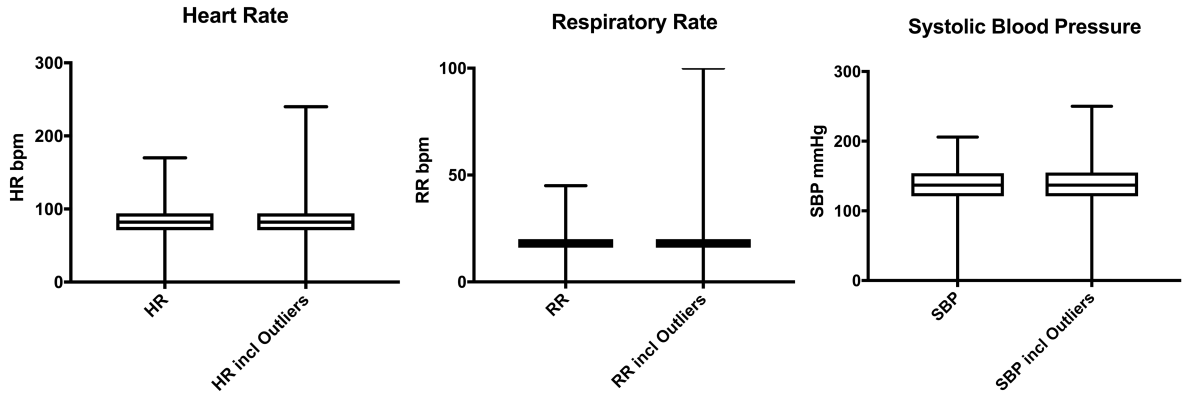


Figure 4.1: Box and whisker plot for physiological parameters (including and excluding outliers).

As in **chapter 3** and the JTTR, not all interventions in **Figure 2.3** are recorded as variables on the TARN database, therefore a number of surrogates were used to conduct the analysis. **Table 4.1** compares the life-saving interventions defined through Delphi consensus with the most closely representative variable recorded on the TARN database. It was not possible to use a surrogate variable for four interventions (application of a chest seal, use of haemostatic agents and the administration of uncross-matched blood or chemical antidotes). Patients were categorised as Priority One if they received one or more of these life-saving interventions. The Delphi study in **chapter 2** considered that interventions were life-saving if they were performed within one hour. Whilst the TARN database allows for entry of the date and time when individual interventions were performed, this was universally poorly populated, with the majority of patients recorded as receiving interventions, but with no date and time recorded as to when these occurred.

The published paper assumes that all interventions performed occurred during the initial resuscitation phase. However, for some interventions, they are categorized as being performed 'pre-hospital', 'ED' or 'in-hospital'. Recognising that the assumption made in the publication represents a study weakness, further analysis was undertaken on patients receiving interventions (with the exception of surgical procedures) only in either the 'pre-hospital' or 'ED' setting.

	Life-saving intervention	Recorded variable used as surrogate.
1	Intubation for actual or impending airway obstruction.	Intubation
2	Surgical airway for actual or impending airway obstruction.	Cricothyroidotomy, tracheostomy
3	Thoracostomy (needle/finger/tube).	Needle thoracocentesis, chest drain, tube drain into pleural cavity
4	Application of a chest seal (commercial/improvised).	Not searchable
5	Positive pressure ventilation for ventilatory inadequacy.	Manual, mechanical ventilation, respiratory arrest
6	Application of a tourniquet for haemorrhage control.	Direct compression of haemorrhage
7	Use of haemostatic agents for haemorrhage control.	Not searchable
8	Insertion of an intra-osseous device for resuscitation purposes.	Intraosseous cannulation
9	Receiving uncross-matched blood.	Not searchable
10	Receiving ≥ 4 units of blood/blood products.	>= 4 units blood
11	Administration of tranexamic acid.	Tranexamic Acid
12	Laparotomy for trauma.	Laparotomy, Abdominal Packing, repair colon laceration, repair kidney laceration, repair liver laceration,
13	Thoracotomy or pericardial window for trauma.	Thoracotomy
14	Surgery to gain proximal vascular control.	Repair of artery
15	Interventional radiology for haemorrhage control.	Embolisation (interventional radiology)
16	Application of a pelvic binder.	Pelvic sling
17	ALS/ACLS for a patient in a peri-arrest/cardiac arrest situation.	CPR, defibrillation
18	Neurosurgery for the evacuation of an intra-cranial haematoma.	Evacuation of EDH or SDH
19	Craniotomy/Burr hole insertion.	Craniectomy, open craniotomy, burr hole of cranium
20	Spinal nursing for a C1-3 fracture.	Spinal immobilisation AND C1,C2,C3 fractures OR Application of skeletal traction AND C1,C2,C3 fractures OR Spinal stabilisation AND C1,C2,C3 fractures
21	Administration of a seizure-terminating medication.	Anticonvulsant administration
22	Active/passive rewarming for initial core temp <32 degrees Celsius.	Active warming
23	Correction of low blood glucose.	Glucose administration
24	Administration of chemical antidotes.	Not searchable

Table 4.1: Comparison of life-saving interventions and surrogates used for analysis.[127]

ALS/ACLS – Advanced Life Support / Advanced Cardiac Life Support, CPR – Cardiopulmonary Resuscitation, EDH – Extradural haematoma, SDH – Subdural haematoma

In keeping with the derivation study, first recorded hospital physiology was used to categorise patients as Priority One or Not Priority One by the MPTT, Military/NARU Sieve, MIMMS Triage Sieve, START and Careflight. Surrogates required for categorisation by START, Careflight and Military/NARU sieve, remained consistent with those used in **chapter 3**, i.e. a SBP of 90mmHg for palpable pulse (START and Careflight) and GCS<13 for unconscious and not obeying commands (Military/NARU Sieve and START/Careflight respectively). A comparative analysis was performed using sensitivity and specificity, with under and over-triage (1-sensitivity and 1-PPV respectively) calculated for all triage tools. Statistical significance was determined between triage tools using a McNemar test with Bonferroni correction (α=0.05/4 = 0.0125); this method has previously been discussed in **chapter 3.**

Only patients with complete physiology were included in the analysis, which, as discussed in **chapter 3** can introduce selection bias. To explore for this, the study characteristics were compared between these two groups (patients with complete versus incomplete physiology). Additionally, to mitigate for any effects that performing a list-wise deletion may have, multiple imputation was used to model the missing data. This was performed using the *ice* procedure in STATA, under a missing at random assumption with the modelling strategy based on six variables (age, 30-day outcome, gender, life-saving intervention received, mechanism of

injury, ISS).[128] From this, five sets of imputed data were generated, on which an additional comparative analysis was performed.

Due to the nature of an ageing population, the leading mechanism of injury in the TARN database is 'falls less than two metres'. Whilst this reflects the change in trauma trends seen within the UK, it is unlikely to be reflective of the mechanism of injury experienced during a major incident; a sensitivity analysis of the MPTT was therefore performed with this cohort of patients excluded. Additional subgroup analyses were conducted to identify the performance of the MPTT against existing triage tools when the population was split by age, gender and mode of injury (blunt versus penetrating).

Supplementary results

Approximately 220,000 patients were included in the TARN database during the study period. Only patients who were direct admissions from the scene of injury were included – the TARN database includes records of patients who were transferred from one hospital to another; these patients were excluded on the premise that the care recorded at the secondary facility would be beyond the initial resuscitation phase. There were a large number of cases with missing data (n=68,042, 31.1%) and these were removed from further analysis (**Figure 4.2)**. Where GCS is not recorded, some cases are assigned a value of 97 representing 'missing, presumed normal' and 98 representing 'missing, presumed abnormal'. Only patients with a reported GCS between 3 and 15 were included. Of those with complete physiological data, an additional 2316 (1.8%) patients were excluded as outliers **(Table 4.2).** Full study characteristics are shown in **Table 2** in the published paper.

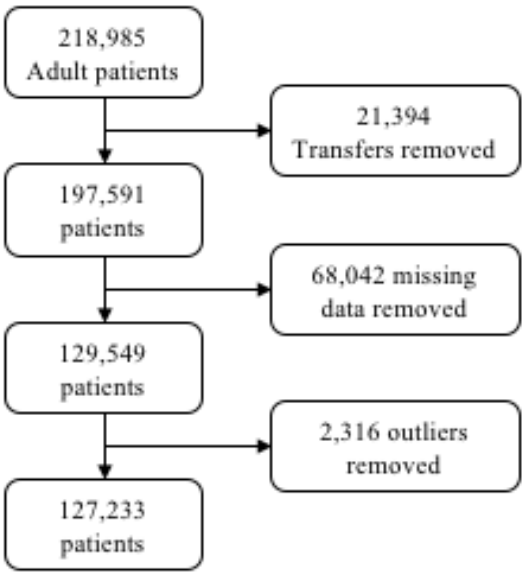


Figure 4.2: TARN Participation flow diagram.[127]

	Number	Percentage
Complete data recorded	129549	
Outliers	2316	1.8%
Respiratory rate (>45bpm)	357	0.28%
Heart rate (>170bpm)	86	0.07%
Systolic blood pressure (>206mmHg)	1883	1.5%

Table 4.2: Frequency of outliers.

Bpm – breaths per minute.

As was shown in the derivation study in **chapter 3**, the MPTT demonstrated the greatest sensitivity for predicting the need for a life-saving intervention, with the lowest rates of under-triage **(Table 4.3)**. However this comes at the expense of the lowest specificity and the greatest rate of over-triage (67.1%), although this is comparable to the overall over-triage rate observed following the London 7/7 bombings (64%).[61]

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT	57.6% (56.9-58.2)	71.5% (71.2-71.8)	42.4% (41.8-43.0)	67.1% (66.5-67.7)
MIMMS Triage Sieve	12.9% (12.5-13.4)	96.7% (96.6-96.8)	87.1% (86.7-87.5)	51.6% (51.0-52.2)
Military/NARU Sieve	28.0% (27.5-28.6)	94.1% (93.9-94.2)	72.0% (71.4-72.6)	46.7% (46.1-47.3)
START	28.8% (28.2-29.4)	94.3% (94.2-94.4)	71.2% (70.6-71.8)	45.0% (44.4-45.6)
Careflight	23.6% (23.1-24.1)	95.9% (95.7-96.0)	76.4% (75.9-76.9)	42.1% (41.5-42.7)

Table 4.3: Comparative performance of the MPTT with existing triage tools.[127]

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value

Under and over-triage were calculated using the same methodology described in **chapter 3**; a comparison with alternative methods for calculating these measures is demonstrated in **Table 4.4**.

McNemar's test was used to determine if a statistically significant difference in performance existed between the MPTT, the Military/NARU Sieve and the MIMMS Triage Sieve.

MPTT versus MIMMS Triage Sieve - χ^2=36,804, p <0.001
MPTT versus Military/NARU Sieve - χ^2=30,405, p <0.001

For all comparisons, with an adjusted significance level of α=0.0125, the null hypothesis that the MPTT and respective triage tools (MIMMS Triage Sieve, Military/NARU Sieve) had equal performance was rejected.

	MPTT	MIMMS Triage Sieve	Military/NARU Sieve	START	Careflight
This study					
Under-triage *(1-sensitivity)*	42.4% (41.8-43.0)	87.1% (86.7-87.5)	72.0% (71.4-72.6)	71.2% (70.6-71.8)	76.4% (75.9-76.9)
Over-triage *(1-PPV)*	67.1% (66.6-67.7)	51.6% (51.0-52.2)	46.7% (46.1-47.3)	45.0% (44.4-45.6)	42.1% (41.5-42.7)
Alternative methods					
Under-triage *(1-NPV)*	12.6% (12.2-13.0)	17.9% (17.4-18.4)	15.6% (15.2-16.1)	15.4% (15.0-15.9)	15.0% (15.7-16.6)
Over-triage *(1-specificity)*	28.5% (28.2-28.7)	3.3% (3.2-3.5)	5.9% (5.8-6.1)	5.7% (5.6-5.8)	4.2% (4.0-4.3)

Table 4.4: Comparison of alternative methods of calculating under and over-triage.

PPV; Positive Predictive Value, NPV; Negative Predictive Value

Missing Data Analysis

To explore for the effect of performing a list-wise deletion for all cases with missing or incomplete physiological data, study characteristics were compared between the two groups with outliers excluded. Variables compared included gender, age, outcome, ISS and life-saving intervention requirement. Statistical analysis was with Pearson Chi Square and Mann Whitney tests for categorical (gender, outcome, life-saving intervention) and continuous (age, ISS) variables respectively.[114]

	Age median (IQR)	ISS median (IQR)	Gender (% male)	Outcome (% alive)	Life-saving intervention (% Priority One)
Complete (n=127,233)	61 (43-80)	9 (9-16)	55.6%	94.3%	19.5%
Incomplete (n=65,726)	55 (36-74)	10 (9-24)	44.4%	90.0%	34.7%

Table 4.5: Comparison of study characteristics between patients with complete and incomplete physiological data.

IQR – interquartile range.

All statistical analyses reached significance ($p<0.001$) implying that there was a difference between the two groups, but this must be interpreted with caution due to the large difference in group sizes (Complete n=127,233 and Incomplete n=68,042). **Table 4.5** demonstrates that there was a greater tendency for patients in the incomplete group to require a life-saving intervention (i.e. Priority One), with a higher mortality, and although the median ISS is comparable between the two groups (10 versus 9), the third quartile is considerably greater (24 versus 16). These results give an assumption that the cohort of patients removed due to incomplete physiological data were potentially sicker than those with complete recordings. In order to mitigate for this effect, multiple imputation was used to replace the missing physiological variables (procedure described in the methods section with 807,450 cases generated (210,251 Priority One)), and a comparative analysis was conducted **Table 4.6**.

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT	60.2% (60.0-60.4)	71.3% (71.1-71.4)	39.8% (39.6-40.0)	57.6% (57.4-57.7)
MIMMS Triage Sieve	14.8% (14.6-14.9)	96.4% (96.3-96.4)	85.2% (85.1-85.4)	41.2% (41.1-41.3)
Military/NARU Sieve	32.5% (32.3-32.7)	93.6% (93.6-93.7)	67.5% (67.3-67.7)	35.8% (35.7-35.9)
START	32.5% (32.3-32.7)	93.9% (93.6-94.0)	67.5% (67.3-67.7)	34.7% (34.6-34.8)
Careflight	27.8% (27.6-28.0)	95.7% (95.6-95.7)	72.2% (72.0-72.4)	30.6% (30.5-30.7)

Table 4.6: Comparative analysis following multiple imputation.

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value

Following imputation an increase in sensitivity was observed for all triage tools, corresponding with a small reduction in specificity. Performance overall was unchanged, with the MPTT demonstrating the greatest sensitivity with the lowest rate of under-triage. As with the main statistical analysis, the MPTT demonstrated a statistically significant difference in performance over both the MIMMS Triage Sieve and the Military/NARU Sieve ($p<0.0001$).

Low falls (defined as falls <2 metres) accounted for over half the study population with complete data recorded (n=68,354, 53.7%). This mechanism of injury is unlikely to be truly representative of that of a major incident, therefore a sensitivity analysis of the MPTT and existing triage tools was conducted with these patients excluded. The cohort of patients sustaining low falls were disproportionately female, older and had a lower ISS when compared to the remaining population ($p<0.001$). Therefore, once removed, a change in study

characteristics were observed (**Table 4.7**), with the study population have a greater percentage of younger, male patients with a higher median ISS.

	Age median (IQR)	ISS median (IQR)	Gender (% male)	Outcome (% alive)	Life-saving intervention (% Priority One)
All data (n=127,233)	61.4 (43.1-80)	9 (9-16)	55.6%	94.3%	19.5%
Low falls only (n=68,354)	74.9 (59.5-85.4)	9 (9-10)	40.1%	93.1%	10.1%
Low falls removed (n=58,879)	45.5 (29.9-61.5)	10 (9-17)	73.6%	95.6%	30.4%

Table 4.7: Comparison of study characteristics between entire study population and cohort with low falls removed.

IQR – interquartile range.

In a sensitivity analysis (**Table 4.8)**, the MPTT again outperformed existing triage tools, with the greatest sensitivity and lowest under-triage. As with previous analyses, the MPTT has the highest rate of over-triage, but demonstrates an absolute reduction of 12.1% when compared to the whole population analyses. This is not unique to the MPTT, with all triage tools demonstrating a reduction in over-triage. As with the original analysis, a statistically significant difference in performance was observed between the MPTT and both the MIMMS Triage Sieve and the Military/NARU Sieve ($p<0.0001$).

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT	61.6% (60.9-62.3)	67.1% (66.7-67.6)	38.4% (37.7-39.1)	55.0% (54.5-55.5)
MIMMS Triage Sieve	14.6% (14.1-15.1)	96.1% (96.0-96.3)	85.4% (84.9-86.0)	37.8% (37.3-38.2)
Military/NARU Sieve	30.2% (30.0-30.9)	93.6% (93.3-93.8)	69.8% (69.1-70.5)	32.8% (32.3-33.2)
START	31.2% (30.6-31.9)	93.7% (93.5-93.9)	68.8% (68.1-69.4)	31.5% (31.1-32.0)
Careflight	25.3% (24.7-25.9)	95.9% (95.7-96.1)	74.7% (74.1-75.3)	26.9% (26.5-27.3)

Table 4.8: Sensitivity analysis – low falls excluded from analysis (n=58,879).

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value

Due to the nature of incomplete data describing when interventions were performed, the published paper categories the Priority One patient as receiving any life-saving intervention, irrespective of the location (pre-hospital versus ED versus In-hospital). An additional analysis was conducted when interventions (with the exception of surgical procedures) were limited to being performed in either the pre-hospital or ED setting (**Table 4.9)**. Overall performance was unchanged when compared to the main study analysis.

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT	59.0% (58.4-59.7)	71.2% (70.9-71.5)	41.0% (40.3-41.6)	69.4% (69.1-69.7)
MIMMS Triage Sieve	13.5% (13.1-14.0)	96.6% (96.5-96.7)	86.5% (86.0-86.9)	54.2% (53.9-54.5)
Military/NARU Sieve	29.5% (28.9-30.1)	93.9% (93.7-94.0)	29.5% (28.9-30.1)	49.1% (48.8-49.4)
START	30.3% (29.7-30.9)	94.1% (94.0-94.3)	69.7% (69.1-70.3)	47.5% (47.8-47.2)
Careflight	24.9% (24.4-25.5)	95.7% (95.6-95.8)	75.1% (74.5-75.6)	44.5% (44.1-44.8)

Table 4.9 Sensitivity analysis – pre-hospital and ED only interventions included in analysis.

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value

Pre-hospital versus first recorded hospital physiology

The use of first recorded hospital physiology to categorise patients using the respective triage tools is a potential limitation of this study. In **chapter 3,** it was observed that in the military setting, the median physiological values were directly comparable between the two settings. In order to explore the potential effect in this study of using first recorded hospital physiology for categorisations, a comparison was conducted using median and IQR **(Table 4.10).** As was observed with the JTTR, both pre-hospital and first recorded hospital physiology was directly comparable.

Physiological Parameter	Pre-hospital	First recorded hospital
GCS	15 (15-15)	15 (15-15)
Heart Rate (bpm)	84 (72-97)	82 (71-94)
Respiratory Rate (bpm)	18 (16-20)	18 (16-20)
Systolic Blood Pressure (mmHg)	137 (120-156)	137 (121-154)

Table 4.10 Pre-hospital versus first recorded hospital physiology (median (IQR)).

Bpm- breaths per minute, IQR – interquartile range.

In addition to the analyses described above, a subgroup analysis was performed to determine the MPTT's performance at identifying patients in need of life-saving intervention when the population was split by injury type (penetrating versus blunt), gender and age.

Injury Type

Blunt trauma (n=122,802, 96.5%) is the predominant mechanism of injury on the TARN database, with penetrating trauma the minority (n=4,431, 3.5%). When the complete study population is split by mechanism and analysed, the population sustaining penetrating trauma is younger - 33.2 (24.3-47.8) versus 62.1 (44.5-80.5) years - and predominantly male (83.7% versus 54.6%). Although absolute numbers of patients sustaining penetrating trauma is low, the majority (62.7%) received a life-saving intervention and therefore were considered Priority One; in contrast only 17.9% of patients sustaining blunt trauma received a life-saving intervention, despite the ISS being comparable (Penetrating 9 (9-14) versus Blunt 9 (9-16)).

No difference from the main study was observed with triage tool performance in a comparative analysis; the MPTT demonstrated the greatest sensitivity over all tools with both blunt and penetrating trauma. All triage tools demonstrated lower specificities in the penetrating trauma cohort. Additionally, with the exception of the MPTT and the MIMMS Triage Sieve, an absolute reduction in sensitivity was also observed in the penetrating trauma cohort.

Gender

Over half the TARN study population were male (n=70,747, 55.6%). When the study characteristics are compared for the two subgroups, it is observed that the male cohort are younger (52.6(35.3-69.9) versus 73.2(56.2-85.1) years) with a greater proportion receiving life-saving interventions (24.6% versus 13.0%). Median ISS was comparable (9), although the third quartile was higher in the male subgroup (17 versus 13).

When mechanism of injury is compared, low falls predominate in both subgroups, but is approximately doubled in the female subgroup (38.7% versus 72.5%). In contrast, whilst road traffic collisions are the second most frequently occurring mechanism of injury in both subgroups; the proportion of males affected is more than double that of females (29.3% versus 12.8%). Sensitivities were lower for all triage tools in the female subgroup, but this was matched by an increase in specificity. The MPTT continued to outperform all triage tools in both subgroups, with the greatest sensitivity and lowest rate of under-triage, but as with prior analyses, it has the greatest rate of over-triage and lowest specificity.

Age

In keeping with previous published TARN studies, the study population was split into four age categories (18-25 years, 26-49 years, 50-74 years and 75+ years).[126] Male patients predominated in the 18-25 (78.3%) and 26-49 (75.8%) age categories, with an approximately equal proportion in the 50-74 category (55.2% male), before becoming the minority (34.6%) in those injured over 75+ years. A reduction in numbers of patients requiring a life-saving intervention is observed throughout the categories; 32.8% of those aged 18-24 required a life-saving intervention reducing to 12.8% in those aged 75+ years. Blunt trauma predominated all age categories, but penetrating trauma was greatest in those aged 18-24 years (11.6%). This proportion declines throughout the categories: 25-49 years (7.0%), 50-74 years (1.7%) to being negligible in those aged 75+ years (0.6%). In keeping with this, the mechanism of injury changes considerably throughout the categories – less than 10% of those aged 18-24 years sustained their injuries from low falls; by contrast 59.1% of those aged 50-74 years did, increasing to 83.0% of those aged 75+ years. For patients aged 18-24 years, the most prevalent mechanism of injury was road traffic collisions (52.1%).

In the comparative analysis, the MPTT continued to outperform existing methods of triage across all age groups with the greatest sensitivity and the lowest rates of under-triage, although this is again associated with the lowest specificity and highest rate of over-triage. Both under and over-triage is observed to increase throughout the age categories for all triage tools with it being at its lowest in those aged 18-24 years **(Figure 4.3).**

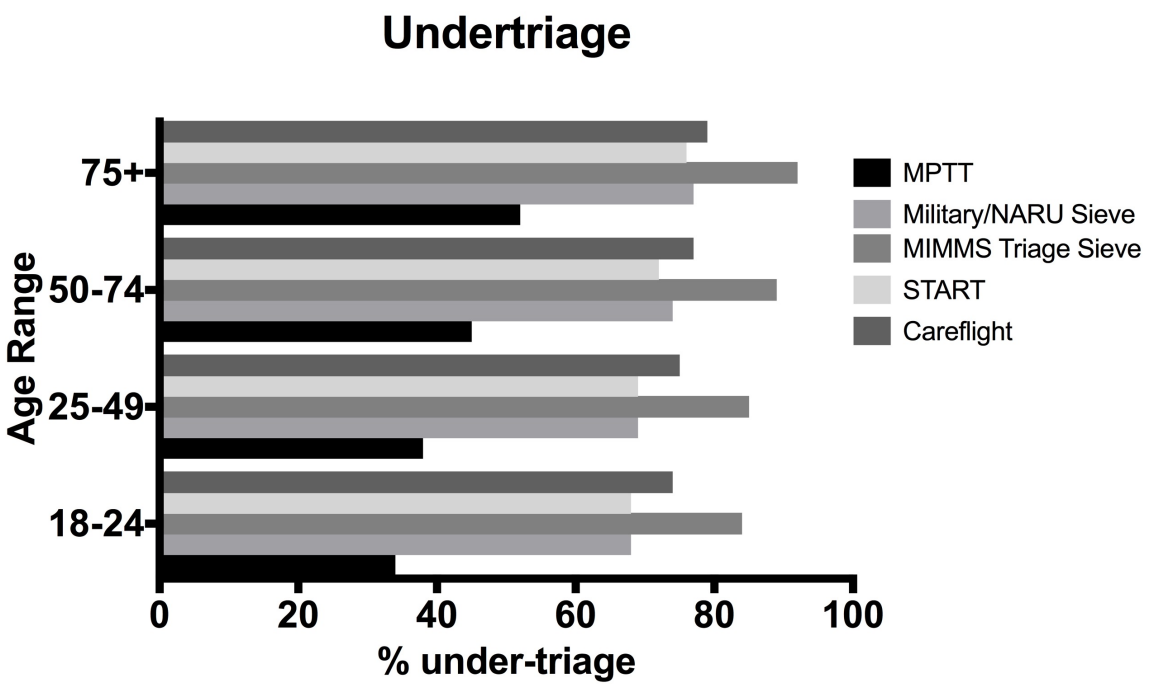


Figure 4.3a: Relationship between triage tool performance (rates of under-triage) and age.

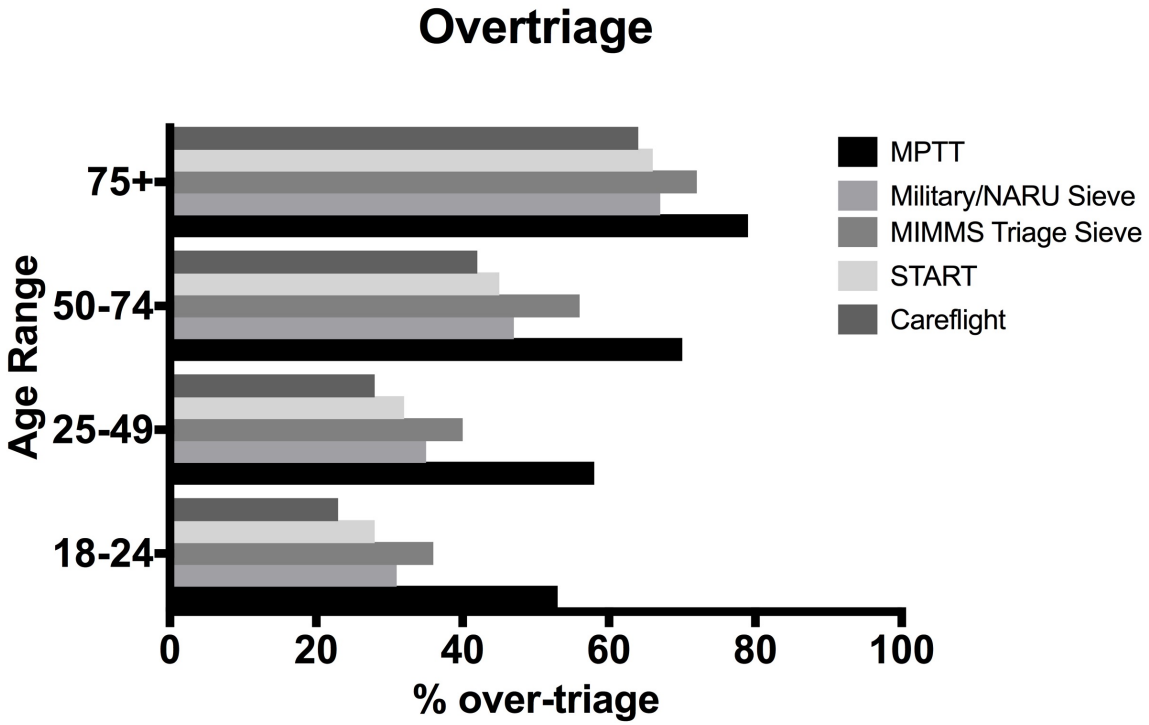


Figure 4.3b: Relationship between triage tool performance (rates of over-triage) and age.

Supplementary limitations

As with **chapter 3** a key limitation of this study is the use of a trauma registry (TARN) to validate the MPTT for use in the civilian environment and this is discussed in the published paper. Large numbers of patients on the database were found to have missing data, and this cohort were observed to be more likely to be seriously injured, with a greater proportion of Priority One patients. To explore for the effect of performing a list-wise deletion in the primary analysis **(Table 4.3)**, multiple imputation was used to simulate the missing data. Comparative analysis following imputation demonstrated the MPTT continued to outperform existing methods at identifying need for life-saving intervention with the lowest rates of under-triage. However, whilst multiple imputation can help to explore the effect of missing data, it is still only a surrogate for the missing physiology and remains a limitation.

The nature of the inclusion criteria **(Appendix 1)** for entry onto the TARN database represents a limitation, which as with the JTTR, introduces a selection bias; minimally injured patients are unlikely to be included. As discussed in **chapter 3** this means that the specificities reported in this study should be interpreted with caution. The use of first recorded hospital physiology to categorise patients represents a limitation, although the effect of this is likely to be minimal, as the median and IQR of physiological parameters were comparable to those measured in the pre-hospital setting **(Table 4.10)**.

In the published paper, patients were categorised as Priority One if they received a life-saving intervention irrespective of where it occurred, representing a potential weakness and a limitation of the study. For robustness, in this chapter, an additional analysis was performed with patients only being categorised as Priority One if they received the life-saving intervention in the pre-hospital or ED setting (in addition to surgical procedures). The overall results from this analysis **(Table 4.9)** did not differ from the main analysis **(Table 4.3)** with the MPTT continuing to demonstrate the greatest sensitivity for identifying patients in need of life-saving intervention.

The predominant mechanism of injury on the TARN database is low falls, which is not only unlikely to represent the mechanism encountered at a major incident, but carries with it a different population characteristic (majority female, older with fewer patients requiring life-saving intervention). To mitigate for this, a sensitivity analysis was performed with this cohort excluded, which also demonstrated that the MPTT outperformed existing methods of triage **(Table 4.8)**. When patients on the TARN database are divided for sub-group analysis (mode of injury, gender and age), the MPTT demonstrated improved performance over existing methods for identifying patients in need of life-saving intervention. These findings suggest that the MPTT is suitable as a replacement to existing primary major incident triage tools, irrespective of the injury mode, gender or age of patients involved.

Chapter conclusion

In this study, the performance of the MPTT has been compared to existing methods of triage on a civilian trauma registry population. Existing methods of UK triage (Military/NARU Sieve) demonstrate poor performance at identifying those patients in need of a life-saving intervention; where in the derivation study this was off-set by low rates of over-triage, in the civilian setting, existing triage tools still have rates of over-triage approaching 50%. The MPTT is the first example of an evidence-based triage tool designed to specifically identify those patients in need of a life-saving intervention. Outperforming existing triage tools in the retrospective military setting, it continues to outperform, both clinically and statistically, in the civilian trauma registry population. This study has successfully validated the MPTT on a civilian population using the TARN database. It is suggested that the MPTT be considered as an alternative to existing UK (civilian and military) methods of primary major incident triage. In **chapters 5 and 6**, the case supporting the use of the MPTT is strengthened with a prospective analysis of its performance and a study describing the implications of under-triage.

Chapter 5: The prospective validation of the Modified Physiological Triage Tool on deployed Military Operations

Reference:

Vassallo J, Horne S, Smith JE, Wallis LA. The prospective validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to major incident triage. J R Army Med Corps. 2017 Dec;163(6):383-387

Declaration from author

The following co-authors contributed to the paper: Simon Horne, Jason E Smith and Lee A Wallis.

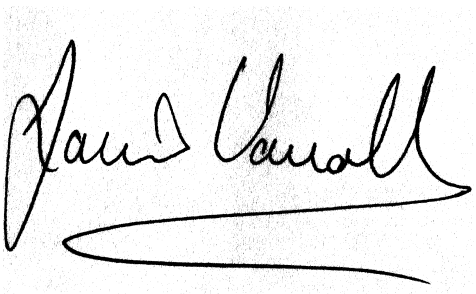
In the case of Chapter 5, contribution by authors to the work was as follows:

Nature of contribution

- JV and SH conceived the idea and designed the study. SH collected the data. JV drafted the work with all authors contributing to revise it critically for important intellectual content. All authors approved the final published version and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- **Extent of contribution:** JV: 75%; SH: 10%; JES: 10%; LAW: 5%

The following co-authors contributed to the work:

1. Prof. Lee A Wallis
2. Prof. Jason E Smith
3. Dr Simon Horne



Signed: James Vassallo

Declaration by co-authors

The undersigned hereby certify that:

1. The above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. There are no other author of the publication according these criteria;
5. Potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. The original data are stored at the following location and will be held for at least five years from date indicated below

Location of stored data:

Data were stored on the authors (JV) encrypted account at the University of Birmingham, allocated through the Academic Department of Military Emergency Medicine.

31st January 2018

Prof. Jason E. Smith	Date
	8th February 2018
Prof. Lee A. Wallis	Date

Main findings:

- Existing major incident triage tools, including those currently in use in UK military and civilian practice continue to demonstrate poor performance at predicting need for life-saving intervention in this prospective military cohort.
- The Modified Physiological Triage Tool outperforms existing triage tools, with the greatest sensitivity for predicting need for life-saving intervention, corresponding with the lowest rates of under-triage.
- Within this prospective military cohort, the Modified Physiological Triage Tool demonstrated greater sensitivity at predicting need for life-saving intervention than was observed in both the retrospective derivation and civilian validation datasets.

Motivation for conducting study

In **chapters 3 and 4** the MPTT outperformed existing methods of triage at identifying patients in need of a life-saving intervention, but this came at the expense of low specificity and high rates of over-triage. A key limitation of both these studies is the use of trauma registries to conduct the analyses; whilst they contain large numbers of patients in need of a life-saving intervention, minimally injured patients are a minority, with considerable numbers unlikely to have been included due to the inclusion criteria of the respective trauma registries. By collecting data in a prospective manner, consecutive trauma patients, including those minimally injured and who don't meet trauma registry inclusion criteria, can be analysed, yielding a more accurate representation of triage tool performance.

Aim

The aim of this study was to conduct a prospective validation of the Modified Physiological Triage Tool in a military setting.

Objectives

- Identify gold standard Priority One patients in terms of requirement for life-saving intervention.
- Determine the ability of the MPTT to predict the requirement for life-saving intervention.
- Undertake a comparative validation with existing triage tools.

A copy of the published paper follows over the next five pages.

The prospective validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to major incident triage

James Vassallo,[1,2] S Horne,[3] J E Smith,[3,4] L A Wallis[1]

[1]Division of Emergency Medicine, University of Cape Town, Cape Town, South Africa
[2]Institute of Naval Medicine, Hampshire, UK
[3]Emergency Department, Derriford Hospital, Plymouth, UK
[4]Academic Department of Military Emergency Medicine, Royal Centre for Defence Medicine, Birmingham, UK

Correspondence to
Dr James Vassallo, Institute of Naval Medicine, Alverstoke, Gosport, PO12 2DL, UK; vassallo@doctors.org.uk

Received 23 February 2017
Revised 6 May 2017
Accepted 21 May 2017

ABSTRACT

Introduction Triage is a key principle in the effective management of major incidents. There is limited evidence to support existing triage tools, with a number of studies demonstrating poor performance at predicting the need for a life-saving intervention. The Modified Physiological Triage Tool (MPTT) is a novel triage tool derived using logistic regression, and in retrospective data sets has shown optimum performance at predicting the need for life-saving intervention.

Materials and methods Physiological data and interventions were prospectively collected for consecutive adult patients with trauma (>18years) presenting to the emergency department at Camp Bastion, Afghanistan, between March and September 2011. Patients were considered priority 1 (P1) if they received one or more interventions from a previously defined list. Patients were triaged using existing triage tools and the MPTT. Performance was measured using sensitivity and specificity, and a McNemar test with Bonferroni calculation was applied for tools with similar performance.

Results The study population comprised 357 patients, of whom 214 (59.9%) were classed as P1. The MPTT (sensitivity: 83.6%, 95% CI 78.0% to 88.3%; specificity: 51.0%, 95% CI 42.6% to 59.5%) outperformed all existing triage tools at predicting the need for life-saving intervention, with a 19.6% absolute reduction in undertriage compared with the existing Military Sieve. The improvement in undertriage comes at the expense of overtriage; rates of overtriage were 11.6% higher with the MPTT than the Military Sieve. Using a McNemar test, a statistically significant ($p<0.001$) improvement in overall performance was demonstrated, supporting the use of the MPTT over the Military Sieve.

Discussion and conclusions The MPTT outperforms all existing triage tools at predicting the need for life-saving intervention, with the lowest rates of undertriage while maintaining acceptable levels of overtriage. Having now been validated on both military and civilian cohorts, we recommend that the major incident community consider adopting the MPTT for the purposes of primary triage.

Key messages

- Major incident triage must be rapid, reliable and reproducible irrespective of the provider delivering it.
- Existing major incident triage tools perform poorly at predicting need for life-saving intervention.
- The MPTT outperforms all existing triage tools at predicting the need for life-saving intervention with the lowest rates of undertriage.
- Derived using logistic regression, it's likely that the MPTT's performance is the optimum a simple physiological triage tool can have.

INTRODUCTION

Major incidents occur worldwide on a regular basis, ranging from natural disasters to terrorist-related incidents, and are brought to our attention through the increasing availability of 24-hour media outlets. Within Europe alone, a number of high profile terrorist atrocities have occurred in the last decade, such as the Paris marauding terrorist firearm attacks (MTFAs) in November 2015, resulting in over 100 fatalities and 300 injured.[1] Successful management of the Paris MTFA is attributed to the preparedness of the hospitals, the emergency medical services and the adoption of war surgery principles. The injuries sustained were from high-velocity ballistic weapons, closely mimicking those seen on the battlefield.[1]

A key principle in the successful management of a major incident, irrespective of mechanism, is the prompt recognition of the critically ill or injured patients and their timely evacuation to the most appropriate facility.[2] Triage is the means by which this process is carried out, categorising patients on the basis of their clinical acuity.[3] Within a major incident setting, this categorisation is currently most commonly done using an assessment of basic patient physiology, with the intention of detecting any existing physiological instability.[4]

Within the UK, the Major Incident Medical Management and Support (MIMMS) teaches a two-stage approach to triage — using the Triage Sieve as a rapid assessment on scene and the Triage Sort at casualty clearing stations or in hospitals.[2] Alternative methods exist in other countries, including Simple Triage and Rapid Treatment (START) as recommended in the USA and by the United Nations, and CareFlight in use in Australia.[5] In response to the coroner's inquest following the London 7/7 bombing attacks, changes have been proposed to the existing Triage Sieve, to include control of catastrophic haemorrhage and an assessment of patient conscious level.[6] These changes would bring civilian practice in line with current UK military teaching (the Military Sieve).[7] A comparison of existing triage methods is shown in Table 1.

There is limited evidence to support existing triage methods, and repeated studies have

To cite: Vassallo J, Horne S, Smith JE, *et al*. *J R Army Med Corps* Published Online First: [*please include* Day Month Year]. doi:10.1136/jramc-2017-000771

Table 1 Comparison of existing major incident triage tools

Method	First assessment	Second assessment	Third assessment	Fourth assessment	Fifth assessment
START	Walking?	Breathing? Rate >29	Palpable pulse?	Obeys commands?	
CareFlight	Walking?	Obeys commands?	Breathing? Palpable radial pulse?		
Triage Sieve	Walking?	Breathing? <10 rate >30	HR >120		
Military Sieve	Walking?	Catastrophic limb haemorrhage?	Breathing? <10 rate >30	HR >120	Unconscious?
Modified Military Sieve	Walking?	Breathing? <12 rate >24	HR <40 rate >120	Unconscious?	
Modified Physiological Triage Tool	Walking?	Breathing? <12 rate >22	HR >100	GCS <14	

demonstrated limited performance of triage tools at predicting the priority 1 (P1) patient,[8 9] if defined as a casualty who is in need of a life-saving intervention.[3] The Modified Physiological Triage Tool (MPTT) was derived from a military cohort using logistic regression methodology with the purpose of identifying those in need of life-saving intervention.[10] Previous studies have successfully validated its use within both a military and civilian environment, and demonstrated superior performance characteristics when compared with existing triage methods.[10 11]

The aim of this study was to perform a prospective evaluation of the MPTT, a novel physiological triage tool.

MATERIALS AND METHODS

Physiological data and interventions performed within the emergency department and operating theatre at Camp Bastion, Helmand Province, Afghanistan, were prospectively collected for all adult patients (≥18 years) with trauma between March and October 2011. Patient demographics and injury mechanism were not prospectively recorded. In order to provide patient characteristics, a separate, retrospective analysis of the Joint Theatre Trauma Registry (JTTR) was performed for the study period.

Only patients with complete in-hospital physiological data (HR, RR, GCS and systolic BP (SBP)) were included. In order to prevent bias and increase statistical power, outliers defined a priori as RR >45 beats per minute (bpm), HR >170 and SBP >206 mm Hg, in keeping with the MPTT derivation study, were removed.[10]

Interventions were recorded as free text on a separate data collection sheet by study investigators. Patients were subsequently categorised as gold standard P1 if they received one or more life-saving interventions from a previously defined list.[3]

Patients were triaged using existing triage tools (Triage Sieve, Military Sieve, Modified Military Sieve, START and CareFlight) and the MPTT against the gold standard definition of the P1 patient. In keeping with previous work, in order to classify patients with military triage tools, START and CareFlight, a surrogate of GCS<13 was used to define the unconscious patient and an SBP of 90 mm Hg was taken to represent the presence of a palpable pulse.[8 10 11] Patients were assumed to be non-ambulant for the purposes of triage tool classification.

Performance was measured using a combination of sensitivity, specificity, undertriage (1-sensitivity) and overtriage (1-positive predictive value), with 95% CIs calculated for each. For triage tools with similar performance, a McNemar test with Bonferroni calculation was applied to determine statistically significant difference in performance.[12]

This study was registered as a service evaluation with the Royal Centre for Defence Medicine (project number RCDM/Res/Audit/1036/12/0050). Additionally the study received approval from the Human Research Ethics Committee of the University of Cape Town, the primary institution of the lead author (reference 285/2013).

RESULTS

During the study period, of 497 patients who presented to the emergency department, 29 (5.8%) were excluded as the data recorded were not sufficient to determine P1 status. A further 107 (21.5%) were removed due to incomplete physiological data and 4 (0.2%) were physiological outliers (HR >170 bpm n=2, RR >45 bpm n=2). The final data set for analysis consisted of 357 patients (71.8%), of whom 59.9% (n=214) were P1 (Figure 1).

The JTTR included 458 patients during the study period, of whom the overwhelming majority were male, with blast being the predominant mechanism of injury. In keeping with blast being the predominant mechanism, extremity injuries (lower>upper) occurred most frequently (Table 2).

The MPTT demonstrated the greatest sensitivity of all existing triage tools (83.6%, 95% CI 78.0% to 88.3%), which was an absolute increase of 14.9% and 19.6%, respectively, over the existing Military Sieve and the Modified Military Sieve, respectively, giving an undertriage rate for the MPTT of 16.4%. By contrast, of all existing civilian triage tools, START had the greatest sensitivity (57.5%, 95% CI 50.6% to 64.2%) with an

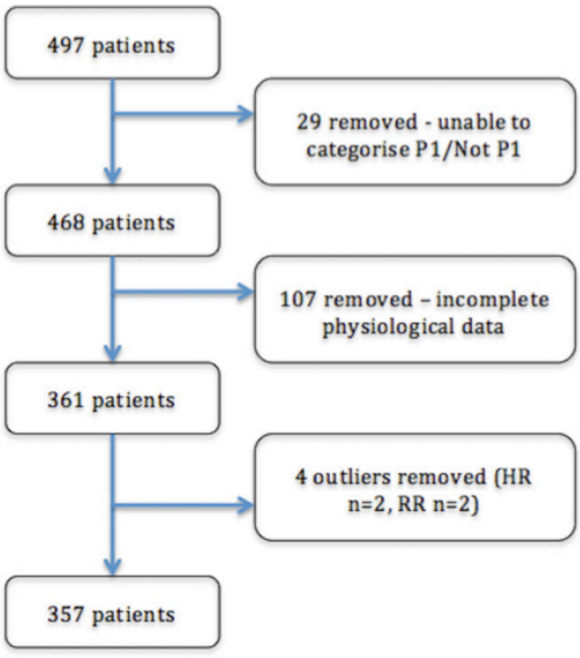


Figure 1 Patient participation flow diagram. P1, priority 1.

Table 2 Study characteristics

No of patients*	458
Gender (n (%))†	455 (97.2)
Male	12 (2.6)
Female	
Injury Severity Score (median (IQR))	5 (2–17)
Age (years) (median (IQR))	24 (21–29)
Outcome (n (%))	441 (96.3)
Survivor	17 (3.7)
Fatality	
Mechanism of injury (n (%))	1 (0.2)
Assault	2 (0.4)
Burns	7 (1.5)
Crush	268 (58.5)
Explosive	4 (0.9)
Fall <5m	4 (0.9)
Fall >5m	139 (30.4)
Gunshot Wounds (GSW)	22 (4.8)
Motor Vehicle Collision (MVC)	2 (0.4)
Other	4 (0.9)
Stabbing	5 (1.1)
Unknown	
Injury body region (n (%))	33 (7.2)
Abdomen	5 (1.1)
External	43 (9.4)
Face	56 (12.2)
Head	190 (41.5)
Lower extremities	4 (0.9)
Neck	4 (0.9)
Other‡, spine	9 (2.0)
Thorax	40 (8.7)
Upper extremities	74 (16.2)
Priority 1 (N (%))	236 (51.5)
Priority 1	222 (48.5)
Not priority 1	

*Number of patients refers to retrospective Joint Theatre Trauma Registry search for the study period.
†Gender not recorded for one patient (0.2%).
‡Includes data not coded (n=3, 0.7%).

undertriage rate of 42.5%, demonstrating an absolute decrease in sensitivity of over 25% when compared with the MPTT. The existing UK civilian Triage Sieve performed poorly with sensitivity and specificity of 46.7% (95% CI 39.9% to 53.7%) and 88.1% (95% CI 81.6% to 92.9%), respectively.

The MPTT had the lowest specificity (51.0%, 95% CI 42.6% to 59.5%) and with it the highest rate of overtriage (28.1%), an absolute increase of 11.6% compared with the existing Military Sieve. Using a McNemar test with Bonferroni correction, statistically significant differences were recorded between both the MPTT and the Military Sieve (χ^2= 83.012, p<0.001) and the MPTT and the Modified Military Sieve (χ^2=64.015, p<0.001). Figure 2 summarises the performance accuracy of the triage tools in their ability to predict the need for life-saving intervention, with a sensitivity analysis displayed in table 3.

DISCUSSION

In this study we have prospectively validated the MPTT in a military environment. A key principle of major incident triage is that irrespective of the provider using it, it must be rapid, reproducible and reliable. This is the third study demonstrating the MPTT's improved performance at predicting the need for life-saving intervention when compared with existing triage tools.[10 11]

There is a paucity of evidence surrounding major incident triage in both the adult and paediatric population, with an increasing number of studies questioning the evidence base and demonstrating limited performance of existing triage tools.[8 9]

Based on the existing Triage Sieve, the MPTT (table 1) was developed to provide an evidence-based physiological triage tool for use as the primary triage method at a major incident. Its components were derived using logistic regression, demonstrating the optimum individual physiological thresholds at predicting need for a life-saving intervention from a previously defined list.[3 10] Analysis and validation studies on both military and civilian trauma registries have demonstrated superior performance by the MPTT in terms of sensitivity and minimising undertriage, although at the expense of poorer but still acceptable levels of specificity and overtriage.[10 11] Because of the nature of its derivation, the performance demonstrated by the MPTT in this study is likely to represent the optimum performance that a physiological triage tool can have at predicting the need for life-saving intervention.

The need for life-saving intervention as an outcome measure for triage tool performance is well documented, and it is a more appropriate measure than the Injury Severity Score (ISS).[13] Unlike the ISS, it represents an assessment of immediate acuity and not a retrospectively defined assessment of anatomical injury.[9] Previous studies have demonstrated a lack of correlation between the ISS and need for life-saving intervention.[13 14] Indeed, the majority of our patients did not sustain, by definition, *'major trauma'* (ISS>15), but approximately 60% received a life-saving intervention and were considered P1.

Our study has demonstrated that the MPTT has the greatest sensitivity at predicting the need for life-saving intervention within a prospective military cohort, yielding the lowest rate of undertriage. However, this comes at the expense of specificity and overtriage, which at 51.0% and 28.1%, respectively, was the highest observed in this study.

To date there are no guidelines by which to benchmark the performance of our major incident triage tools. Within the field triage setting for single trauma patients, it is recommended that overtriage and undertriage be kept to a maximum of 35% and 5%, respectively.[15] While this is achievable using a multistage field triage algorithm, incorporating physiological, anatomical and mechanistic assessments, it is unlikely to be achievable by a single physiological algorithm alone. All triage tools within our analysis satisfied this overtriage threshold. With an undertriage rate of 16.4%, the MPTT clearly exceeds the 5% threshold, but is far superior to the highest performing existing method, START (42.5%).

Using a military data set with which to validate a triage tool for use in civilian major incidents is a limitation of this study. Previous studies (including the civilian validation of the MPTT) report an overwhelming preponderance of blunt trauma, with falls <2 m the most common mechanism of injury affecting an older population (median age 61.4 years), with an almost equal predilection for gender (55.6% male).[11 16] While this is representative of the epidemiology of individual patient injury, worldwide the incidence of MTFAs is increasing; high-velocity weapons and improvised explosive devices are producing similar patterns of injury to those encountered on the battlefield in Afghanistan.[1]

While the MPTT has demonstrated improved performance compared with existing methods in both the military and civilian environments, we acknowledge that major incidents are inherently different, with no two being the same. The ability to provide an effective response to a major incident is multifactorial, with the location, number of casualties involved and the resources available being key features.

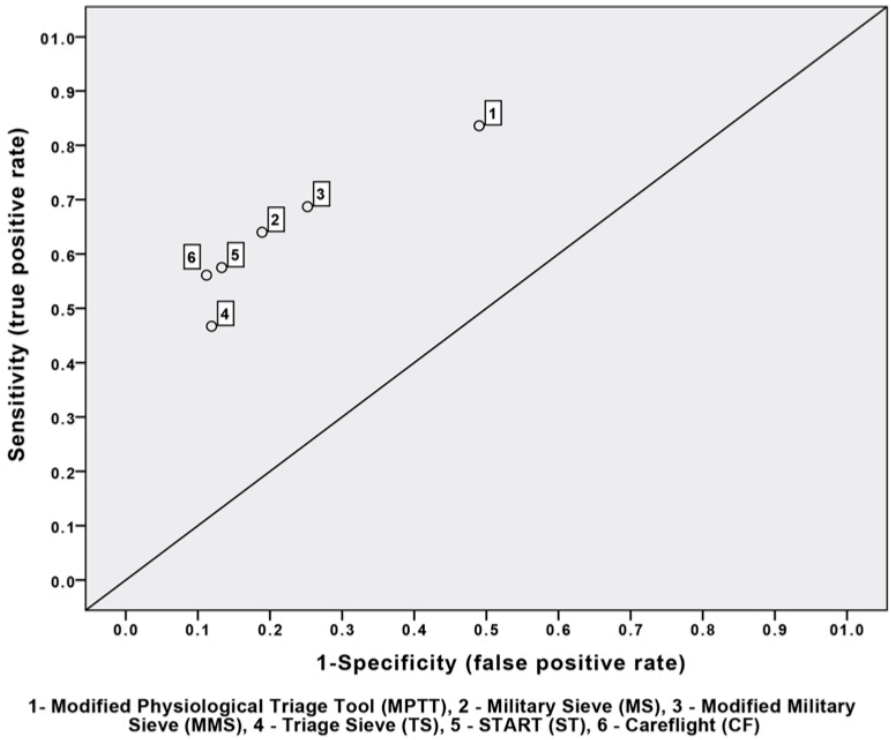


Figure 2 Triage tool performance.

Mortality has previously been shown to increase in a linear relationship as overtriage increases.[17] While an overall scene overtriage rate of 64% was tolerated following the London 7/7 bombings, it must be recognised that this was within an urban environment, with a developed major trauma system.[18] We would speculate that it is unlikely at this level to be tolerated in the setting of a rural environment or an immature major trauma system.

MIMMS teaches a progressive method of triage, with secondary triage (using the Triage Sort) providing a more detailed assessment of the patient within a permissive environment. We support this concept and believe that initial primary triage should be as sensitive as possible in order to reduce the number of patients undertriaged. Once within the casualty clearing station or other permissive environment, secondary triage can occur, allowing for refinement of the triage process and a reduction in patients overtriaged. The Triage Sort as it exists currently shows limited performance for predicting the need for life-saving intervention[19]; we speculate that future work may be required in order to refine the Triage Sort, and support the consideration of including an assessment of anatomical injury, mechanism of injury and clinical acumen.

Limitations

There are clear limitations to our study, a number of which are in common with major incident research in general. We have chosen to perform the prospective validation of the MPTT on a military population, after the tool was derived on a military cohort. While the MPTT has previously been successfully validated on a large civilian cohort, we acknowledge that our population is unlikely to be fully representative of the population involved in a civilian major incident.[11]

Our prospective data collection did not record details of mechanism of injury or demographics. In order to provide these study characteristics, we performed a retrospective search of the JTTR for the study period.

Table 3 Sensitivity analysis

Model	Sensitivity (%) (95% CIs)	Specificity (%) (95% CIs)	Undertriage (%) (1-sensitivity)	Overtriage (%) (1-positive predictive value)
START	57.5 (50.6% to 64.2%)	86.7 (80.0% to 91.8%)	42.5	13.4
CareFlight	56.1 (49.1% to 62.8%)	88.8 (82.5% to 93.5%)	43.9	11.8
Triage Sieve	46.7 (39.9% to 53.7%)	88.1 (81.6% to 92.9%)	53.3	14.5
Military Sieve	64.0 (57.2% to 70.4%)	81.1 (73.7% to 87.2%)	36.0	16.5
Modified Military Sieve	68.7 (62.0% to 74.8%)	74.8 (66.9% to 81.7%)	31.3	19.7
Modified Physiological Triage Tool	83.6 (78.0% to 88.3%)	51.0 (42.6% to 59.5%)	16.4	28.1

Modified Physiological Triage Tool : 12<RR>22, HR>100, GCS<14; Military Sieve: 10<RR>30, HR>120, GCS<13; Triage Sieve: 10<RR>30, HR>120; Modified Military Sieve: 12<RR>24, 40<HR>120, GCS<13; START: RR>30, SBP<90, GCS<13; CareFlight: SBP<90, GCS<13.

Despite the data being collected prospectively, 140 cases (28.2%) were removed from our analysis due to incomplete recording of physiological data.

Incomplete data capture has been previously described following a major incident, with rates as high as 38.0% recorded following the London 7/7 bombings.[9] Within both the major incident setting and our operational setting, human factors are likely to explain some of the data loss — individuals working in austere, high-pressured environments with multiple patients. During our study period, a number of personnel changes would have occurred, and this may have also contributed to a reduction in data collection. We acknowledge that these factors in conjunction may in turn lead to a form of selection bias.

In keeping with previous work, as the presence of radial pulse was not a recorded variable, for the purposes of classification using START and CareFlight, an SBP of 90 mm Hg was adopted as a surrogate to represent the presence of palpable pulse. We recognise this as a limitation and accept that a number of individuals will still have a radial pulse at an SBP of less than 90 mm Hg. Despite a number of other triage studies using both higher and lower values, 90 mm Hg was used due to its correlation with increased mortality following both blunt and penetrating trauma.[5 9 20 21] We acknowledge that BP measurement during primary major incident triage is inappropriate, but in the absence of a recorded variable a surrogate is required for the purposes of comparative validation.

Additionally we have made the assumption that all patients within the study are non-ambulant. While the principal means of patient transport is through helicopter transfer, supporting this assumption to an extent, we acknowledge that a number of helicopter patients are ambulant and are transported seated. Additionally some patients could have self-presented if they were injured close to the site of the medical treatment facility. In a true major incident setting, these patients would be triaged as P3, walking wounded with no physiological assessment performed until arriving at a casualty clearing station where they would undergo secondary triage.[2]

In an ideal setting, triage tools should be evaluated in the situations in which they are designed to function, that is, a major incident. Owing to the unpredictable nature of major incidents, this is largely impractical and so we frequently turn to the retrospective analysis of major incidents or trauma registries to perform research, both of which have limitations. Numbers of seriously injured patients at a major incident may be low — there were only eight at the Royal London Hospital following the London 7/7 bombings — and are confounded by missing data (only four of the seriously injured had available records).[9] By comparison, trauma registries have a greater number of patients, although still with the challenge of missing data. However due to most registries having inclusion criteria, we are unable to represent the population at a major incident who are P3 or have minor injuries. This in turn will have an effect on our ability to reliably comment on the specificities we report in the analysis of our triage tools.

CONCLUSION

In summary we present a prospective validation of the MPTT, the first evidence-based physiological triage tool for use in the major incident setting. The findings of this study demonstrate that the MPTT outperforms all other existing triage tools at predicting the need for life-saving intervention, with the lowest rates of undertriage while maintaining acceptable levels of overtriage. Having now been validated on both military and civilian cohorts, we recommend that its use be considered for the purposes of major incident primary triage.

Contributors JV and SH conceived the study. SH collected the data. JV conducted the analysis, supervised by JES. JV drafted the manuscript, and all authors contributed substantially to its revision. JV takes responsibility for the paper as a whole.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 Hirsch M, Carli P, Nizard R, *et al*. Health professionals of assistance Publique-Hôpitaux de Paris (APHP). The medical response to multisite terrorist attacks in Paris. *Lancet* 2015;386:2535–8.
2 Advanced Life Support Group. *Major incident medical management and support: the practical approach*. London: BMJ Books, 2002.
3 Vassallo J, Smith JE, Bruijns SR, *et al*. Major incident triage: a consensus based definition of the essential life-saving interventions during the definitive care phase of a Major incident. *Injury* 2016;47:1898–902.
4 Jenkins JL, McCarthy ML, Sauer LM, *et al*. Mass-casualty triage: time for an evidence-based approach. *Prehosp Disaster Med* 2008;23:3–8.
5 Garner A, Lee A, Harrison K, *et al*. Comparative analysis of multiple-casualty incident triage algorithms. *Ann Emerg Med* 2001;38:541–8.
6 *Coroner's Inquests into the London Bombings of 7 July 2005*, 2011.
7 Clinical guidelines for Operations. Joint Service publication 999.change 2012. publications@dcdc.org.uk
8 Horne S, Vassallo J, Read J, *et al*. UK triage--an improved tool for an evolving threat. *Injury* 2013;44:23–8.
9 Challen K, Walter D. Major incident triage: comparative validation using data from 7th July bombings. *Injury* 2013;44:629–33.
10 Vassallo J, Beavis J, Smith JE, *et al*. Major incident triage: derivation and comparative analysis of the modified physiological triage Tool (MPTT). *Injury* 2017;48:992–9.
11 Smith JE, Vassallo J. Major incident triage: the civilian validation of the modified physiological triage tool. *Emerg Med J* 2016;33:908.1–908.
12 Hazra A, Gogtay N. Biostatistics Series Module 4: comparing groups - Categorical variables. *Indian J Dermatol* 2016;61:385–92.
13 Baxt WG, Upenieks V. The lack of full correlation between the Injury Severity score and the resource needs of injured patients. *Ann Emerg Med* 1990;19:1396–400.
14 Wallis L, Carley S, Hodgetts CT. A procedure based alternative to the injury severity score for Major incident triage of children: results of a Delphi consensus process. *Emerg Med J* 2006;23:291–5.
15 American College of Surgeons. *Resources for the optimal care of the injured patient*. Chicago, IL: American College of Surgeons 2014 https://www.facs.org/~/media/files/quality%20programs/trauma/vrc%20resources/resources%20for%20optimal%20care.ashx (accessed 18 Jan 2017).
16 Kehoe A, Smith JE, Edwards A, *et al*. The changing face of major trauma in the UK. *Emerg Med J* 2015;32:911–5.
17 Frykberg ER. Medical management of disasters and mass casualties from terrorist bombings: how can we cope? *J Trauma* 2002;53:201–12.
18 Aylwin CJ, König TC, Brennan NW, *et al*. Reduction in critical mortality in urban mass casualty incidents: analysis of triage, surge, and resource use after the London bombings on July 7, 2005. *Lancet* 2006;368:2219–25.
19 Vassallo J, Horne S, Ball S, *et al*. Usefulness of the shock index as a secondary triage tool. *J R Army Med Corps* 2015;161:53–7.
20 Hasler RM, Nüesch E, Jüni P, *et al*. Systolic blood pressure below 110 mmHg is associated with increased mortality in penetrating Major trauma patients: multicentre cohort study. *Resuscitation* 2012;83:476–81.
21 Hasler RM, Nuesch E, Jüni P, *et al*. Systolic blood pressure below 110 mmHg is associated with increased mortality in blunt major trauma patients: multicentre cohort study. *Resuscitation* 2011;82:1202–7.

Discussion of study

Supplementary methods

In **chapters 3 and 4** the MPTT underwent a successful comparative analysis and validation of its performance with existing triage tools. Whilst these retrospective studies on trauma registry data convey the advantage of including large numbers of injured patients requiring life-saving interventions, they are associated with limitations. A key limitation of both studies is the inclusion criteria for entry onto both the JTTR and TARN registries, resulting in the exclusion of less-severely injured patients, thereby making the interpretation of a triage tool's specificity potentially unreliable.

In order to supplement the previous retrospective studies, and to provide an accurate analysis of the MPTT's performance (including reliably reporting specificities), an additional study was performed to validate and further support the use of the MPTT. A prospective observational study was conducted over the six-month period March-October 2011, with data being collected prospectively by the author (SH) for consecutive adult ($\geq$18 years) trauma patients presenting to the ED in the deployed field hospital at Camp Bastion, Afghanistan. By including consecutive patients, those less severely injured and not fulfilling trauma registry inclusion criteria were included in the analysis, whilst still maintaining high numbers of patients requiring life-saving interventions (Priority One patients). Due to the nature of military deployments and with healthcare personnel (SH) only deployed for a fixed amount of time, the data collection period was restricted to this time.

In keeping with the studies in **chapters 3 and 4**, only patients with complete physiological data were included and outliers, defined *a priori* as SBP >206mmHg, RR >45bpm and HR >170bpm were removed from the analysis (**Figure 5.1)**. Interventions were recorded by free text, with patients categorised as Priority One if they received one or more life-saving interventions from **Figure 2.3**. Study characteristics such as age, outcome, mechanism of injury and injured body region were not recorded prospectively, therefore a separate analysis was conducted using the JTTR for the study period as a surrogate.

Using first recorded hospital physiology patients were categorised as Priority One or Not Priority One using the MPTT, the Military/NARU Sieve, START, Careflight and the MIMMS Triage Sieve. As with **chapters 3 and 4,** patients were assumed to be non-ambulant, and for the purposes of categorisation using START and Careflight, a surrogate SBP of 90mmHg was used to represent presence of a palpable pulse. Again, in keeping with previous chapters a surrogate of GCS<13 was used to determine unconsciousness for both the Military/NARU Sieve. The published paper also included the Modified Military Sieve, described in **chapter 3** in the comparative analysis and its performance is described separately in the supplementary results below. Statistical analysis was conducted using sensitivity, specificity and the calculation of under and over-triage. A McNemar test with Bonferroni correction (α=0.05/5=0.01) was used to determine if a statistically significant difference in performance existed between the MPTT and Military/NARU Sieve and the MIMMS Triage Sieve.

Supplementary results

During the study period, 497 consecutive adult trauma patients were assessed in the ED at Camp Bastion, Afghanistan. Interventions were recorded free-hand and reviewed by the authors (JV and SH) to determine whether patients were Priority One or Not Priority One. It was not possible to classify 29 patients (5.8%) and these were removed from the analysis. A further 107 patients (21.5%) were removed due to incomplete physiological data. Finally, four patients were removed as physiological outliers (HR>170, n=2, RR>45, n=2). The final dataset for analysis consisted of 357 patients (71.8%). As described in the supplementary methods, descriptive statistics were not collected prospectively, therefore an analysis of the JTTR was conducted using the dataset in **chapter 3.** The JTTR held records for 458 patients (92.2%) for the dates of the prospective study period, thereby allowing for an accurate representation of the prospective study population **(Table 2, published paper)**.

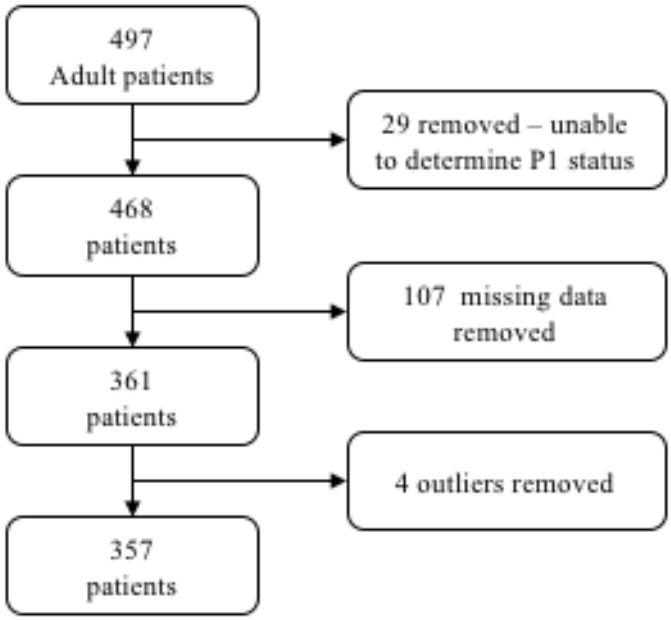


Figure 5.1 Prospective study participation flow diagram.[129]

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT	83.6% (78.1-88.0)	51.1% (42.9-59.1)	16.4% (12.0-21.9)	28.0% (21.3-35.8)
MIMMS Triage Sieve	46.7% (40.2-53.4)	88.1% (81.8-92.4)	53.3% (59.8-46.6)	14.7% (9.8-21.4)
Military/NARU Sieve	64.0% (57.4-70.2)	81.1% (73.9-86.7)	36.0% (29.9-42.6)	16.8% (11.5-23.8)
START	57.5% (50.8-63.9)	86.7% (80.2-91.3)	42.5% (36.1-49.2)	13.3% (8.7-19.8)
Careflight	56.1% (49.4-62.6)	88.8% (82.6-93.0)	43.9% (37.4-50.6)	11.9% (7.6-18.2)

Table 5.1: Comparative performance of the MPTT with existing triage tools.

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value

In keeping with the comparative analyses in **chapters 3 and 4**, the MPTT demonstrated the greatest sensitivity, corresponding to the lowest rates of under-triage **(Table 5.1)**. Under and over-triage were calculated using the same methodology as in previous chapters with additional methods (described in **chapter 3**) reported in **Table 5.2**.

The sensitivity reported in this study exceeds that observed in the derivation study (83.6% versus 69.5%) with no overlapping of 95% confidence intervals. As was anticipated from previous analyses, the MPTT had the lowest specificity of all triage tools, with a 14.2% absolute reduction when compared to the JTTR derivation study **(chapter 3)**. This reduction is likely to be as a result of the inclusion and analysis of all consecutive trauma patients, not only those fulfilling JTTR inclusion criteria; an additional 37 patients were reported in the prospective cohort over those recorded on the JTTR for the same period. Again, in keeping with previous studies, the MPTT had the highest rate of over-triage (28.0%), but within this setting, this is within the 35% over-triage threshold suggested by the American College of Surgeons for the field-triage process.[16]

Compared to the derivation study in **chapter 3**, the performance of the Modified Military Sieve is improved within this prospective cohort (sensitivity: 68.7% (62.0-74.8), specificity: 74.8% (66.9-81.7)) and is comparable to its original derivation dataset (sensitivity: 71.2% (68.2-74.1), specificity: 79.3% (75.9-82.7)).[18] However with respect to sensitivity and rates of under-triage, the MPTT outperformed the Modified Military Sieve with an absolute increase in sensitivity of 14.9%. As in previous chapters, a McNemar test with Bonferroni correction was used to determine if a statistically significant difference in performance existed between the triage tools. For all comparisons and with an adjusted significance level ($\propto$=0.05/5 =0.01), the Null hypothesis that the MPTT had equal performance with existing triage tools was rejected.

MPTT versus MIMMS Triage Sieve - χ^2=130.0, p <0.001

MPTT versus Military/NARU Sieve - χ^2=83.0, p <0.001

	MPTT	**MIMMS Triage Sieve**	**Military/NARU Sieve**	**START**	**Careflight**
This study					
Under-triage ***(1-sensitivity)***	16.4% (12.0-21.9)	53.3% (59.8-46.6)	36.0% (29.9-42.6)	42.5% (36.1-49.2)	43.9% (37.4-50.6)
Over-triage ***(1-PPV)***	28.0% (21.3-35.8)	14.7% (9.8-21.4)	16.8% (11.5-23.8)	13.3% (8.7-19.8)	11.9% (7.6-18.2)
Alternative methods					
Under-triage ***(1-NPV)***	32.2% (26.3-38.8)	47.7% (41.1-54.3)	39.7% (33.4-46.4)	42.5% (36.1-49.2)	42.5% (36.1-49.2)
Over-triage ***(1-specificity)***	49.0% (40.9-57.1)	11.9% (18.2-7.6)	18.9% (13.3-26.1)	13.3% (8.7-19.8)	11.2% (7.0-17.4)

Table 5.2: Comparison of alternative methods of calculating under and over-triage.

PPV; Positive Predictive Value, NPV; Negative Predictive Value

Supplementary limitations

As with previous chapters, this study is associated with the limitation of validating a major incident triage tool in a different context to what it is designed to function in. However, where **chapters 3 and 4** were associated with the additional limitation of trauma registry inclusion criteria, in this study consecutive trauma patients have been analysed.

Whilst physiological data and interventions were recorded prospectively, a limitation of this study was the lack of recording of patient characteristics, thereby relying on a separate analysis of the JTTR for the study period. Despite data being recorded prospectively, 136 patients (27.3%) were excluded due to incomplete data; whilst proportionally this is less than was observed in **chapters 3 and 4**, it still results in a form of selection bias. With a lack of prospectively collected study characteristics, it is not possible to quantify whether those with missing data were more seriously injured.

The use of a free-text box to record interventions received is an additional limitation of this study, and is demonstrated by being unable to ascertain whether 29 patients (5.8%) received a life-saving intervention. For those recorded as having received an intervention, it was not possible to ascertain whether the interventions recorded were the only ones received, i.e. did the patient also receive a subsequent surgical procedure? A further limitation is the inability to quantify the time period in which the intervention occurred as timings were not recorded for interventions. With the interventions in **Figure 2.3** representing binary outcomes (i.e. received or didn't receive the life-saving intervention), a more appropriate method of data collection might have been to have a box-checklist for each life-saving intervention and with this, a prospective record of when the intervention was performed. If this study was to be repeated in the future, these limitations regarding data collection should be considered in order to provide more reliable and robust data collection.

Whilst not a mitigation for the limitations described, they are likely to be explicable due to the number and training of deployed personnel. Within an established UK trauma service, the likelihood is that there will a trauma research nurse, who is additional to the clinical trauma team, not directly involved in clinical care and who is able to collect this data without interruption. By contrast, in this study, the author (SH) collecting data was the senior Emergency Specialist whose primary role is a clinical one in the deployed setting.

In common with previous chapters and described in the published paper, additional limitations exist and include the assumption that patients were non-ambulant, and the requirement for surrogates (described in the methods) for classification with START, Careflight and the Military/NARU Sieve.

Chapter conclusion

In this study, the MPTT has undergone an additional validation using prospectively collected data for consecutively injured adult trauma patients treated in the ED at Camp Bastion, Afghanistan. Within this prospective cohort, the MPTT demonstrated the greatest sensitivity at predicting the need for life-saving intervention, correlating with the lowest rates of under-triage. Whilst this comes at the expense of the greatest rate of over-triage, the over-triage rate is considerably lower than was observed in **chapters 3 and 4**, and is within the American College of Surgeons recommended limits for individual field triage.[16]

Chapter 6: Exploring the implications of under-triage by the Modified Physiological Triage Tool and existing triage tools in a civilian trauma population

Reference:

Vassallo J, Smith JE, Wallis LA. Investigating the effects of under-triage by existing major incident triage tools. Eur J Emerg Med 2017 doi: 10.1097/MEJ.0000000000000513.

Declaration from author

The following co-authors contributed to the paper: Jason E Smith and Lee A Wallis.

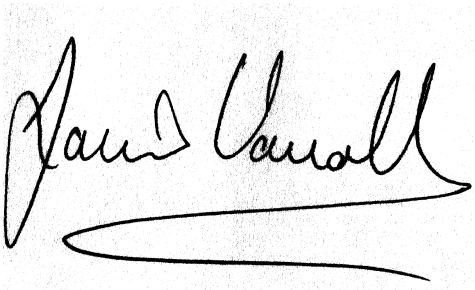
In the case of Chapter 6, contribution by authors to the work was as follows:

Nature of contribution

- JV and JES conceived the idea. JV drafted the work with all authors contributing to revise it critically for important intellectual content. All authors approved the final published version and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- **Extent of contribution:** JV: 85%; JES: 10%; LAW: 5%

The following co-authors contributed to the work:

1. Prof. Lee A Wallis
2. Prof. Jason E Smith



Signed: James Vassallo

Declaration by co-authors

The undersigned hereby certify that:

1. The above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. There are no other author of the publication according these criteria;
5. Potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. The original data are stored at the following location and will be held for at least five years from date indicated below

Location of stored data:

Data were stored on the authors (JV) encrypted account at the University of Birmingham, allocated through the Academic Department of Military Emergency Medicine.

31st January 2018

Prof. Jason E. Smith — Date

8th February 2018

Prof. Lee A. Wallis — Date

Main findings:

- The mortality of patients under-triaged by the Modified Physiological Triage Tool is identical to that of the overall study population, and is lower than those under-triaged by both the Military/NARU Sieve and the MIMMS Triage Sieve.
- Patients under-triaged by the Modified Physiological Triage Tool were significantly less injured with a lower median ISS when compared to the Military/NARU Sieve and the MIMMS Triage Sieve.
- Serious head and thoracic injuries formed the majority of the Priority One cohort and the Modified Physiological Triage Tool demonstrated the greatest ability at identifying these patients. Significantly fewer patients with serious head and thoracic injuries were under-triaged by the Modified Physiological Triage Tool.

Motivation for conducting study

Derived on a retrospective military cohort, the MPTT demonstrated improved performance at identifying patients in need of a life-saving intervention, and was subsequently successfully validated using a retrospective civilian trauma database and a prospective military cohort. However, these studies have demonstrated that the improved sensitivity and lowest rates of under-triage come at the expense of the greatest rates of over-triage. Whilst the priority of initial primary triage at a major incident should be to identify those patients in need of life-saving intervention, the overall effectiveness of the triage tool is a balance between identifying these Priority One patients and minimising those inappropriately misclassified as either needing (over-triage) or not needing a life-saving intervention (under-triage). Existing guidance as to the performance of major incident triage tools is limited, with the stipulation that both under and over-triage should simply be kept to a minimum.[16]

Previous studies have demonstrated that increased rates of over-triage can impair patient management through overwhelming healthcare resources and have an impact on morbidity and mortality.[36,40,61] It would seem logical that under-triage, i.e. misclassifying patients in need of a life-saving intervention, will adversely impact both morbidity and mortality, but this is no more than conjecture; to date, there have been no studies looking at the implications of under-triage. With existing triage tools demonstrating high rates of under-triage, far in excess of that observed with the MPTT, this study aimed to explore the implications of under-triage of existing triage tools within the civilian trauma registry population.

Aim

The aim of this study was to determine the clinical significance of under-triage of patients by existing major incident triage tools.

Objectives

- Report the mortality and injury severity of patients under-triaged by existing triage tools.
- Determine the ability of existing triage tools at identifying serious injury (AIS $\geq$3).
- Compare the safety profile of the MPTT with existing triage tools.

A copy of the published paper follows over the next six pages.

Investigating the effects of under-triage by existing major incident triage tools

James M. Vassallo[a,b], Jason E. Smith[c,d] and Lee A. Wallis[a]

Objectives **Triage is a key principle in the effective management of a major incident. Its effectiveness is a balance between identifying those in need of life-saving intervention, and those triaged incorrectly as either needing/not needing a life-saving intervention. The primary aim of this study was to report mortality in those under-triaged by existing major incident triage tools. Secondary aims were to report the ability of triage tools at identifying serious injury by body region (defined as an Abbreviated Injury Scale severity score ≥ 3).**

Patients and methods **Retrospective database analysis of the UK Trauma Audit Research Network for all adult patients (≥18 years) between 2006 and 2014. Patients were defined as priority one using a previously published list. Using the first recorded hospital physiology, patients were categorized by the Modified Physiological Triage Tool (MPTT), National Ambulance Resilience Unit (NARU) Sieve and the Major Incident Medical Management and Support (MIMMS) Triage Sieve. Categorical and continuous data were analyzed using a χ^2-test and Mann–Whitney *U*-test respectively.**

Results **During the study period, 218 985 adult patients met the Trauma Audit Research Network inclusion criteria, with 24 791 (19.5%) priority one patients, of which 70% were male with a median age of 51 (33–71) years and injury severity score of 16 (9–25). The MPTT showed the lowest rate of under-triage (42.4%, $P < 0.001$). Compared with existing methods, the MPTT under-triage population had significantly lower mortality (5.7%, $P < 0.001$) with significantly fewer serious thorax and head injuries under-triaged than both the NARU Sieve and MIMMS Triage Sieve ($P < 0.001$).**

Conclusion **This study has defined the implications of under-triage in the context of a major trauma population. The MPTT misses fewer severely injured patients, with a significant reduction in mortality. We suggest the MPTT to be considered as an alternative to existing primary major incident triage tools.** ***European Journal of Emergency Medicine*** **00:000–000**

European Journal of Emergency Medicine 2017, **00**:000–000

Keywords: Emergency Medical Services, life-saving interventions, major incidents, mass casualty incidents, physiological assessment, trauma, triage

[a]Division of Emergency Medicine, University of Cape Town, Cape Town, South Africa, [b]Institute of Naval Medicine, Gosport, [c]Emergency Department, Derriford Hospital, Plymouth and [d]Academic Department of Military Emergency Medicine, Royal Centre for Defence Medicine (Research and Academia), Medical Directorate, Birmingham, UK

Correspondence to James M. Vassallo, MBBS, Institute of Naval Medicine, Alverstoke PO12 2DL, UK
Tel: + 44 175 243 7629; fax: + 44 845 155 8235; e-mail: jamie.vassallo@nhs.net

Received 5 June 2017 **Accepted** 4 October 2017

Introduction

Major incidents occur worldwide on a regular basis, ranging from industrial and transport accidents to terrorist atrocities and natural disasters. Triage, the process of prioritizing patients on the basis of their clinical acuity is a key principle in the effective management of a major incident and must be able to be performed rapidly, reliably and be reproducible irrespective of the provider using it [1]. Within the UK, a two-stage approach to major incident triage is employed, using simple physiological algorithms that, dependent on the level of derangement, allocate patients to one of three categories, with priority one being the most emergent [2]. The first stage, primary triage, occurs at the scene of the incident, and is frequently a quick 'first look' at the patient with minimal physiological inputs. Secondary triage is used subsequently, for example to evaluate casualties in a more permissive environment (e.g. casualty clearing station), and is a more thorough assessment of the patient (including additional physiological parameters, e.g. blood pressure measurement) [2].

There is no standardized definition of the priority one patient, with some authors using an Injury Severity Score (ISS) definition of major trauma (ISS ≥ 15) and others using the requirement for life-saving intervention [3,4]. Although the ISS provides an assessment of injury severity, it is a retrospective measurement and demonstrates poor correlation with patient acuity and need for life-saving intervention [5]. In the major incident context, we believe it is more appropriate to identify those patients requiring life-saving intervention.

The overall effectiveness of triage is a balance between identifying those genuinely in need of a life-saving intervention (priority one), and minimizing those falsely identified as either needing or not needing intervention

0969-9546 DOI: 10.1097/MEJ.0000000000000513

(over and under-triage). Frequently, the priority is to minimize under-triage as failing to identify those in need of life-saving interventions has clear implications, but repeatedly this has been shown to be at the expense of increased rates of over-triage [6–8]. As with under-triage, over-triage is associated with increased mortality; overwhelming medical facilities with noncritical casualties reduces the ability to provide for those with time-critical injuries, and can result in the loss of potentially salvageable lives [8]. Currently, there is no guidance for the accepted thresholds of over-triage and under-triage within the major incident setting, with the American College of Surgeons stating both should be kept to a minimum [9].

Previous studies using both trauma registries and major incident data have demonstrated that existing primary triage tools have limited performance at identifying those in need of life-saving intervention [7,10,11]. Derived specifically to predict the need for life-saving intervention and as an alternative to existing primary major incident triage tools, the Modified Physiological Triage Tool (MPTT) demonstrated the lowest rates of under-triage in the military setting both retrospectively and prospectively [10,11]. In another linked study by our group the MPTT was validated using the civilian Trauma Audit Research Network (TARN) database; the MPTT again had the lowest rate of under-triage, while maintaining levels of over-triage comparable to those tolerated at a previous civilian major incident [12,13].

To date, there have been no studies describing the implications of under-triage. The primary aim of this study was to report mortality in the patient groups under-triaged by existing methods of major incident primary triage. Secondary aims were to report the ability of primary triage tools at identifying serious injury by body region [defined as an Abbreviated Injury Scale (AIS) severity score ≥ 3] and to describe the safety profile of the MPTT in comparison to UK civilian and military triage tools.

Patients and methods

The TARN has maintained a national database of trauma patients since 1988 and is the largest trauma database in Europe [14]. TARN collects data on adult patients ($\geq$18 years) sustaining moderate to major injuries from all trauma receiving hospitals in England and Wales. Trained clerical staff from the receiving hospital submit data to TARN and the data follows the patient pathway from injury through to discharge. TARN eligibility includes trauma patients who are admitted to hospital for at least 3 days, have a critical care unit admission or who die in hospital.

We undertook a retrospective review of the TARN database from 1 January 2006 to 31 December 2014. Only direct admissions from scene of injury with complete physiological data were included (interhospital trauma transfers were excluded). In keeping with previous studies, outliers (defined as respiratory rate > 45 bpm, heart rate > 170 bpm or systolic blood pressure > 206 mmHg) were removed. Patients were defined as priority one if they received one or more life-saving interventions from a previously published list, derived through international consensus of experts involved in major incident management [1]. Because of the nature of the TARN database, patients were assumed to be nonambulant. Patients declared dead at scene and not conveyed to hospital are not included in the TARN database and therefore were not included in our analysis.

Following the 7 July London bombings, the UK National Ambulance Resilience Unit (NARU) published a modified version of the Major Incident Medical Management and Support (MIMMS) Triage Sieve [15]. Including an assessment of conscious level and control of external catastrophic haemorrhage, the physiological assessments within the NARU Sieve are analogous with the UK Military Sieve [16]. For this reason, we describe our analysis of the NARU Sieve and UK Military Sieve as the UK Military Sieve alone.

Using the first recorded hospital physiology, patients were categorized as priority one or not priority one using the MPTT, the MIMMS Triage Sieve and the UK Military Sieve. Despite the NARU Sieve replacing the traditional MIMMS Triage Sieve in the UK major incident practice, we have included MIMMS Triage Sieve in our analysis as it is still widely taught in the UK as well as worldwide (Table 1).

Basic demographics and injury data are reported as number (percentage), mean (95% confidence intervals) and median (interquartile range) as appropriate. Categorical data were analyzed using a χ^2-test and continuous data with a Mann–Whitney U-test. Statistical analysis was performed in Prism, version 7.0c (GraphPad, La Jolla, California, USA). As part of a larger programme of work, this study received approval by the Human Research Ethics Committee of the University of Cape Town (reference 285/2013), the primary institution of the lead author.

Results

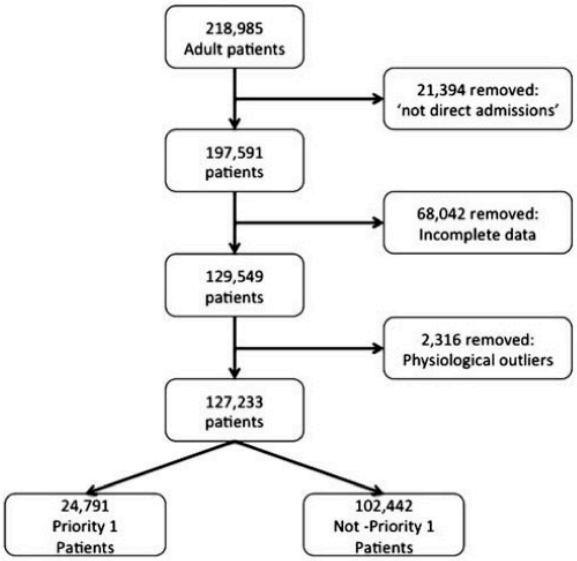
During the study period 218 985 adult patients met the TARN inclusion criteria, with 127 233 included in our analysis. Overall, 24 791 (19.5%) received a life-saving intervention and were identified as priority one (Fig. 1). In comparison to the overall study population, the priority one cohort was younger (51 vs. 61 years), predominantly male (70 vs. 55%) and had a higher ISS (16 vs. 9). Falls less than 2 m (54%) was the leading injury mechanism in the overall study population, followed by road traffic collisions (RTCs) (29%). In the priority one cohort this was reversed, with RTCs the predominant mechanism (34%), followed by falls

Table 1 Comparison of triage tools

Methods	First assessment	Second assessment	Third assessment	Fourth assessment	Fifth assessment
MIMMS Triage Sieve	Walking?	Breathing? < 10 rate > 30	Heart rate > 120	–	–
Military Sieve	Walking?	Catastrophic limb haemorrhage?	Breathing? < 10 rate ≥ 30	Heart rate > 120	Unconscious?
NARU Sieve	Catastrophic haemorrhage?	Walking?	Unconscious?	Breathing? < 10 rate ≥ 30	Heart rate > 120
MPTT	Walking?	Breathing? < 12 rate ≥ 22	Heart rate ≥ 100	GCS < 14	–

GCS, Glasgow Coma Scale; MIMMS, Major Incident Medical Management and Support; MPTT, Modified Physiological Triage Tool; NARU, National Ambulance Resilience Unit.

Fig. 1



Participation flow diagram.

less than 2 m (28%) (Table 1). Injuries (AIS ≥ 3) to the thorax and head predominated (47.0 and 27.4%, respectively) with intubation (35.5%) and thoracocentesis (31.9%) the most frequently performed life-saving interventions. Additional study demographics are provided in Table 2.

Table 2 Characteristics of study population

	Priority one cohort[a]	Whole study population
No. of patients [*n* (%)]	24 791 (19.5)	127 233
Sex [*n* (%)]		
Male	17 424 (70.3)	70 747 (55.6)
Female	7367 (29.7)	56 486 (44.4)
ISS [Median (IQR)]	16 (9–25)	9 (9–16)
Age [Median (IQR)] (years)	50.6 (32.6–71.1)	61.4 (43.1–80.0)
30-Day outcome [*n* (%)]		
Alive	21 728 (87.6)	119 967 (94.3)
Dead	3063 (12.4)	7266 (5.7)
Mode of injury [*n* (%)]		
Blunt	22 011 (88.8)	122 802 (96.5)
Penetrating	2780 (11.2)	4431(3.5)
Mechanism of injury [*n* (%)]		
RTC	8411 (33.9)	27 915 (21.9)
Crush	276 (1.1)	935 (0.7)
Amputation (total + partial)	48 (0.2)	123 (0.1)
Fall > 2 m	4385 (17.7)	18 141 (14.3)
Fall < 2 m	6885 (27.8)	68 354 (53.7)
Shooting	190 (0.8)	332 (0.3)
Stabbing	2295 (9.3)	2899 (2.3)
Blast	19 (0.1)	77 (0.1)
Blow(s)	1536 (6.2)	5833 (4.6)
Burns	38 (0.2)	105 (0.1)
Other	708 (2.9)	2519 (2.0)
Injury body region [*n* (%)]		
Abdomen	4618 (18.6)	8010 (4.2)
Face	4080 (16.5)	13 402 (7.1)
Head	8482 (34.2)	30 167 (15.9)
Limb	10 557 (42.6)	73 755 (38.9)
Spine	7318 (29.5)	28 942 (15.3)
Thorax	12 873 (51.9)	31 499 (16.6)
Other	1699 (6.9)	3731 (2.0)
Priority one [*n* (%)][a]		
Priority one	–	24 791 (19.5)
Not priority one	–	102 442 (80.5)

IQR, interquartile range; RTC, road traffic collision.
[a]Defined as receiving one or more life-saving interventions.

Primary outcome

The UK Military and MIMMS Triage Sieve under-triaged 17 842 [71.9%, 95% confidence interval (CI): 71.4–72.5] and 21 583 (87.1%, 95% CI: 86.6–87.5) priority one patients respectively, whereas the MPTT under-triaged 10 521 (42.4%, 95% CI: 41.8–43.1) priority one patients ($P < 0.001$, $\chi^2 = 11\,580$) (Table 3).

Table 3 Rates of under-triage

	Military Sieve	MIMMS Triage Sieve	MPTT
n (%)	17 842 (71.9)	21 583 (87.1)	10 521 (42.4)
95% CIs	71.4–72.5	86.6–87.5	41.8–43.1

CI, confidence interval; MIMMS, Major Incident Medical Management and Support; MPTT, Modified Physiological Triage Tool.

30-Day mortality and injury severity score

Overall, 30-day mortality in the priority one cohort was 12.4%; in the MPTT under-triage group, mortality was identical to the overall study population (5.7%), and demonstrated an absolute improvement in 30-day survival of 0.5% over the UK Military Sieve (5.7 vs. 6.2%, $P = 0.08$). Mortality was significantly greater in the MIMMS Triage Sieve under-triage group (10.9%, $P < 0.001$).

Median ISS was 9 (9–16) for the overall TARN study population ($n = 127\,233$) and 16 (9–25) for the priority one cohort ($n = 24\,791$). Patients under-triaged by the MPTT had a median ISS of 10 (9–18), significantly lower than both the UK Military Sieve [median: 13 (9–20), $P < 0.001$] and the MIMMS Triage Sieve [median: 14 (9–25), $P < 0.001$].

Interventions

The requirement for all life-saving interventions was lower in the MPTT under-triage group. Proportionally, those under-triaged by the MPTT had a significantly lower requirement for thoracocentesis (29.7%, 95% CI: 28.8–30.6), intubation and ventilation (19.0%, 95% CI: 18.3–19.8) and massive transfusion (5.2%, 95% CI: 4.8–5.7) than both the UK Military and MIMMS Triage Sieve ($P < 0.001$) (Table 4).

Secondary outcome

Injuries sustained

Across the whole study population ($n = 127\,233$), serious injuries to the limbs predominated (34.6%), followed by those with head (19.4%) and thorax (18.4%) injuries. However, in the cohort of patients requiring life-saving interventions, injuries to the thorax predominated (47.1%), followed by head (27.4%) and limbs (18.4%). The relative frequencies of severe injuries for the whole study population, priority one cohort and those under-triaged by the MPTT, UK Military Sieve and MIMMS Triage Sieve are shown in Table 5.

Of the patients under-triaged by the three triage tools, the MPTT had the lowest proportion of thoracic injuries ($P < 0.001$, $\chi^2 = 119.7$). There was no difference in the number of patients with serious head injuries between the MPTT and UK Military Sieve; 16.3% (95% CI: 15.5–17.0) compared with 16.4% (95% CI: 15.9–16.9), $P = 0.80$). When compared with the existing MIMMS Triage Sieve, the MPTT had significantly fewer patients with head injuries ($P < 0.001$).

The MPTT under-triaged significantly fewer patients with serious thoracic and head injuries ($P < 0.001$). Although the UK Military Sieve offers an improved performance compared with the MIMMS Triage Sieve, there was an absolute increase of 36.2 and 17.9% in patients with serious thoracic and head injuries requiring life-saving intervention, respectively, when compared with the MPTT (Table 5).

Discussion

In this study, we have highlighted the effects, and compared the implications, of under-triage when different primary triage tools are used in the context of a major trauma population. Patients under-triaged by the MPTT demonstrate a significantly lower mortality when compared with the UK Military and MIMMS Triage Sieve. Patients requiring life-saving intervention had more serious thorax (47.1%) and head (27.4%) injuries in comparison to the overall study population, where serious limb injuries predominated (34.6%).

Patients under-triaged by the MPTT had the lowest median ISS, implying a reduction in injury severity, with an identical 30-day mortality rate to the overall TARN study population. The MPTT showed a significant difference in detection of serious body region injury, under-triaging approximately half the number of patients with serious thoracic and head injuries.

Without an assessment of conscious level it is unsurprising that those under-triaged by the MIMMS Triage

Table 4 Frequency of interventions performed in the priority one cohort and patients under-triaged by the MPTT, UK Military Sieve and MIMMS Triage Sieve

		n (%)		
	Priority one cohort[a]	MPTT ($n = 10\,521$)	UK Military Sieve ($n = 17\,842$)	MIMMS Triage Sieve ($n = 21\,583$)
Intubation/ventilation	8813	1998 (19.0)	3809 (21.3)	7102 (32.9)
Massive transfusion[b]	2077	550 (5.2)	1237 (6.9)	1480 (6.9)
Thoracocentesis	8158	3122 (29.7)	6177 (34.6)	6577 (30.5)
External haemorrhage control	235	84 (0.8)	165 (0.9)	187 (0.9)
Intraosseous access	39	9 (0.1)	11 (0.1)	17 (0.1)
Tranexamic acid	4246	1619 (15.4)	3069 (17.2)	3540 (16.4)
Laparotomy	2644	1103 (10.5)	2073 (11.6)	2173 (10.1)
Thoracotomy	1123	438 (4.2)	862 (4.8)	911 (4.2)
Proximal vascular control	290	136 (1.3)	235 (1.3)	249 (1.2)
Interventional radiology	200	86 (0.8)	149 (0.8)	163 (0.8)
Pelvic binder	1166	587 (5.6)	943 (5.3)	1029 (4.8)
ACLS protocols	374	76 (0.7)	147 (0.8)	214 (1)
Neurosurgery[c]	1553	588 (5.6)	835 (4.7)	1434 (6.6)
Spinal nursing	3114	2059 (19.6)	2747 (15.4)	2955 (13.7)
Seizure termination	390	172 (1.6)	269 (1.5)	386 (1.6)
Correction of hypoglycaemia	83	37 (0.3)	56 (0.3)	71 (0.3)
Rewarming	471	181 (1.8)	303 (1.7)	386 (1.8)

ACLS, Advanced Cardiac Life Support; MIMMS, Major Incident Medical Management and Support; MPTT, Modified Physiological Triage Tool.
[a]Defined as receiving one or more life-saving interventions.
[b]Defined as administration of four or more units of blood/blood products.
[c]Defined as craniotomy, burr holes or removal of intracranial haemorrhage.

Table 5 Frequency of severe injuries (AIS ≥ 3) by body region within the whole study population, the priority one cohort and in those under-triaged by the MPTT, the UK Military Sieve and the MIMMS Triage Sieve

	MPTT under-triage ($n = 10\,521$) (% priority one cohort)	UK Military Sieve under-triage ($n = 17\,842$) (% priority one cohort)	MIMMS Triage Sieve under-triage ($n = 21\,583$) (% priority one cohort)	Priority one cohort ($n = 24\,791$) (% priority one cohort)	Whole study population ($n = 127\,233$) (% whole study population)
Abdomen	1062 (38.8)	2071 (75.7)	2228 (81.5)	2735 (11.0)	3984 (3.1)
Face	47 (26.6)	89 (50.3)	154 (87.0)	177 (0.7)	360 (0.3)
Head	1711 (25.2)	2924 (43.1)	5795 (85.4)	6783 (27.4)	24732 (19.4)
Limb	2030 (44.6)	3464 (76.1)	3865 (84.9)	4551 (18.4)	43 989 (34.6)
Spine	1509 (58.5)	2150 (83.4)	2356 (91.4)	2579 (10.4)	8941 (7.0)
Thorax	4420 (37.9)	8657 (74.2)	9701 (83.1)	11 670 (47.1)	23 420 (18.4)
Other	50 (12.1)	111 (26.8)	257 (62.1)	414 (1.7)	582 (0.5)

AIS, Abbreviated Injury Scale; MIMMS, Major Incident Medical Management and Support; MPTT, Modified Physiological Triage Tool.

Sieve have a significantly higher proportion of head injuries [2]. The addition of an assessment of conscious level (e.g. in the UK Military Sieve) improves this performance, but the unchanged physiological parameters within the UK Military (and NARU) Sieve still demonstrate significantly high rates of under-triage, missing disturbingly high numbers of severe thoracic and head injuries [15,16].

A number of studies have previously compared overall triage tool performance using both retrospective major incident data and also analysis of trauma databases [7,17,18]. In both the derivation and subsequent validation studies of the MPTT, significantly lower rates of under-triage have been demonstrated when compared with existing triage tools in both military and civilian trauma populations [10–12]. However, we are unaware of any studies that have further analyzed triage tool performance, specifically looking at their areas of weakness in under-triage and the consequences of this.

Although it is likely that including non-physiological assessments as part of the triage process (e.g. anatomical injury assessment), will improve performance, for the purposes of quick, primary triage, this may not be feasible. Secondary triage in its current form remains a physiological assessment, with previous studies demonstrating little additional benefit over the MIMMS Triage Sieve [19]. With the secondary triage process being performed in a more permissive environment, with greater resources available, we believe this represents the ideal opportunity to perform both physiological and non-pyhysiological assessments as part of the triage process. In light of our findings here, and the serious anatomical injuries under-triaged by existing tools, a thorough review of secondary triage is indicated. We suggest that the feasibility of including anatomical discriminators should be explored in an attempt to improve the overall performance of on-scene triage at a major incident.

A key limitation of our study is the use of a retrospective trauma database to evaluate the performance of triage tools designed for use in a major incident setting. A number of recent European major incidents have been the result of terrorist atrocities, producing injuries more akin to that seen in the combat environment. Although the mechanism of injury in this study's cohort (priority one patients) was predominately RTCs (compared with low falls overall), this injury pattern is unlikely to be wholly representative of a major incident population. In mitigation, the MPTT has been shown to outperform existing tools in the military environment, where the ballistic and explosive injuries seen in recent terrorist incidents are more common [10,11].

In an ideal setting, studies looking at the performance of major incident triage tools would be performed prospectively in the environment in which they are designed to function in. Because of the unpredictable nature of major incidents, this is not feasible; therefore, we frequently use trauma databases as a surrogate source of injured patients. Although the retrospective review of major incidents convey the advantage of utilizing a genuine scenario, previous attempts to validate triage tools have been limited by small numbers of seriously injured patients [7]. With small sample sizes, the ability to draw conclusions on tools' performance is limited. However, by using a trauma database, it is possible to compare the performance of triage tools and their ability to predict the need for life-saving intervention in a large cohort of seriously injured patients.

In keeping with other database studies, the use of the TARN database is associated with a number of limitations. Incomplete data recording is a recognized limitation of database analyses and our study is no different; a large number of cases were excluded because of incomplete physiological data. In addition, because of the TARN inclusion criteria, the population covered by TARN is likely to be skewed towards those sustaining more severe injury. It is therefore likely that the proportion of patients receiving a life-saving intervention will actually be lower in a real major incident population than our sample, and that the rates of under-triage may therefore also be lower.

Conclusion

This study has defined the effects of under-triage when different triage tools are used in the context of a major trauma population, and has compared the implications of under-triage in the patients affected by this. The MPTT appears to miss fewer severely injured patients than other

triage tools and results in fewer life-saving interventions being necessary in the population identified as not priority one. This improved safety profile of under-triage supports previous studies that demonstrated the MPTT's superior performance over existing triage tools. We suggest that the MPTT should be considered for the purposes of primary major incident triage as an alternative to existing primary triage tools.

Acknowledgements

Our thanks to Professor Fiona Lecky, Research Director and Antoinette Edwards, Chief Executive Officer, as the Trauma Audit and Research Network (TARN) for facilitating access to the TARN database.

J.V. conceived the study. J.V. conducted the analysis, supervised by J.E.S. J.V. drafted the manuscript, and all authors contributed substantially to its revision. J.V. takes responsibility for the manuscript as a whole.

Conflicts of interest

Two of the authors (J.V. and J.E.S.) are serving members of the UK Royal Navy. For the remaining authors there are no conflicts of interest.

References

1 Vassallo J, Smith JE, Bruijns SR, Wallis LA. Major incident triage: a consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident. *Injury* 2016; **47**:1898–1902.
2 Advanced Life Support Group. *Major incident medical management and support: the practical approach*, 3rd ed. London, UK: BMJ Publishing; 2011.
3 Wallis L, Carley S, Hodgetts CT. A procedure based alternative to the injury severity score for major incident triage of children: results of a Delphi consensus process. *Emerg Med J* 2006; **23**:291–295.
4 Wallis LA, Carley S. Comparison of paediatric major incident primary triage tools. *Emerg Med J* 2006; **23**:475–478.
5 Baxt WG, Upenieks V. The lack of full correlation between the Injury Severity Score and the resource needs of injured patients. *Ann Emerg Med* 1990; **19**:1396–1400.
6 Sasser SM, Hunt RC, Faul M, Sugerman D, Pearson WS, Dulski T, *et al.* Guidelines for field triage of injured patients: recommendations of the National Expert Panel on Field Triage, 2011. *MMWR Recomm Rep* 2012; **61**:1–20.
7 Challen K, Walter D. Major incident triage: comparative validation using data from 7th July bombings. *Injury* 2013; **44**:629–633.
8 Frykberg ER, Tepas JJ. Terrorist bombings. Lessons learned from Belfast to Beirut. *Ann Surg* 1988; **208**:569–576.
9 American College of Surgeons. *Resources for the optimal care of the injured patient 2014*. Chicago, IL: American College of Surgeons; 2014.
10 Vassallo J, Beavis J, Smith JE, Wallis LA. Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT). *Injury* 2017; **48**:992–999.
11 Vassallo J, Horne S, Smith JE, Wallis LA. The prospective validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to major incident triage. *J R Army Med Corps* 2017. doi:10.1136/jramc-2017-000771. [Epub ahead of print].
12 Vassallo J, Smith J, Bouamra O, Lecky F, Wallis L. The civilian validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to primary major incident triage. *Emerg Med J* 2017. doi:10.1136/emermed-2017-206647. [Epub ahead of print].
13 Aylwin CJ, König TC, Brennan NW, Shirley PJ, Davies G, Walsh MS, *et al.* Reduction in critical mortality in urban mass casualty incidents: analysis of triage, surge, and resource use after the London bombings on July 7, 2005. *Lancet* 2006; **368**:2219–2225.
14 Barnard E, Yates D, Edwards A, Fragoso-Iñiguez M, Jenks T, Smith JE. Epidemiology and aetiology of traumatic cardiac arrest in England and Wales: a retrospective database analysis. *Resuscitation* 2017; **110**:90–94.
15 National Ambulance Resilience Unit, United Kingdom. NARU input to new Triage Sieve. Available at: *https://naru.org.uk/naru-input-to-new-triage-sieve/*. [Accessed 20 May 2017].
16 Ministry of Defence. Clinical Guidelines for Operations (JSP 999); 2013. Available at: *https://www.gov.uk/government/publications/jsp-999-clinical-guidelines-for-operations*. [Accessed 20 May 2017].
17 Garner A, Lee A, Harrison K, Schultz CH. Comparative analysis of multiple-casualty incident triage algorithms. *Ann Emerg Med* 2001; **38**:541–548.
18 Cross KP, Cicero MX. Head-to-head comparison of disaster triage methods in pediatric, adult, and geriatric patients. *Ann Emerg Med* 2013; **61**:668–676.
19 Vassallo J, Horne S, Ball S, Smith J. Usefulness of the Shock Index as a secondary triage tool. *J R Army Med Corps* 2015; **161**:53–57.

Discussion of study

Supplementary methods

Existing methods of UK triage including the Military/NARU Sieve and the MIMMS Triage Sieve demonstrate high rates of under-triage, exceeding that of the MPTT in both the military and civilian environment. In an attempt to further support the use of the MPTT over existing methods of UK primary triage, and to describe its safety profile, an analysis of patient characteristics was undertaken for the cohorts under-triaged by these triage tools.

A retrospective analysis was conducted using the same TARN dataset and with the same patient inclusion criteria described in the civilian validation of the MPTT in **chapter 4**. In keeping with the civilian validation, outliers were identified using Z scores (described in **chapter 3**) and removed from the analysis. Patients were defined as Priority One if they received one or more life-saving interventions from **Figure 2.3** and using first recorded hospital physiology were prioritised as either Priority One or Not Priority One using the MPTT, the Military/NARU Sieve and the MIMMS Triage Sieve. Although the MIMMS Triage Sieve has been replaced by the NARU Sieve (with analogous physiological assessments to the Military Sieve) in UK clinical practice, it was included in the analysis as it continues to be taught on the MIMMS course (in the UK and worldwide) as the method of primary triage.

A typographical error currently exists in **Table 1** of the published paper with the Military/NARU Sieve having an upper respiratory rate threshold of RR >= 30, this should read RR > 30. The analysis was conducted using the correct variable – RR > 30.

Population characteristics were determined and compared for the whole population and the Priority One cohort (published paper **Table 2**). Additional population characteristics are described in the supplementary results for the individual cohorts under-triaged by the triage tools. For all groups (whole population, Priority One cohort, and individual under-triage cohorts) 30-day outcome and injury severity (using ISS) were compared. Additionally, frequency of interventions and proportions of serious injuries by different body region (defined as AIS score $\geq$ 3) were compared. Statistical analysis was with a χ^2-test and Mann-Whitney *U*-test for categorical and continuous data respectively.

Supplementary results

During the study period 127,233 patients were included in the analysis with complete physiological data, of these 24,791 (19.5%) patients were identified as receiving a life-saving intervention (**Figure 6.1)**. The MPTT under-triaged the fewest patients, with the MIMMS Triage Sieve having the highest rate of under-triage (**Table 6.1**).

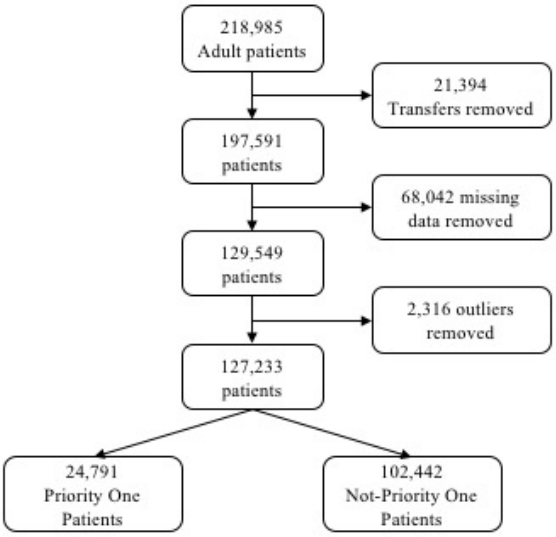


Figure 6.1: Participation flow diagram.[130]

	MPTT	**Military/NARU Sieve**	**MIMMS Triage Sieve**
N (%)	10,521 (42.4)	17,842 (71.9)	21,583 (87.1)
95% Confidence Intervals	41.8-43.1	71.4-72.5	86.6-87.5

Table 6.1: Frequency of under-triage.[130]

As described in the published paper, the Priority One cohort differed considerably to the overall study population; a younger, more male population injured predominantly through road traffic collisions. Additional study characteristics are provided for the individual cohorts under-triaged by the triage tools **(Table 6.2)**. The primary aim was to report mortality between the cohorts under-triaged by the different tools and this is described in the published paper.

No further analyses were conducted.

	Whole Study Population	Priority One Cohort	MPTT Under-triage cohort	Military/NARU Sieve Under-triage cohort	MIMMS Triage Sieve Under-triage cohort
No of patients	127,233	24,791 (19.5%*)	10,521 (42.4%**)	17,842 (71.9%**)	21,583 (87.1%**)
Gender (n (%))					
Male	70,747 (55.6%)	17,424 (70.3%)	7,054 (67.0%)	12,340 (69.2%)	15,048 (69.7%)
Female	56,486 (44.4%)	7,367 (29.7%)	3,467 (33.0%)	5,502 (30.8%)	6,535 (30.3%)
ISS (Median (IQR))	9 (9-16)	16 (9-25)	10 (9-18)	13 (9-20)	14 (9-25)
Age (years) (Median (IQR))	61.4 (43.1-80.0)	50.6 (32.6-71.1)	55.3 (36.6-75.7)	52.1 (33.8-72.7)	51.7 (33.3-72.3)
30 Day Outcome (n (%))					
Alive	119,967 (94.3%)	21,728 (87.6%)	9,921 (94.3%)	16,734 (93.8%)	19,223 (89.1%)
Dead	7,266 (5.7%)	3,063 (12.4%)	600 (5.7%)	1,108 (6.2%)	2,360 (10.9%)
Mode of Injury (n (%))					
Blunt	122,802 (96.5%)	22,011 (88.8%)	9,444 (89.8%)	15,631 (87.6%)	19,256 (89.2%)
Penetrating	4,431(3.5%)	2,780 (11.2%)	1077 (10.2%)	2,211 (12.4%)	2,327 (10.8%)
Mechanism of injury (n (%))					
Road traffic collision	27,915 (21.9%)	8,411 (33.9%)	3,293 (31.3%)	6,010 (33.7%)	7,132 (33.0%)
Crush	935 (0.7%)	276 (1.1%)	143 (1.4%)	228 (1.3%)	237 (1.1%)
Amputation (Total + Partial)	123 (0.1%)	48 (0.2%)	18 (0.1%)	38 (0.2%)	40 (0.2%)
Fall > 2m	18,141 (14.3%)	4,385 (17.7%)	1,697 (16.1%)	2897 (16.2%)	3,873 (17.9%)
Fall < 2m	68,354 (53.7%)	6,885 (27.8%)	3,645 (34.6%)	5346 (30.0%)	6,285 (29.1%)
Shooting	332 (0.3%)	190 (0.8%)	76 (0.7%)	139 (0.8%)	152 (0.7%)
Stabbing	2,899 (2.3%)	2,295 (9.3%)	876 (8.3%)	1,844 (10.3%)	1,923 (8.9%)
Blast	77 (0.1%)	19 (0.1%)	9 (0.1%)	12 (0.1%)	14 (0.1%)
Blow(s)	5,833 (4.6%)	1,536 (6.2%)	562 (5.3%)	966 (5.4%)	1,356 (6.3%)
Burns	105 (0.1%)	38 (0.2%)	7 (0.1%)	21 (0.1%)	27 (0.1%)
Other	2,519 (2.0%)	708 (2.9%)	195 (1.9%)	341 (1.9%)	544 (2.5%)
Injury body region (n (%))					
Abdomen	8,010 (4.2%)	4,618 (18.6%)	1,729 (16.4%)	3,434 (19.2%)	3,762 (17.4%)
Face	13,402 (7.1%)	4,080 (16.5%)	1,231 (11.7%)	2,270 (12.7)	3,485 (16.1%)
Head	30,167 (15.9%)	8,482 (34.2%)	2,447 (23.3%)	4,230 (23.7%)	7,269 (33.7%)
Limb	73,755 (38.9%)	10,557 (42.6%)	4,482 (42.6%)	7,886 (44.2%)	9,055 (42.0%)
Spine	28,942 (15.3%)	7,318 (29.5%)	3,525 (33.5%)	5,564 (31.2%)	6,430 (29.8%)
Thorax	31,499 (16.6%)	12,873 (51.9%)	4.890 (46.5%)	9,508 (53.3%)	10,748 (49.8%)
Other	3,731 (2.0%)	1,699 (6.9%)	449 (4.3%)	870 (4.9%)	1,260 (5.8%)
Priority one (N (%))					
Priority one	24,791 (19.5%)				
Not Priority one	102,442 (80.5%)				

Table 6.2: Population study characteristics (* percentage of whole population, ** percentage of Priority One cohort).[130]

Supplementary limitations

This study is associated with the same limitations described in both the published paper and in **chapter 4**. These include, but are not limited to, the use of a trauma registry to conduct research on a major incident triage tool, and the frequency of missing data. As previously discussed, one of the limitations of the TARN database is the high proportion of patients injured through low falls (53.7%). Whilst in **chapter 4** a sensitivity analysis was performed of triage tool performance with these patients excluded, this has not been done in this study. Whilst the proportion of patients injured through low falls is reduced in the Priority One cohort (27.8%), this may still represent a limitation of this study, and is a potential area in which to conduct further work.

Chapter conclusion

The American College of Surgeons state that both under and over-triage at a major incident should be kept to a minimum.[16] This study supports this statement, and has been able to provide objective evidence of the implications associated with under-triage. Within the trauma registry population, existing UK major incident triage tools (both military and civilian) have high rates of under-triage, and this is associated with higher mortality and more severely injured patients. With the lowest rate of under-triage, and associated with the lowest mortality, the MPTT should be considered as an alternative to existing methods of triage for the purposes of primary major incident triage. In **chapter 7,** a feasibility assessment is undertaken of whether pragmatic changes can be made to the MPTT in order to improve its applicability as a primary major incident triage tool.

Chapter 7: Improving the applicability of the Modified Physiological Triage Tool

Reference:

Vassallo J, Smith JE, Wallis LA. Major incident triage and the implementation of a new triage tool, the MPTT-24. J R Army Med Corps. 2017. doi: 10.1136/jramc-2017-000819.

Declaration from author

The following co-authors contributed to the paper: Jason E Smith and Lee A Wallis.

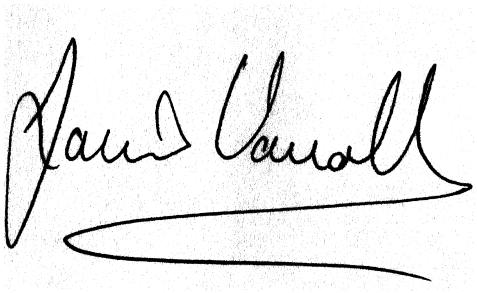
In the case of Chapter 7, contribution by authors to the work was as follows:

Nature of contribution

- JV and JES conceived the idea. JV drafted the work with all authors contributing to revise it critically for important intellectual content. All authors approved the final published version and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
- **Extent of contribution:** JV: 85%; JES: 10%; LAW: 5%

The following co-authors contributed to the work:

1. Prof. Lee A Wallis
2. Prof. Jason E Smith



Signed: James Vassallo

Declaration by co-authors

The undersigned hereby certify that:

1. The above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. There are no other author of the publication according these criteria;
5. Potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. The original data are stored at the following location and will be held for at least five years from date indicated below

Location of stored data:

Data were stored on the authors (JV) encrypted account at the University of Birmingham, allocated through the Academic Department of Military Emergency Medicine.

31st January 2018

Prof. Jason E. Smith — Date

8th February 2018

Prof. Lee A. Wallis — Date

Main findings:

- The Modified Physiological Triage Tool-24 differs from the Modified Physiological Triage Tool by using an increased upper respiratory rate threshold of 24 breaths per minute and replacing the existing conscious level assessment with does the patient respond to Voice. Additionally, it includes an assessment of catastrophic haemorrhage.
- Where the previous upper respiratory rate threshold (22) required a 30 second period to easily measure it, the adoption of a higher upper threshold allows for the potential for a quicker triage assessment; with 24 being divisible by four, the provider is able to measure the respiratory rate over a 15 second period.
- The adoption of a simplified method of assessing a patient's conscious level increases the triage tool's transferability and allows for it to be used by less experienced providers.
- The Modified Physiological Triage Tool-24 demonstrates a reduction in sensitivity in both military and civilian populations when compared to the Modified Physiological Triage Tool, but continues to outperform the existing UK military and civilian (Military/NARU Sieve) method of primary major incident triage.

Motivation for conducting study

Derived using logistic regression, the MPTT represents the combination of the optimum physiological thresholds at predicting the need for life-saving intervention. Within both military and civilian populations, it has been shown to outperform existing methods of triage with the lowest rates of under-triage. Whilst it has been statistically derived it may not represent the optimum method for primary major incident triage; the key principle of which is that it can be performed rapidly, reliably and with reproducible results, irrespective of the provider using it.

In **chapter 3** the optimum ranges of RR for predicting the need for life-saving intervention were identified as <12 or ≥22 bpm. Commonly providers measuring HR and RR will count for a set period of time (e.g. 15 seconds) and then multiply by four to calculate the rate per minute. With an upper RR threshold of ≥22 bpm this is not easily achievable, as 22 is not easily divisible by four, therefore providers are required to count the RR over a 30 second period thereby doubling the time taken to measure the RR. By increasing the upper threshold to 24 bpm, providers are able to more easily measure the RR over a 15 second period, but it is not known what the implications will be on the overall performance of the triage tool.

The MPTT uses a GCS <14 as the conscious level assessment to determine whether a patient is Priority One. Whilst this represents the optimum threshold to identify the need for life-saving intervention and is a specific value (unlike the Military/NARU Sieve, START or Careflight), it relies on the individual performing the triage assessment being familiar and experienced with assessing the GCS. Like the RR, calculating the GCS can be time-consuming and requires providers to have a description of the individual eye, verbal and motor

components. However, even with this, wide inter-rater reliability has previously been described.[131] The AVPU (Alert, responds to Voice, responds to Pain and Unconscious) scale is an alternative, simplified assessment of conscious level. With 'responds to Voice' correlating to a median GCS score of 13, identical to the existing threshold in the MPTT, the GCS <14 assessment was replaced with "responds to Voice".[131,132] By replacing the conscious level assessment with whether the patient "responds to Voice", providers unfamiliar with the GCS are likely to be able to reliably assess the conscious level and in a shorter period of time.

In recent years, a number of European major incidents have been as a result of terrorist incidents, producing injuries more comparable to those seen on the battlefield.[1,61,84] After the London 7/7 bombings and the associated Coroner's Inquest, the MIMMS Triage Sieve was replaced by the NARU Sieve in the UK, the first stage of which is the assessment and treatment of catastrophic haemorrhage using a tourniquet or haemostatic dressing.[45,133] The inclusion of this assessment is a logical step for any new primary major incident triage algorithm, and is in keeping with existing UK military and civilian practice.[46] The result of these pragmatic changes is the Modified Physiological Triage Tool-24 (MPTT-24) **(Figure 7.1)**.

Aim

The aim of this study was to determine whether pragmatic changes could be made to the MPTT without unduly affecting its performance.

Objectives

- Conduct a feasibility assessment of adopting an increased upper RR threshold (24 bpm) in the MPTT-24.
- Compare the performance characteristics of the MPTT-24 to the MPTT and the Military/NARU Sieve.
- Report the mortality and injury severity of the cohorts of patients under-triaged by the MPTT-24.

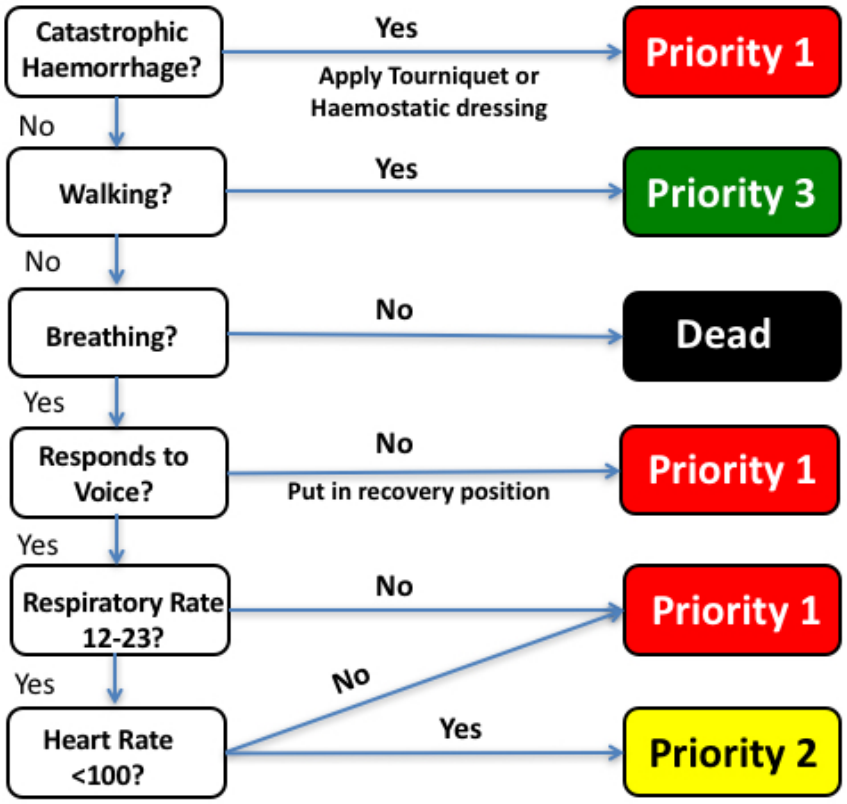


Figure 7.1: Modified Physiological Triage Tool-24 triage algorithm.[134]

A copy of the published paper follows over the next four pages.

OPEN ACCESS

Major incident triage and the implementation of a new triage tool, the MPTT-24

James Vassallo,[1,2] J E Smith,[3,4] L A Wallis[1]

[1]Division of Emergency Medicine, University of Cape Town, Cape Town, South Africa
[2]Institute of Naval Medicine, Gosport, UK
[3]Emergency Department, Derriford Hospital, Plymouth, UK
[4]Academic Department of Military Emergency Medicine, Royal Centre for Defence Medicine (Research & Academia), Medical Directorate, Birmingham, UK

Correspondence to
Dr James Vassallo, Institute of Naval Medicine, Alverstoke, Gosport PO12 2DL, UK;
vassallo@doctors.org.uk

Received 1 June 2017
Revised 31 August 2017
Accepted 1 September 2017

ABSTRACT

Introduction The Modified Physiological Triage Tool (MPTT) is a recently developed primary triage tool and in comparison with existing tools demonstrates the greatest sensitivity at predicting need for life-saving intervention (LSI) within both military and civilian populations. To improve its applicability, we proposed to increase the upper respiratory rate (RR) threshold to 24 breaths per minute (bpm) to produce the MPTT-24. Our aim was to conduct a feasibility analysis of the proposed MPTT-24, comparing its performance with the existing UK Military Sieve.

Method A retrospective review of the Joint Theatre Trauma Registry (JTTR) and Trauma Audit Research Network (TARN) databases was performed for all adult (>18 years) patients presenting between 2006–2013 (JTTR) and 2014 (TARN). Patients were defined as priority one (P1) if they received one or more LSIs. Using first recorded hospital RR in isolation, sensitivity and specificity of the ≥24 bpm threshold was compared with the existing threshold (≥22 bpm) at predicting P1 status. Patients were then categorised as P1 or not-P1 by the MPTT, MPTT-24 and the UK Military Sieve.

Results The MPTT and MPTT-24 outperformed existing UK methods of triage with a statistically significant ($p<0.001$) increase in sensitivity of between 25.5% and 29.5%. In both populations, the MPTT-24 demonstrated an absolute reduction in sensitivity with an increase in specificity when compared with the MPTT. A statistically significant difference was observed between the MPTT and MPTT-24 in the way they categorised TARN and JTTR cases as P1 ($p<0.001$).

Conclusions When compared with the existing MPTT, the MPTT-24 allows for a more rapid triage assessment. Both continue to outperform existing methods of primary major incident triage and within the military setting, the slight increase in undertriage is offset by a reduction in overtriage. We recommend that the MPTT-24 be considered as a replacement to the existing UK Military Sieve.

Key messages

- The Modified Physiological Triage Tool (MPTT) was derived on a military cohort using logistic regression and outperforms all existing triage tools at predicting the need for life-saving intervention in both military and civilian populations.
- Increasing the upper respiratory rate threshold to 24 (MPTT-24) allows for a reduction in the time required to use the triage tool.
- Using the Alert; responds to Verbal stimulus; responds to Painful stimulus; Unresponsive (AVPU) scale as supposed to the GCS to measure conscious level will enable the MPTT-24 to be used by a greater number of personnel, increasing its applicability.
- Performance of the MPTT-24 is largely unchanged from the MPTT, and it clinically and statistically outperforms the existing UK Military Sieve at predicting the need for life-saving intervention.
- We recommend that the MPTT-24 be considered as an alternative to the existing UK Military Sieve for the purposes of primary major incident triage in the military setting.

INTRODUCTION

Triage is the process of prioritising patients on the basis of their clinical acuity and is a key principle of effective major incident management.[1] Within the UK, existing military and civilian doctrine utilises a two-stage approach to triage with primary and secondary triage being performed. Primary triage is a quick assessment of the patient, conducted at the scene and is frequently performed in difficult settings. For it to be effective, it must be rapid, reliable and reproducible, irrespective of the provider using it.[1]

The UK Military Sieve and National Ambulance Resilience Unit Sieve are the algorithms used by the Defence Medical Services and Ambulance Services, respectively, for primary major incident triage.[2 3] Utilising simple physiological assessments, patients are categorised into one of three categories with priority one the most urgent. Secondary triage takes place in a more permissive environment, such as at a casualty clearing station or at the hospital entrance. Unlike primary triage, it is a more thorough assessment of the patient, frequently performed by more experienced and senior clinicians. If needed, it allows for the refinement of the triage category allocated during the primary triage process prior to treatment or admission to hospital.[1]

A number of studies have shown that existing methods of triage have limited accuracy at predicting the need for life-saving intervention in both the military and civilian environments.[4] Derived specifically for this purpose, the Modified Physiological Triage Tool (MPTT) has shown the greatest sensitivity for predicting the need for life-saving intervention, with the lowest rates of undertriage and acceptable levels of overtriage in both military and civilian populations.[5–7]

Respiratory Rate (RR) and Glasgow Coma Scale (GCS) form key components of the MPTT and can both be time consuming to accurately measure,

To cite: Vassallo J, Smith JE, Wallis LA. *J R Army Med Corps* Published Online First: [*please include* Day Month Year]. doi:10.1136/jramc-2017-000819

	Intervention
1	Intubation for actual airway obstruction
2	Intubation for impending airway obstruction
3	Surgical airway for airway obstruction
4	Surgical airway for impending airway obstruction
5	Needle thoracocentesis
6	Finger thoracostomy
7	Tube thoracostomy
8	Application of a chest seal (commercial/improvised)
9	Positive Pressure Ventilation for ventilatory inadequacy
10	Application of a tourniquet for haemorrhage control
11	Use of haemostatic agents for haemorrhage control
12	Insertion of an intra-osseous device for resuscitation purposes
13	Receiving uncross-matched blood
14	Receiving ≥4 units of blood/blood products
15	Administration of tranexamic acid
16	Laparotomy for trauma
17	Thoracotomy for trauma
18	Pericardial window for trauma
19	Surgery to gain proximal vascular control
20	Interventional radiology for haemorrhage control
21	Application of a pelvic binder
22	ALS/ACLS protocols for a patient in a *peri*-arrest situation
23	ALS/ACLS protocols for a patient in cardiac arrest
24	Neurosurgery for the evacuation of an intra-cranial haematoma
25	Craniotomy
26	Burr Hole Insertion
27	Spinal nursing for a C1-3 fracture
28	Administration of a seizure-terminating medication
29	Active rewarming for initial core temp <32° celcius
30	Passive rewarming for initial core temp <32° celcius
31	Correction of low blood glucose
32	Administration of chemical antidotes

Figure 1 Life-saving interventions defining the priority one patient. ACLS, advanced cardiovascular life support.

with significant inter-rater reliability being described previously.[8] We propose to modify the MPTT by increasing the upper respiratory rate threshold to 24 breaths per minute (MPTT-24), allowing providers to more easily do a 15 second RR count and multiply by four (or 10 seconds and multiply by six), thereby potentially halving the time currently required to use the MPTT. In addition, we have adopted the Alert; responds to Verbal stimulus; responds to Painful stimulus; Unresponsive (AVPU) scale for the purposes of the conscious level assessment, replacing the existing GCS<14 assessment.[9 10]

Accepting a more pragmatic approach—with a threshold RR which is easily calculated within a shorter time frame—may change the test characteristics of the MPTT. The aim of this study was to conduct a feasibility analysis of the proposed MPTT-24 and compare its test characteristics with both the original MPTT and the existing UK Military Sieve.

MATERIALS AND METHODS

A retrospective review of the Joint Theatre Trauma Registry (JTTR) and Trauma Audit Research Network (TARN) databases was performed for all adult (≥18 years) patients presenting between 2006–2013 (JTTR) and 2014 (TARN).

The JTTR holds data on all seriously injured patients treated by UK Defence Medical Services in the deployed setting with continuous data available from 2003. The default entry criterion was a patient who triggered trauma team activation, but this was expanded in 2007 to include all patients with trauma who were returned to the Royal Centre for Defence Medicine for definitive treatment.[5 11] Established in 1988, TARN is the largest trauma database in Europe, collecting data from all trauma receiving hospitals in England and Wales on patients with moderate to severe injuries and contains data from point of injury through to discharge. TARN inclusion criteria include hospital admission >3 days, admission to critical care or death in hospital.[12 13] Patients declared dead at scene and not conveyed to hospital are not included in the database. Patients were assumed to be non-ambulant due to the nature of the TARN database and its inclusion criteria.[6]

Patients were defined as priority one (P1) if they had received one or more life-saving interventions from a previously defined list, derived through international consensus of experts involved in major incident management (Figure 1).[14] Using first recorded hospital RR in isolation, the sensitivity and specificity of the ≥24 breaths per minute threshold were compared with the existing threshold (≥22 breaths per minute) at predicting P1 status. Patients were then categorised as P1 or not-P1 by the MPTT, the MPTT-24 (Figure 2) and the UK Military Sieve. A McNemar test was used to determine statistical significance between the triage tools.

ETHICS STATEMENT

The use of the JTTR was approved by the Medical Directorate, Royal Centre for Defence Medicine. Additionally, as part of a larger programme of work, this study received ethical approval from the Human Research Ethics Committee of the University of Cape Town, the primary academic institution of the lead author (reference 285/2013).

RESULTS

Basic study characteristics are shown in table 1. In both populations, the increased threshold in RR in isolation was associated with an absolute reduction in sensitivity (TARN 11.4%, JTTR 13.5%) and an increase in specificity (TARN 8.9%, JTTR 13.8%). An increase in OR and positive predictive value was observed when using a higher RR for both TARN and JTTR (table 2).

When incorporated into the MPTT-24, an absolute reduction in sensitivity was observed (TARN 8.9%, JTTR 3.2%) with an increase in specificity. There was a statistically significant difference between the MPTT and MPTT-24 in the way they categorised TARN and JTTR cases as P1 ($p<0.001$).

The MPTT-24 demonstrated a statistically significant ($p<0.001$) increase in sensitivity (TARN 25.5%, JTTR 23.5%) over the existing UK Military Sieve in its ability to identify those in need of a life-saving intervention.

DISCUSSION

In this study, we have demonstrated that pragmatic modifications to the MPTT, in the form of the MPTT-24, can be implemented while maintaining comparable performance at predicting the need for life-saving intervention in both civilian and military trauma registry populations. With these modifications, the MPTT-24 continues to outperform the existing UK Military Sieve.

In keeping with the existing UK Military Sieve,[2] we have included an assessment of catastrophic external haemorrhage in the MPTT-24. While experience of such injuries is likely to be limited in day-to-day civilian trauma care, we note previous European terrorist major incidents (Paris 2015 and London 2007) where the demand for tourniquets was high.[15] In the context of an ongoing Marauding Terrorist Firearms Attack, the ability to provide treatment will be limited; controlling catastrophic external haemorrhage through tourniquets or haemostatic dressings may help to preserve life until the incident becomes more permissive.

The MPTT assesses the patient's conscious level using the GCS, with patients scoring 13 or lower being considered P1. While this represents the optimum threshold of conscious level at predicting need for life-saving intervention, it is not

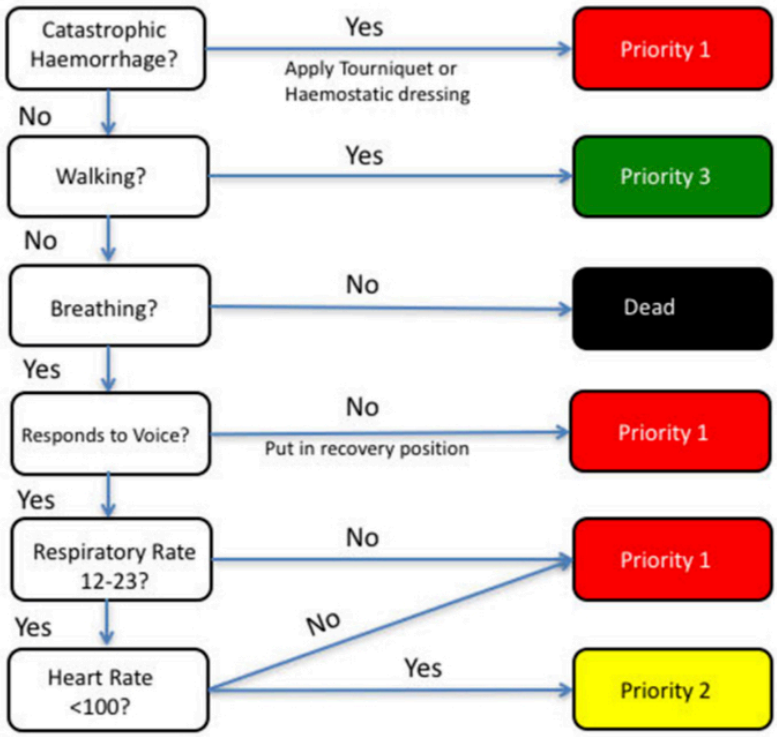


Figure 2 Modified Physiological Triage Tool (MPTT)-24 algorithm with increased respiratory rate upper threshold (≥24), conscious level assessment using Alert; responds to Verbal stimulus; responds to Painful stimulus; Unresponsive (AVPU scale) and the additional assessment for external catastrophic haemorrhage. Vassallo 2017. CC BY 4.0.

Table 1 Study characteristics

	JTTR (2006–2013)	TARN (2006–2014)
Number of cases	3654	127 233
Male N, %	3593 (98.3%)	70 747 (55.6%)
Age, median (IQR)	24 (21–29)	61.4 (43.1–80.0)
ISS, median (IQR)	5 (2–16)	9 (9–16)
Mortality	2.1%	5.7%
Mechanism of injury N,%	Explosive 2012, 55.1% GSW 1252, 34.3%	Fall <2 m 18 141, 14.3% RTC 27 915, 21.9%
Injured body region N,%	Lower limb 1317, 36.0% Upper limb 593, 16.2%	Limb 43 989, 34.6% Head 24 732, 19.4%
Priority One N,%	1738, 47.6%	24 791, 19.5%

GSW, Gun shot wound; JTTR, Joint Theatre Trauma Registry; RTC, Road traffic collision; TARN, Trauma Audit Research Network.

without limitations.[5] Previous studies have demonstrated wide inter-rater reliability when using the GCS.[8] Calculating the GCS requires familiarity and prior experience with the scale, but even then it can be time consuming. The AVPU score was designed as a rapid assessment of conscious level and is a simpler alternative to the GCS.[16 17] A number of studies have looked at the correlation between GCS and AVPU with agreement that the division between being 'alert' and 'responds to voice' occurs at a median GCS of 13.[9 16 18] For the purposes of simplifying the conscious level assessment in the primary triage process, we have replaced 'GCS<14' with 'responds to voice' in the MPTT-24. This pragmatic step should allow users with limited medical training to be able to use the MPTT-24 with similar results, thus increasing both its usability and applicability in the major incident setting.

A key principle of primary major incident triage is that it can be conducted rapidly and measuring the respiratory rate can be time consuming. By increasing the upper respiratory rate threshold of the MPTT, users are able to measure the respiratory rate over a 15 second period, allowing for a potential reduction in the time required to prioritise patients with the MPTT-24 by up to 15 seconds. If this reduction is applied to a theoretical scenario with 20 patients requiring triage, then up to 5 min could be saved by using the MPTT-24 rather than the MPTT. However, we acknowledge that this increased threshold is unlikely to convey any additional time benefit if users choose to measure the respiratory rate over a 30 second period.

Adopting the MPTT-24 comes at the expense of a reduction in sensitivity and therefore a higher rate of undertriage (1 - sensitivity). Clinically, this increased rate in undertriage is negligible; within the military setting, 30 genuine P1 patients would need to be assessed before an additional patient is undertriaged by the MPTT-24. Likewise, the reduction in overtriage (1 - positive predictive value)is negligible between the MPTT and MPTT-24 and needs even greater number of patients before a difference is observed.

In the civilian setting, the rate of overtriage for both the MPTT-24 and MPTT is high (66.0% and 67.1%, respectively). Although this is comparable to the overall overtriage rate following the London 7/7 attacks (64%),[19] we acknowledge that if sustained, this level may not be tolerable in the setting of a non-developed system or rural environment.[20] The MPTT and

Table 2 Performance analysis of test characteristics for RR (≥22 and 24 thresholds), MPTT, MPTT-24 and the existing UK Military Sieve

	Sensitivity	Specificity	OR	PPV
JTTR				
RR≥22	48.7% (45.5–51.9)	68.2% (65.1%–71.2%)	2.04 (1.69–2.45)	61.1% (65.2–71.2)
RR≥24	35.2% (32.2–38.4)	82.0% (79.4%–84.4%)	2.48 (2.01–3.07)	66.7% (62.5–70.7)
MPTT	69.9% (67.7–72.0)	65.3% (63.2–67.4)	4.37 (1.90–5.02)	64.8% (62.7–67.0)
MPTT-24	66.7% (64.5–68.9)	69.9% (67.8–71.9)	4.65 (2.02–5.34)	67.0% (64.7–69.1)
UK Military Sieve	43.2% (40.9–45.6)	93.7% (92.5–94.7)	11.29 (9.18–13.88)	86.1% (83.6–88.4)
TARN				
RR≥22	47.5% (46.7–48.3)	73.9% (73.6–74.3)	2.56 (2.47–4.16)	35.6% (35.0–36.3)
RR≥24	36.1% (35.4–36.9)	82.8% (82.5–83.2)	2.73 (1.31–2.84)	39.0% (38.3–39.8)
MPTT	57.8% (56.9–58.2)	71.5% (71.3–71.8)	3.41 (3.31–3.51)	32.9% (32.4–33.2)
MPTT-24	53.5% (52.9–54.1)	74.8% (74.6–75.1)	3.43 (3.33–3.53)	34.0% (33.4–34.5)
UK Military Sieve	28.0% (27.5–28.6)	94.1% (93.9–94.2)	6.17 (5.94–6.41)	53.3% (52.5–54.2)

JTTR, Joint Theatre Trauma Registry; RR, Respiratory Rate; MPTT, Modified Physiological Triage Tool; PPV, positive predictive value; TARN, Trauma Audit Research Network.

MPTT-24 were designed for the purposes of primary major incident triage alone and not as a replacement to secondary triage. Within the UK, patients will undergo a secondary triage process, with a review of the original triage categories and where appropriate, those initially overtriaged can be reallocated to a lower triage category at the discretion of experienced clinicians, thus reducing the overall overtriage rate.[1]

A key limitation of our study is the use of first recorded hospital physiology to calculate triage priorities. While prehospital data is recorded on both the JTTR and TARN databases, complete data are available for only 16.7% and 37.2% of military and civilian cases, respectively, making prioritisation with prehospital data unreliable. However, when complete hospital and prehospital physiology were compared in both datasets, we observed that the median and IQR were almost identical.

CONCLUSION

When compared with the existing MPTT, the MPTT-24 allows for the potential for a more rapid triage assessment, while maintaining comparable performance and continuing to outperform existing methods used in the UK. Within a military setting, the slight increase in undertriage is offset by a reduction in overtriage. We recommend that the MPTT-24 be considered as a replacement to the existing UK Military Sieve for the purposes of primary major incident triage.

Correction notice This article has been corrected since it was published Online First. Figure 2 has been corrected.

Twitter @jamievassallo

Acknowledgements Our thanks to Professor Fiona Lecky, Research Director and Antoinette Edwards, Chief Executive Officer, at the Trauma Audit and Research Network (TARN) for facilitating access to the TARN database.

Contributors JV conceived the study and conducted the analysis supervised by JES. JV drafted the manuscript and all authors contributed substantially to its revision. JV takes the responsibility for the paper as a whole.

Competing interests JV and JES are serving members of HM Armed Forces.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 Advanced Life Support Group. Triage. In: Carley S, Mackway-Jones K, *Major incident medical management and support*. Oxford, UK: Blackwell Publishing Ltd, 2005:97–107.
2 Ministry of Defence. Clinical guidelines for operations (JSP 999). 2013 https://www.gov.uk/government/publications/jsp-999-clinical-guidelines-for-operations
3 National Ambulance Resilience Unit, United Kingdom. NARU input to new triage sieve. 2014. Cited 26 May 2017 https://naru.org.uk/naru-input-to-new-triage-sieve/
4 Challen K, Walter D. Major incident triage: comparative validation using data from 7th July bombings. *Injury* 2013;44:629–33.
5 Vassallo J, Beavis J, Smith JE, *et al*. Major incident triage: derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT). *Injury* 2017;48:992–9.
6 Vassallo J, Smith J, Bouamra O, *et al*. The civilian validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to primary major incident triage. *Emerg Med J* 2017 (accessed 23 Jul 2017) [Epub ahead of print].
7 Vassallo J, Horne S, Smith JE, *et al*. The prospective validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to major incident triage. *J R Army Med Corps* 2017 (Epub ahead of print).
8 Gill MR, Reiley DG, Green SM. Interrater reliability of Glasgow Coma Scale scores in the emergency department. *Ann Emerg Med* 2004;43:215–23.
9 Kelly CA, Upex A, Bateman DN. Comparison of consciousness level assessment in the poisoned patient using the alert/verbal/painful/unresponsive scale and the Glasgow Coma Scale. *Ann Emerg Med* 2004;44:108–13.
10 Mackay CA, Burke DP, Burke JA, *et al*. Association between the assessment of conscious level using the AVPU system and the Glasgow Coma Scale. *Pre-hospital Immediate Care* 2000:17–19.
11 Smith JE. The epidemiology of blast lung injury during recent military conflicts: a retrospective database review of cases presenting to deployed military hospitals, 2003–2009. *Philos Trans R Soc Lond B Biol Sci* 2011;366:291–4.
12 Kehoe A, Smith JE, Edwards A, *et al*. The changing face of major trauma in the UK. *Emerg Med J* 2015;32:911–5.
13 Barnard EB, Morrison JJ, Madureira RM, *et al*. Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA): a population based gap analysis of trauma patients in England and Wales. *Emerg Med J* 2015;32:926–32.
14 Vassallo J, Smith JE, Bruijns SR, *et al*. Major incident triage: a consensus based definition of the essential life-saving interventions during the definitive care phase of a major incident. *Injury* 2016;47:1898–902.
15 Hirsch M, Carli P, Nizard R, *et al*. The medical response to multisite terrorist attacks in Paris. *Lancet* 2015;386:2535–8.
16 Gill M, Martens K, Lynch EL, *et al*. Interrater reliability of 3 simplified neurologic scales applied to adults presenting to the emergency department with altered levels of consciousness. *Ann Emerg Med* 2007;49:403–7.
17 Kheirabadi AR, Tabeshpour J, Afshari R. Comparison of three consciousness assessment scales in poisoned patients and recommendation of a new scale: AVPU plus. *Asia Pac J Med Toxicol* 2015;4:58–63.
18 McNarry AF, Goldhill DR. Simple bedside assessment of level of consciousness: comparison of two simple assessment scales with the Glasgow Coma scale. *Anaesthesia* 2004;59:34–7.
19 Aylwin CJ, König TC, Brennan NW, *et al*. Reduction in critical mortality in urban mass casualty incidents: analysis of triage, surge, and resource use after the London bombings on July 7, 2005. *Lancet* 2006;368:2219–25.
20 Frykberg ER. Medical management of disasters and mass casualties from terrorist bombings: how can we cope? *J Trauma* 2002;53:201–12.

Discussion of study

Supplementary methods

As described in the published paper, the first stage of this study was to explore the effect of using an increased upper RR threshold (≥24 bpm) compared to the existing MPTT (≥22 bpm). Subsequently, the performance of the MPTT-24 was compared to the MPTT and the Military/NARU Sieve. Two databases (TARN and JTTR) were used for the analyses described in the published paper with the same datasets as used in **chapters 3 and 4.** Study participation including the removal of outliers and the surrogates used for analysis, was the same as in the original studies, and has been previously described in the respective chapters (JTTR: **chapter 3,** TARN: **chapter 4).** In addition to the results in the published paper (sensitivity, specificity, odds ratio and PPV), under and over-triage were calculated with 95% confidence intervals.

Supplementary to the analyses described in the published paper, an analysis was undertaken to assess the MPTT-24's performance using the prospective military cohort described in **chapter 5.** In addition, the safety profile of the MPTT-24 was examined, with the study characteristics identified of the cohort of patients under-triaged by the MPTT-24. In keeping with the study described in **chapter 6** an analysis of mortality, injury severity and the ability to detect serious injury (AIS ≥3) by body region was undertaken with a comparison to the MPTT.

Statistical analysis comparing the performance of triage tools was performed using a McNemar test with a Bonferroni correction. This has previously been described in **chapter 3**.

Supplementary results

As discussed in the published paper, adopting a higher RR upper threshold in isolation resulted in an absolute reduction in sensitivity in both military (13.5%) and civilian (11.4%) trauma registry populations. The reduction in sensitivity was associated with an almost matched increase in specificity (military: 13.8%, civilian: 8.9%).

JTTR Dataset

Both variants of the MPTT outperformed existing methods of triage at predicting the need for life-saving intervention with the lowest rates of under-triage. There was a clinically and statistically significant difference in performance between both the MPTT (χ^2=998, p<0.001), the MPTT-24 (χ^2=856, p<0.001) and the existing Military/NARU Sieve **(Table 7.1)**. Whilst a statistically significant difference in performance was observed (χ^2=140, p<0.001) between the MPTT and the MPTT-24, clinically the two tools are directly comparable in performance; the statistically significant difference is likely to be as a result of the size of dataset used.

Figure 7.2 depicts the performance of both variants of the MPTT in a hypothetical major incident (20 Priority One: 30 Priority Two: 180 Priority Three patients) within the military setting (using the performance triage tool characteristics observed in **Table 7.1)**. Here the MPTT-24 is shown to under-triage an additional one Priority One patient, but with one less Priority Two patient over-triaged compared to the MPTT.

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT-24	66.7% (64.5-68.9)	69.9% (67.8-71.9)	33.7% (31.5-35.9)	33.3% (31.2-35.4)
MPTT	69.9% (67.7-72.0)	65.3% (63.2-67.4)	30.5% (28.4-32.7)	35.4% (33.3-37.6)
MIMMS Triage Sieve	24.2% (22.3-26.3)	94.8% (93.8-95.7)	75.8% (73.7-77.7)	19.1% (17.4-20.9)
Military/NARU Sieve	43.2% (40.9-45.6)	93.7% (92.5-94.7)	56.8% (54.4-59.1)	13.8% (12.4-15.4)
START	38.1% (35.8-40.4)	96.9% (96.1-97.6)	61.9% (59.6-64.2)	8.2% (7.05-9.51)
Careflight	32.9% (30.7-35.2)	98.4% (97.8-98.9)	67.1% (64.8-69.3)	5.0% (4.1-6.0)

Table 7.1: Comparative performance of the MPTT-24 with existing triage tools (JTTR).[129]

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value

Figure 7.2a: Comparison of under and over-triage rates of the MPTT using the JTTR.

Figure 7.2b: Comparison of under and over-triage rates of the MPTT-24 using the JTTR.

The original analysis submitted for the published paper was consistent with those in the previous chapters, with no calculation of odds ratios. Following the peer-review process, the reviewers requested this calculation and it is therefore provided in the published paper, thus explaining the discrepancy between the analyses in the published papers and their respective chapters. Whilst the odds ratio is useful for demonstrating the performance in isolation of adopting a higher RR threshold, when calculated for triage tools it can lead to

confusion and an incorrect assumption about the tools' performance. Calculated using the formula below, the odds ratio relies on specificity for the calculation.[135]

Odds ratio = [Sensitivity / (1-sensitivity)] / [(1-specificity) / specificity)]

The fundamental problem associated with the odds ratio is that sensitivity is the most important assessment in primary major incident triage i.e. the identification of patients in need of a life-saving intervention. Where in **Table 7.1**, the MPTT has the greatest sensitivity (69.9%, (67.7-72.0)), this is at the expense of the lowest specificity (65.3%, (63.2-67.4)), which equates to an odds ratio of 4.37 (1.90-5.02). By contrast, the Military/NARU Sieve, which has a considerably lower sensitivity (43.2%, (40.9-45.6)), but high specificity (93.7%, (92.5-94.7)) has an odds ratio of 11.29 (9.18-13.88). When odds ratios are compared, it gives the impression that, the Military/NARU Sieve with a higher odds ratio, is a 'better' method of triage than the MPTT, despite it under-triaging over half (56.8%) of the study population. It is for this reason that the odds ratios must be interpreted with caution in the published paper.

TARN Dataset

Both variants of the MPTT outperformed existing methods of triage and as was observed with the JTTR dataset, there was a clinically and statistically significant difference in performance between both the MPTT (χ^2=30,405, p<0.001), the MPTT-24 (χ^2=26,005, p<0.001) and the Military/NARU Sieve **(Table 7.2)**.

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT-24	53.5% (52.9-54.1)	74.8% (74.6-75.1)	46.5% (45.9-47.1)	66.0% (65.7-66.3)
MPTT	57.6% (56.9-58.2)	71.5% (71.2-71.8)	42.4% (41.8-43.0)	67.1% (66.5-67.7)
MIMMS Triage Sieve	12.9% (12.5-13.4)	96.7% (96.6-96.8)	87.1% (86.7-87.5)	51.6% (51.0-52.2)
Military/NARU Sieve	28.0% (27.5-28.6)	94.1% (93.9-94.2)	72.0% (71.4-72.6)	46.7% (46.1-47.3)
START	28.8% (28.2-29.4)	94.3% (94.2-94.4)	71.2% (70.6-71.8)	45.0% (44.4-45.6)
Careflight	23.6% (23.1-24.1)	95.9% (95.7-96.0)	76.4% (75.9-76.9)	42.1% (41.5-42.7)

Table 7.2: Comparative performance of the MPTT-24 with existing triage tools (TARN).[129]

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value

Again, whilst the clinical performance of the MPTT-24 is directly comparable to the MPTT in terms of sensitivity and specificity, a statistically significant difference in performance was observed (χ^2=4,398, p<0.001). As with the JTTR dataset, this is likely to be explained by the use of a large dataset, where a small change in performance can result in a statistically significant difference in performance being observed. **Figure 7.3** demonstrates the difference in performance when the MPTT and MPTT-24 are applied to a hypothetical major incident in the civilian setting (with the same ratio of patients as **Figure 7.2** and performance characteristics from **Table 7.2**).

Figure 7.3a: Comparison of under and over-triage rates of the MPTT using TARN.

Figure 7.3b: Comparison of under and over-triage rates of the MPTT-24 using TARN.

As with the JTTR (**Figure 7.2)**, the MPTT-24 under-triages an additional one Priority One patient when compared to the MPTT, but over-triages one less Priority Two patient; implying comparable performance between the two triage tools.

Prospective Cohort

When the MPTT-24's performance is assessed using the prospective cohort from **chapter 5**, a similar performance is observed to the cohorts above **(Table 7.3)**. Despite having directly comparable sensitivity and specificity to the MPTT, a statistically significant difference in performance was again observed (χ^2=6.125, p=0.008). **Figure 7.4** demonstrates the performance of both variants of the MPTT when a hypothetical major incident is considered using the performance from **Table 7.3** (same patient ratio as **Figure 7.2** and **7.3**)**.** Over-triage is identical between the MPTT and MPTT-24, but with a higher rate of under-triage, the MPTT-24 under-triages an additional one Priority One patient.

Triage Tool	Sensitivity	Specificity	Under-triage	Over-triage
MPTT-24	82.2% (76.6-86.8)	54.6% (46.4-62.5)	17.8% (13.2-23.4)	27.3% (20.6-35.1)
MPTT	83.6% (78.1-88.0)	51.1% (42.9-59.1)	16.4% (12.0-21.9)	28.0% (21.3-35.8)
MIMMS Triage Sieve	46.7% (40.2-53.4)	88.1% (81.8-92.4)	53.3% (59.8-46.6)	14.7% (9.8-21.4)
Military/NARU Sieve	64.0% (57.4-70.2)	81.1% (73.9-86.7)	36.0% (29.9-42.6)	16.8% (11.5-23.8)
START	57.5% (50.8-63.9)	86.7% (80.2-91.3)	42.5% (36.1-49.2)	13.3% (8.7-19.8)
Careflight	56.1% (49.4-62.6)	88.8% (82.6-93.0)	43.9% (37.4-50.6)	11.9% (7.6-18.2)

Table 7.3: Comparative performance of the MPTT-24 with existing triage tools (Prospective Cohort).[129]

(95% Confidence Intervals), Under-triage: 1-sensitivity, Over-triage: 1-positive predictive value

In keeping with the retrospective cohorts, the MPTT-24 continued to demonstrate a statistically significant difference in performance with the Military/NARU Sieve (χ^2=75.013, p<0.001).

Figure 7.4a: Comparison of under and over-triage rates of the MPTT using prospective military cohort.

Figure 7.4b: Comparison of under and over-triage rates of the MPTT-24 using prospective military cohort.

Under-triage assessment

30-day mortality was comparable for the MPTT and MPTT-24 (94.3% versus 94.4%), with no statistically significant difference demonstrated (p=0.7928). Median ISS was identical for the cohorts under-triaged by both variants of the MPTT. There was an absolute increase of 1.5% in the proportion of patients under-triaged by the MPTT-24 with serious (AIS≥3) thoracic injuries compared to the MPTT (**Table 7.4)**. Demonstrating a statistically significant difference (p=0.0246) this suggests that a greater number of serious thoracic injuries are under-triaged by the MPTT-24.

However, when compared to the Military/NARU Sieve, an absolute reduction of 4.5% in serious thoracic injuries was observed with the MPTT-24. Again, demonstrating a significant difference (p<0.0001) this suggests that more serious thoracic injuries occur in those patients under-triaged by the Military/NARU Sieve. There was no significant difference in the proportion of patients under-triaged with serious head injuries between both variants of the MPTT (p=0.4628) or the MPTT-24 (p=0.2162) and the Military/NARU Sieve. This suggests that there are similar proportions of patients with serious head injuries in both cohorts under-triaged by these tools.

	Whole Study Population	Priority One Cohort	MPTT-24 Under-triage cohort	MPTT Under-triage cohort	Military/NARU Sieve Under-triage cohort
No of patients	127,233	24,791 (19.5%*)	11,524 (46.5%**)	10,521 (42.4%**)	17,842 (71.9%**)
Gender (n (%))					
Male	70,747 (55.6%)	17,424 (70.3%)	7,771 (67.4%)	7,054 (67.0%)	12,340 (69.2%)
Female	56,486 (44.4%)	7,367 (29.7%)	3,753 (32.6%)	3,467 (33.0%)	5,502 (30.8%)
ISS (Median (IQR))	9 (9-16)	16 (9-25)	10 (9-18)	10 (9-18)	13 (9-20)
Age (years) (Median (IQR))	61.4 (43.1-80.0)	50.6 (32.6-71.1)	54.9 (36.3-75.2)	55.3 (36.6-75.7)	52.1 (33.8-72.7)
30 Day Outcome (n (%))					
Alive	119,967 (94.3%)	21,728 (87.6%)	10,877 (94.4%)	9,921 (94.3%)	16,734 (93.8%)
Dead	7,266 (5.7%)	3,063 (12.4%)	647 (5.6%)	600 (5.7%)	1,108 (6.2%)
Mode of Injury (n (%))					
Blunt	122,802 (96.5%)	22,011 (88.8%)	10,297 (89.4%)	9,444 (89.8%)	15,631 (87.6%)
Penetrating	4,431(3.5%)	2,780 (11.2%)	1,227 (10.6%)	1077 (10.2%)	2,211 (12.4%)
Mechanism of injury (n (%))					
Road traffic collision	27,915 (21.9%)	8,411 (33.9%)	3,678 (31.9%)	3,293 (31.3%)	6,010 (33.7%)
Crush	935 (0.7%)	276 (1.1%)	154 (1.3%)	143 (1.4%)	228 (1.3%)
Amputation (Total + Partial)	123 (0.1%)	48 (0.2%)	19 (0.1%)	18 (0.1%)	38 (0.2%)
Fall > 2m	18,141 (14.3%)	4,385 (17.7%)	1,873 (16.3%)	1,697 (16.1%)	2897 (16.2%)
Fall < 2m	68,354 (53.7%)	6,885 (27.8%)	3,870 (33.6%)	3,645 (34.6%)	5346 (30.0%)
Shooting	332 (0.3%)	190 (0.8%)	81 (0.7%)	76 (0.7%)	139 (0.8%)
Stabbing	2,899 (2.3%)	2,295 (9.3%)	1,005 (8.7%)	876 (8.3%)	1,844 (10.3%)
Blast	77 (0.1%)	19 (0.1%)	9 (0.1%)	9 (0.1%)	12 (0.1%)
Blow(s)	5,833 (4.6%)	1,536 (6.2%)	610 (5.3%)	562 (5.3%)	966 (5.4%)
Burns	105 (0.1%)	38 (0.2%)	7 (0.1%)	7 (0.1%)	21 (0.1%)
Other	2,519 (2.0%)	708 (2.9%)	218 (1.9%)	195 (1.9%)	341 (1.9%)
Injury body region (n (%))					
Abdomen	8,010 (4.2%)	4,618 (18.6%)	1,954 (17.0%)	1,729 (16.4%)	3,434 (19.2%)
Face	13,402 (7.1%)	4,080 (16.5%)	1,359 (11.8%)	1,231 (11.7%)	2,270 (12.7)
Head	30,167 (15.9%)	8,482 (34.2%)	2,655 (23.0%)	2,447 (23.3%)	4,230 (23.7%)
Limb	73,755 (38.9%)	10,557 (42.6%)	4,940 (42.9%)	4,482 (42.6%)	7,886 (44.2%)
Spine	28,942 (15.3%)	7,318 (29.5%)	3,824 (33.2%)	3,525 (33.5%)	5,564 (31.2%)
Thorax	31,499 (16.6%)	12,873 (51.9%)	5,539 (48.1%)	4.890 (46.5%)	9,508 (53.3%)
Other	3,731 (2.0%)	1,699 (6.9%)	495 (4.3%)	449 (4.3%)	870 (4.9%)
Priority One (N (%))					
Priority One	24,791 (19.5%)				
Not Priority One	102,442 (80.5%)				

Table 7.4: Population study characteristics (* percentage of whole population, ** percentage of Priority One cohort).[130]

Supplementary limitations

The work within this chapter describes an extension to the studies conducted in the previous chapters and is therefore subject to the same limitations that have been previously described in both the published papers and chapters.

Whilst a number of studies have described that a patient who 'responds to Voice' has a median GCS of 13, there will be individual variation between patients; for example McNarry and Goldhill report an IQR for the GCS of 10-14.[132] It is acknowledged that not all patients who are unable to 'respond to Voice' will have a GCS <14, therefore representing an additional limitation.

Despite it being previously described that assessing the RR over a period of 60 seconds is best practice, this is not practical in the context of primary major incident triage and therefore an approximation is used (e.g. a 30 second count and multiply by two). However, reducing the time period used to measure the RR may be associated with a reduction in accuracy. Whilst no reduction in accuracy has previously been formally described, it is currently being investigated, determining if there is an impact in detecting clinical deterioration when the RR is measured over 15, 30, 60 second time periods.[136]

With the existing threshold of 22 bpm providers using the MPTT are unable to easily assess the RR in less than 30 seconds. By adopting an increased threshold of 24 bpm, providers have the potential to assess the RR over a shorter period of time; either for a 10 or 15 second period and multiplying by six or four respectively. By adopting this higher threshold, the performance of the MPTT-24 doesn't appear to be negatively affected when compared to the MPTT; despite reaching statistical significance, when applied to a hypothetical clinical situation, the performance of both variants of the MPTT are directly comparable. However, should the provider using the MPTT-24 choose to measure the RR over a 30 second period, there is unlikely to be any additional benefit with regards to a reduction in time taken to triage using the MPTT-24.

A key limitation to this study is that it has only described the theoretical potential for a reduction in time required to triage and not demonstrated it. In order to demonstrate that the MPTT-24 does convey a reduction in time over the MPTT, additional work is required, and this is a potential for future studies.

Chapter conclusion

In this study, pragmatic changes have been made to the MPTT to create the MPTT-24, in order to improve its applicability as a primary major incident triage tool. When compared to the MPTT, the MPTT-24 allows for a more rapid triage assessment and increases its utility by non-clinicians. In both the military and civilian setting, the MPTT-24's performance is largely comparable to the MPTT and continues to outperform (clinically and statistically) the existing methods of UK military and civilian triage.

The key principle of primary major incident triage is that it can be conducted rapidly, reliably and with reproducible results irrespective of the background of the provider using it. The priority of the primary triage process must be to identify those patients in need of a life-saving intervention and to minimise rates of under-triage. The MPTT-24 fulfils these principles and it is for these reasons that is recommended as an alternative to existing methods of primary major incident triage.

Chapter 8: Limitations, conclusion and recommendations

Limitations

The work within this thesis and for major incident triage in general, is associated with a number of limitations. In this thesis a combination of military and civilian populations have been used to derive and subsequently validate a novel triage tool, the MPTT-24. Unsurprisingly, the performance of the MPTT-24 is greatest within the military setting, and this is likely to be as a result of the homogeneity of the military demographic, i.e. young males, frequently with limited or no existing medical co-morbidities who have been injured by predominantly blast or ballistic mechanisms of injury.[123] By comparison, the civilian population is more diverse, with not only an older population, but patients can span multiple decades with not only a varying number of medical co-morbidities, but also the potential for polypharmacy that is associated with this. As a simplistic physiological triage tool, the MPTT-24 is designed to represent a 'one size fits all' approach to primary major incident triage and it is therefore unsurprising that in the civilian environment, a reduction in performance is seen.[127] Not only do the demographics differ between these two cohorts, but the resources available to respond are also different – for example, in the military setting, advanced pre-hospital interventions (including rapid sequence induction of anaesthesia and thoracotomy) are available. Within the UK civilian setting, there is considerable variation by region as to whether advanced physician led pre-hospital teams are available, and further variation as to what interventions they may be able to provide.

In **chapter 2**, the Priority One patient was defined in terms of need for life-saving intervention, with 32 interventions considered by an international panel of experts to be life-saving.[24] Whilst this list of interventions can be considered gold-standard, it is acknowledged that it may not be deliverable in all systems of pre-hospital or emergency care worldwide. The ability to perform the life-saving interventions in **Table 2.6** in the pre-hospital environment is reliant not only on a mature pre-hospital service, but also a developed major incident response. Even with these both available, in certain circumstances, it may be more appropriate for urgent evacuation and transport to hospital, rather than delivering the intervention in the pre-hospital setting. Instances where this may be considered would be where a significant threat remains to patients and the EMS personnel responding, such as in an *active-shooter* or a 'marauding terrorist firearms attack' or in a developed urban environment.

Reports following the London 7/7 bombings state that despite the deployment of considerable numbers of advanced pre-hospital care physicians, very few advanced life-saving interventions were performed, with the primary utilisation of physicians being for scene management.[60] By contrast, in the rural setting with longer pre-hospital transfer times to hospital, interventions are more likely to be considered and performed in the pre-hospital environment prior to hospital transfer.

As with all diagnostic tests the performance of triage tools is a balance between sensitivity and specificity, whilst maintaining a triage tool that is still useable. The 'gold standard' aim of major incident triage is to

identify patients in need of a life-saving intervention, therefore sensitivity is of greater importance than specificity. Closely related to sensitivity and specificity are under and over-triage, which, in the major incident context are likely to be more meaningful assessments. The results from **chapter 6** demonstrate that with increased rates of under-triage, calculated using 1-sensivity, increased mortality and injury severity is observed. These findings support the principle of minimising under-triage. However, as has been observed throughout this thesis, the reduction in under-triage comes at the expense of an increased rate of over-triage.

Whilst over-triage has not specifically been explored in this thesis, there are a number of notable studies in the literature that describe its effect. Using a number of terrorist bombing incidents worldwide, Frykberg demonstrated that there was a significant correlation between rates of over-triage and critical mortality, defined as deaths in potentially salvageable patients, thereby presenting the first study to demonstrate that harm may come from over-triage.[36] By contrast, Aylwin reported that there seemed to be no correlation between over-triage and rates of critical mortality following the London 7/7 bombings; instances of critical mortality occurred not only in sites where over-triage existed, but also in sites where there was minimal over-triage. Overall, they reported only 3 cases of critical mortality (15%), despite a seemingly high rate of overall incident over-triage (64%).[61] Whilst this latter study supports the previous priority of minimising under-triage, its findings may not be wholly transferable to all major incidents.

Occurring within the capital city, there were multiple hospitals and a large number of advanced pre-hospital physicians that responded to this incident, which may go some-way to explain the findings observed. Not isolated to London, a similar response was observed following the Manchester arena bombing in 2017.[137] Whilst, terrorism related major incidents may more frequently occur within the urban environment, not all major incidents will be as a result of terrorist atrocities; transport incidents can occur anywhere and in a more rural setting, the response observed in London and Manchester is unlikely to be able to be replicated. In instances such as these, over-triage may well be more closely related to critical mortality.

Whilst the MPTT-24 has a high rate of over-triage within the civilian setting (67%), it must be remembered that it is designed to function as a method of primary triage, rather than a replacement to the whole triage process. Within the UK, where a secondary triage process is employed, all patients will be re-assessed using a secondary triage method, the Triage Sort.[3] This process allows for those patients who are over-triaged as needing a life-saving intervention to be reassessed and downgraded as appropriate, thereby helping to mitigate the effects of this initial higher rate of over-triage.

Conclusion

Triage is a key principle in the effective management of a major incident, helping to bring order to what is likely to be a chaotic environment and to prioritise patients on the basis of their clinical acuity.[3,42] There are a number of different methods of triage in use worldwide, each with little evidence describing its derivation or the benefits of one tool over another tool.[12,15,50] At a major incident, the extent of injury severity or mortality prediction is of little use to the EMS provider; the priority of triage must be to identify those patients in need of a life-saving intervention.[15,98] This thesis has contributed to the literature with six peer-reviewed publications that describe the derivation and validation of a physiological triage tool. In **chapter 1**, a literature review was conducted exploring existing methods of major incident triage and highlighting the difficulty in comparing different studies due to a variety of different outcome measures being used. **Chapter 2** sought to define the Priority One patient in terms of need for life-saving intervention; using a modified Delphi process 32 interventions were considered by the expert panel as life-saving and this was subsequently used as the outcome measurement for the remainder of the thesis.[24]

In **chapter 3** the optimum physiological parameters (HR, RR, GCS) for identifying need for life-saving intervention were determined using logistic regression methodology in a retrospective military cohort. The combination of these parameters formed the MPTT, which outperformed existing methods (Military/NARU Sieve, MIMMS Triage Sieve, START and Careflight) at predicting the need for life-saving intervention.[123] **Chapter 4** sought to validate the MPTT on a civilian trauma registry dataset and again in this environment outperformed the existing methods listed above. Whilst it continued to have the greatest sensitivity, a reduction was observed from the military derivation to the civilian validation.[127] A subsequent validation was undertaken in **chapter 5** using prospectively collected data in the military environment, where in this setting the MPTT demonstrated greater performance than was observed in both **chapter 3 and 4.**[129] A key principle of the MPTT has been to minimise the rate of misclassification of patients in need of life-saving intervention (under-triage). Whilst experience from previous major incidents has demonstrated that the frequency of actual patients needing life-saving interventions is low, the impact of not providing these interventions is made clear in **chapter 6.** Here, the effects of under-triage by the MPTT and existing UK triage tools (Military/NARU Sieve and MIMMS Triage Sieve) are explored. In this study, patients under-triaged by the existing UK methods demonstrated greater mortality with more serious injuries per body region and higher median ISS.[130]

Whilst the MPTT was statistically derived in **chapter 3**, it may not represent the optimum method of primary major incident triage. The key principles of primary major incident triage are that it is rapid, reliable and reproducible, irrespective of the provider using it; this latter quality has been demonstrated by recent terrorism-related major incidents, where initial triage has not been performed by conventional EMS providers.[88] In **chapter 7**, pragmatic changes were made to the MPTT, in the form of the MPTT-24, in an attempt to reduce the time required to use it and to increase its transferability to be used by non-clinicians. Making these changes did reduce the sensitivity of the tool, but when interpreted in a hypothetical clinical context, the impact on

under-triage was minimal. Despite this reduction when compared to its precursor, the MPTT-24 continued to outperform the Military/NARU sieve at identifying patients in need of a life-saving intervention.[134]

Recommendations for further research

This thesis has focussed on the adult population sustaining traumatic injuries during a major incident. There are a number of special circumstances which are beyond the scope of this work, including major incidents involving paediatrics, burn patients and the Chemical, Biological, Radiological, Nuclear environment; these are all areas that should be considered for further research. Whilst the MPTT-24 has been prospectively validated in the military environment, it has not been prospectively validated in the civilian environment. This is a future area of work for the author, and may be achieved through the retrospective application of triage tools to prospectively collected, consecutive adult trauma patients presenting to an ED. Key differences between the MPTT and the MPTT-24 are the incorporation of a higher upper respiratory rate threshold and the replacement of the GCS with "does the patient respond to voice". These changes were implemented primarily to facilitate the potential for a quicker triage assessment. Currently, this is only a theoretical advantage and the time required to complete either triage assessment (MPTT or MPTT-24) has not been measured. An additional area of work could be to explore this, principally using simulation studies, to determine the speed and efficacy of the MPTT-24 when compared to other triage methods.

The key priority of primary major incident triage is to identify those in need of a life-saving intervention, and in order to maximise the sensitivity of this process, a higher rate of over-triage needs to be tolerated. The secondary triage process is key to mitigating the effects of the initial increased over-triage rate, allowing for patients to be re-assessed with their triage categories downgraded as required. With limited evidence to support the use of the existing UK method of secondary triage (the Triage Sort), further research is recommended to investigate the optimum means of secondary triage.[34] It is likely that in order to improve upon the sensitivity and specificity of the MPTT-24, additional measures will be required, such as the assessment of anatomical injury, bringing secondary triage more in line with the individual field triage process. More detailed physiological assessments such as the Shock Index (HR divided by SBP) allow for an assessment of cardiac function during acute hypovolaemia and have demonstrated promise at identifying the need for life-saving intervention;[34,138] this should be investigated and considered for inclusion for the secondary triage process as an alternative to the existing physiological parameters.

Recommendations for operations

Patients in need of a life-saving intervention typically account for less than 20% of all those injured at a major incident – the priority of the triage process is to identify these patients. Existing triage tools demonstrate poor performance at identifying patients in need of life-saving interventions with high rates of under-triage, potentially associated with increased mortality in the population affected. The MPTT-24 outperforms all existing methods of triage at identifying these patients and is associated with the lowest rates of under-triage. Due to the nature in which it was derived, it is likely that the MPTT/MPTT-24 represents the optimum

performance that a simple physiological triage tool can have at predicting the need for a life-saving intervention. Whilst the MPTT has the lowest rate of under-triage this comes at the expense of increased rates of over-triage. For the primary triage process, where the priority is to identify those in need of life-saving intervention this must be accepted; the use of a secondary triage process will allow for a more accurate triage assessment and the re-classification, if required, of those initially triaged as Priority One, thus mitigating the effect of this initial over-triage.

The key principles of primary major incident triage are that it must be able to be performed rapidly, reliably and with reproducible results irrespective of the background of the provider using it. The MPTT-24 fulfils these priorities and having been validated on both military and civilian datasets, its use is recommended as an alternative to existing methods for the purposes of primary major incident triage. In 2017, it was adopted by the UK National Health Service's (NHS) Emergency Preparedness, Resilience and Response framework as the primary method of adult triage in the latest edition of Clinical Guidelines for Major Incidents **(Appendix 3)**. In addition, the DMS have adopted the MPTT-24 as a replacement to the Military Sieve.

References:

1. CNN [Internet]. London train blast: latest of 5 UK terror incidents in 2017; 2017 Sept 15 [cited 2018 Jan 8]; available from: https://edition.cnn.com/2017/09/15/world/uk-terror-events-2017/index.html
2. The Guardian [Internet]. How the Grenfell tower disaster unfolded; 2017 Jun 14 [cited 2018 Jan 8]; available from: https://www.theguardian.com/uk-news/2017/jun/14/how-the-grenfell-tower-disaster-unfolded.
3. Advanced Life Support Group. Triage. In: Advanced Life Support Group, editors. Major incident medical management and support: the practical approach. 2nd edition. London: BMJ Books; 2002 p107-21.
4. Rehn M, Andersen JE, Vigerust T, Krüger AJ, Lossius HM. A concept for major incident triage: full-scaled simulation feasibility study. BMC Emerg Med. 2010 Aug;10(1):17
5. Delgado RC, Gómez CN, Álvarez TC, González PA. An epidemiological approach to mass casualty incidents in the Principality of Asturias (Spain). Scand J Trauma Resusc Emerg Med. 2016 Feb;24(1):1–9.
6. Lennquist S. Major Incidents: Examples and Experiences. In: Lennquist S, editor. Medical Response to Major Incidents and Disasters. Berlin: Springer-Verlag Berlin Heidelberg; 2012 p9-31.
7. Burris DG, Welling DR, Rich NM. Dominique Jean Larrey and the principles of humanity in warfare. J Am Coll Surg. 2004 May; 198(5):831-5.
8. Baker D, Cazalaà J-B, Carli P. Resuscitation great. Larrey and Percy—a tale of two barons. Resuscitation. 2005 Sep;66(3):259–62.
9. Wilson J. Outlines of naval surgery (1846). Edinburgh: Maclachlan, Stewart & Co. 1846. p24-25.
10. Nocera A, Garner A. An Australian mass casualty incident triage system for the future based upon triage mistakes of the past: the Homebush Triage Standard. Aust N Z J Surg. 1999 Aug;69(8):603–8.
11. Benson M, Koenig KL, Schultz CH. Disaster triage: START, then SAVE--a new method of dynamic triage for victims of a catastrophic earthquake. Prehosp Disaster Med. 1996 Apr;11(2):117–24.
12. Garner A, Lee A, Harrison K, Schultz CH. Comparative analysis of multiple-casualty incident triage algorithms. Ann Emerg Med. 2001 Nov;38(5):541–8.
13. Frykberg ER. Triage: principles and practice. Scand J Surg. 2005;94(4):272–8.
14. Jenkins JL, McCarthy ML, Sauer LM, Green GB, Stuart S, Thomas TL, et al. Mass-casualty triage: time for an evidence-based approach. Prehosp Disaster Med. 2008 Jan;23(1):3–8.
15. Challen K, Walter D. Major incident triage: comparative validation using data from 7th July bombings. Injury. 2013 May;44(5):629–33.
16. American College of Surgeons. Resources for the optimal care of the injured patient. Chicago, IL: American College of Surgeons 2014.
17. Kahn CA, Schultz CH, Miller KT, Anderson CL. Does START triage work? An outcomes assessment after a disaster. Ann Emerg Med. 2009 Sep;54(3):424–30.

18. Horne S, Vassallo J, Read J, Ball S. UK triage--an improved tool for an evolving threat. Injury. 2013 Jan;44(1):23–8.
19. Vassallo J, Horne S, Ball S, Whitley J. UK Triage the validation of a new tool to counter an evolving threat. Injury. 2014 Dec;45(12):2071–5.
20. Paul AO, Kay MV, Huppertz T, Mair F, Dierking Y, Hornburger P, et al. Validation of the prehospital mSTaRT triage algorithm. A pilot study for the development of a multicentre evaluation. Unfallchirurg. 2009 Jan;112(1):23–30.
21. Salvador N, Frank M, Schiffner J, Kipke R, Kleber C. Diagnostic precision of triage algorithms for mass casualty incidents. English version. Anaesthetist. 2017 Aug; doi: 10.1007/s00101-017-0352.
22. Jain TN, Ragazzoni L, Stryhn H, Stratton SJ, Corte Della F. Comparison of the Sacco Triage Method versus START triage using a virtual reality scenario in Advance Care Paramedic students. CJEM. 2016 Jul;18(4):288–92.
23. Cuttance G, Dansie K, Rayner T. Paramedic application of a Triage Sieve: a paper-based exercise. Prehosp Disaster Med. 2017 Feb;32(1):3–13.
24. Vassallo J, Smith JE, Bruijns SR, Wallis LA. Major incident triage: A consensus-based definition of the essential life-saving interventions during the definitive care phase of a major incident. Injury. 2016 Sep;47(9):1898–902.
25. Iserson KV, Moskop JC. Triage in medicine, part I: concept, history, and types. Ann Emerg Med. 2007 Feb 28;49(3):275–81.
26. Manchester Triage Group. Emergency Triage. 3rd edition. Chichester: John Wiley & Sons Ltd. 2014, p11-25.
27. Lee JY, Oh SH, Peck EH, Lee JM, Park KN, Kim SH, et al. The validity of the Canadian Triage and Acuity Scale in predicting resource utilization and the need for immediate life-saving interventions in elderly emergency department patients. Scand J Trauma Resusc Emerg Med. 2011 Nov 3;19(1):68.
28. Wisner DH. History and current status of trauma scoring systems. Arch Surg. 1992;127(1):111–7.
29. Champion HR. Trauma scoring. Scand J Surg. 2002;91(1):12–22.
30. Lerner EB. Studies evaluating current field triage: 1966-2005. Prehosp Emerg Care. 2006 Jul;10(3):303–6.
31. Lossius HM, Rehn M, Tjosevik KE, Eken T. Calculating trauma triage precision: effects of different definitions of major trauma. J Trauma Manag Outcomes. 2012 Aug;6(1):9.
32. Baxt WG, Upenieks V. The lack of full correlation between the Injury Severity Score and the resource needs of injured patients. Ann Emerg Med. 1990 Nov;19(12):1396–400.
33. Holcomb JB, Salinas J, McManus JM, Miller CC, Cooke WH, Convertino VA. Manual vital signs reliably predict need for life-saving interventions in trauma patients. J Trauma. 2005 Oct;59(4):821–8.
34. Vassallo J, Horne S, Ball S, Smith J. Usefulness of the Shock Index as a secondary triage tool. J R Army Med Corps. 2015 Mar;161(1):53–7.

35. Yates DW. Major disasters. Surgical triage. Br J Hosp Med. 1979 Oct;22(4):323–5.
36. Frykberg ER, Tepas JJ. Terrorist bombings. Lessons learned from Belfast to Beirut. Ann Surg. 1988 Nov;208(5):569–76.
37. Neidel T, Salvador N, Heller AR. Impact of systolic blood pressure limits on the diagnostic value of triage algorithms. Scand J Trauma Resusc Emerg Med. 2017 Dec;25(1):118. doi: 10.1186/s13049-017-0461-2.
38. Vayer JS, Eyck Ten RP, Cowan ML. New concepts in triage. Ann Emerg Med. 1986 Jul;15(8):927–30.
39. Delaney JS, Drummond R. Mass casualties and triage at a sporting event. Br J Sports Med. 2002 Mar 31;36(2):85–8.
40. Frykberg ER. Medical management of disasters and mass casualties from terrorist bombings: how can we cope? J Trauma. 2002 Aug;53(2):201–12.
41. Lerner EB, Schwartz RB, Coule PL, Weinstein ES, Cone DC, Hunt RC, et al. Mass casualty triage: universal versus specific: Lerner et al reply. Disaster Med Public Health Prep. 2009 Jun;3(2):71-2.
42. Kennedy K, Aghababian RV, Gans L, Lewis CP. Triage: techniques and applications in decision making. Ann Emerg Med. 1996 Jul;28(2):136–44.
43. McManus J, Yershov AL, Ludwig D, Holcomb JB, Salinas J, Dubick MA, et al. Radial pulse character relationships to systolic blood pressure and trauma outcomes. Prehosp Emerg Care. 2005 Oct;9(4):423–8.
44. Holcomb JB, Niles SE, Miller CC, Hinds D, Duke JH, Moore FA. Prehospital physiologic data and lifesaving interventions in trauma patients. Mil Med. 2005 Jan;170(1):7–13.
45. Stephenson J, Andrews L, Moore F. Developing and introducing a new triage sieve for UK civilian practice. Trauma. 2014;17(2):140–1.
46. Ministry of Defence. Clinical Guidelines for Operations (JSP 999) Change 3 2012 Sep. https://www.gov.uk/government/publications/jsp-999-clinical-guidelines-for-operations (accessed Sep 2017).
47. Wolf P, Bigalke M, Graf BM, Birkholz T, Dittmar MS. Evaluation of a novel algorithm for primary mass casualty triage by paramedics in a physician manned EMS system: a dummy based trial. Scand J Trauma Resusc Emerg Med. 2014 Aug;22(1):5–10.
48. Navin DM, Sacco WJ. Science and evidence-based considerations for fulfilling the SALT triage framework. Disaster Med Public Health Prep. 2010 Mar;4(1):10–2.
49. Sacco WJ, Navin DM, Fiedler KE, Waddell RK, Long WB, Buckman RF. Precise formulation and evidence-based application of resource-constrained triage. Acad Emerg Med. 2005 Aug;12(8):759–70.
50. Kilner TM, Brace SJ, Cooke MW, Stallard N, Bleetman A, Perkins GD. In “big bang” major incidents do triage tools accurately predict clinical priority? a systematic review of the literature. Injury. 2011 May;42(5):460–8.

51. Gebhart ME, Pence R. START triage: does it work? Disaster Manage Response. 2007 Jul;5(3):68-73.
52. Hashimoto A, Ueda T, Kuboyama K, Yamada T, Terashima M, Miyawaki A, et al. Application of a first impression triage in the Japan railway west disaster. Acta Med Okayama. 2013;67(3):171–6.
53. Price CL, Brace-McDonnell SJ, Stallard N, Bleetman A, Maconochie I, Perkins GD. Performance characteristics of five triage tools for major incidents involving traumatic injuries to children. Injury. 2016 May;47(5):988–92.
54. Bhalla MC, Frey J, Rider C, Nord M, Hegerhost M. Simple Triage Algorithm and Rapid Treatment and Sort, Assess, Lifesaving, Interventions, Treatment, and Transportation mass casualty triage methods for sensitivity, specificity, and predictive values. Am J Emerg Med. 2015 Nov;33(11):1687–91.
55. Cross KP, Cicero MX. Head-to-head comparison of disaster triage methods in pediatric, adult, and geriatric patients. Ann Emerg Med. 2013 Jun;61(6):668–676
56. Lerner EB, McKee CH, Cady CE, Colella MR, Liu JM, Schwartz R, et al. A consensus-based gold standard for the evaluation of mass casualty triage systems. Prehosp Emerg Care. 2015 Apr;19(2):267–71.
57. Wallis L, Carley S, Hodgetts CT. A procedure-based alternative to the injury severity score for major incident triage of children: results of a Delphi consensus process. Emerg Med J. 2006 Apr;23(4): 291–5.
58. Hirshberg A, Holcomb JB, Mattox KL. Hospital trauma care in multiple-casualty incidents: A critical view. Ann Emerg Med. 2001 Jun;37(6):647–52.
59. Ashkenazi I, Kessel B, Olsha O, Khashan T, Oren M, Haspel J, et al. Defining the problem, main objective, and strategies of medical management in mass-casualty incidents caused by terrorist events. Prehosp Disaster Med. 2008 Jan;23(1):82–9.
60. Lockey DJ, Mackenzie R, Redhead J, Wise D, Harris T, Weaver A, et al. London bombings July 2005: the immediate pre-hospital medical response. Resuscitation. 2005 Aug;66(2):ix–xii.
61. Aylwin CJ, König TC, Brennan NW, Shirley PJ, Davies G, Walsh MS, et al. Reduction in critical mortality in urban mass casualty incidents: analysis of triage, surge, and resource use after the London bombings on July 7, 2005. Lancet. 2006 Dec;368(9554):2219–25.
62. Peleg K, Rozenfeld M, Stein M. Poorer outcomes for mass casualty events victims: is it evidence based? J Trauma. 2010 Sep;69(3):653-8.
63. Haas B, Gomez D, Zagorski B, Stukel TA, Rubenfeld GD, Nathens AB. Survival of the fittest: the hidden cost of undertriage of major trauma. J Am Coll Surg. 2010 Dec; 211(6):804–11.
64. Armstrong JH, Frykberg ER, Burris DG. Toward a National Standard in Primary Mass Casualty Triage. Disaster Med Public Health Prep. 2013 Apr;2(S1):S8–S10.
65. Hupert N, Hollingsworth E, Xiong W. Is overtriage associated with increased mortality? Insights from a simulation model of mass casualty trauma care. Disaster Med Public Health Prep. 2007 Sep;1(S1):S14–24.

66. Wallis LA, Carley S. Comparison of paediatric major incident primary triage tools. Emerg Med J. 2006 Jun;23(6):475–8.
67. Cross KP, Petry MJ, Cicero MX. A better START for low-acuity victims: data-driven refinement of mass casualty triage. Prehosp Emerg Care. 2015 Apr;19(2):272–8.
68. Ashkenazi I, Kessel B, Khashan T, Haspel J, Oren M, Olsha O, et al. Precision of in-hospital triage in mass-casualty incidents after terror attacks. Prehosp Disaster Med. 2006 Jan;21(1):20–3.
69. Kilner T. Triage decisions of prehospital emergency health care providers, using a multiple casualty scenario paper exercise. Emerg Med J. 2002 Jul;19(4):348–53.
70. Schenker JD, Goldstein S, Braun J, Werner A, Buccellato F, Asaeda G, et al. Triage accuracy at a multiple casualty incident disaster drill: the Emergency Medical Service, Fire Department of New York City experience. J Burn Care Res. 2006 Sep;27(5):570–5.
71. Knight JF, Carley S, Tregunna B, Jarvis S, Smithies R, de Freitas S, et al. Serious gaming technology in major incident triage training: a pragmatic controlled trial. Resuscitation. 2010 Sep;81(9):1175–9.
72. Chen KC, Chen CC, Wang TL. The role tabletop exercise using START in improving triage ability in Disaster Medical Assistance Team. Ann Disaster Med. 2003 Feb;1(2):78-83.
73. Peng J, Xiang H. Trauma undertriage and overtriage rates: are we using the wrong formulas? Am J Emerg Med. 2016 Nov;34(11):2191–2.
74. Postma IL, Weel H, Heetveld MJ, van der Zande I, Bijlsma TS, Bloemers FW, et al. Mass casualty triage after an airplane crash near Amsterdam. Injury. 2013 Aug;44(8):1061–7.
75. Barnard E, Yates D, Edwards A, Fragoso-Iñiguez M, Jenks T, Smith JE. Epidemiology and aetiology of traumatic cardiac arrest in England and Wales — A retrospective database analysis. Resuscitation. 2017 Jan;110:90–4.
76. Fuller G, Hasler RM, Mealing N, Lawrence T, Woodford M, Jüni P, et al. The association between admission systolic blood pressure and mortality in significant traumatic brain injury: A multi-centre cohort study. Injury. 2014 Mar;45(3):612–7.
77. Cone DC, MacMillan DS. Mass-casualty triage systems: a hint of science. Acad Emerg Med. 2005 Aug;12(8):739–41.
78. Lerner EB, Schwartz RB, Coule PL, Weinstein ES, Cone DC, Hunt RC, et al. Mass casualty triage: an evaluation of the data and development of a proposed national guideline. Disaster Med Public Health Prep. 2013 Apr;2(S1):S25–S34.
79. Merin O, Miskin IN, Lin G, Wiser I, Kreiss Y. Triage in mass-casualty events: the Haitian experience. Prehosp Disaster Med. 2011 Oct;26(5):386–90.
80. Schultz CH. Comparing disaster triage algorithms: selecting the right metric. Ann Emerg Med. 2013 Dec;62(6):642–3.
81. Cross KP, Cicero MX. In reply. Ann Emerg Med. 2013 Dec;62(6):643–4.

82. Badiali S, Giugni A, Marcis L. Testing the START triage protocol: can it improve the ability of nonmedical personnel to better triage patients during disasters and mass casualties incidents ? Disaster Med Public Health Prep. 2017 Jun;11(3):305–9.
83. Falzone E, Pasquier P, Hoffmann C, Barbier O, Boutonnet M, Salvadori A, et al. Triage in military settings. Anaesth Crit Care Pain Med. 2017 Feb;36(1):43-51.
84. Hirsch M, Carli P, Nizard R, Riou B, Baroudjian B, Baubet T, et al. The medical response to multisite terrorist attacks in Paris. Lancet. 2015 Dec;386(10012):2535–8.
85. Kilner T, Hall FJ. Triage decisions of United Kingdom police firearms officers using a multiple-casualty scenario paper exercise. Prehosp Disaster Med. 2005 Jan;20(1):40–6.
86. Risavi BL, Salen PN, Heller MB, Arcona S. A two-hour intervention using START improves prehospital triage of mass casualty incidents. Prehosp Emerg Care. 2001 Apr;5(2):197–9.
87. Service Médical du RAID. Tactical emergency medicine: lessons from Paris marauding terrorist attack. Crit Care 2016 Feb;20:37.
88. Turner CDA, Lockey DJ, Rehn M. Pre-hospital management of mass casualty civilian shootings: a systematic literature review. Crit Care 2016 Nov;20(1):362-373.
89. Ingrassia PL, Prato F, Geddo A, Colombo D, Tengattini M, Calligaro S, et al. Evaluation of medical management during a mass casualty incident exercise: an objective assessment tool to enhance direct observation. J Emerg Med. 2010 Nov;39(5):629–36.
90. Navin DM, Sacco WJ, Waddell R. Operational comparison of the Simple Triage and Rapid Treatment Method and the Sacco Triage Method in mass casualty exercises. J Trauma Acute Care Surg. 2010 Jul;69(1):215–25.
91. Gutsch W, Huppertz T, Zollner C, Hornburger P, Kay MV, Kreimeier U, et al. Results of the mSTaRT triage from mass casualty incident exercises. Notfall Rettungsmed. 2006;9(4):384–8.
92. Hirshberg A, Frykberg ER, Mattox KL, Stein M. Triage and trauma workload in mass casualty: a computer model. J Trauma. 2010 Nov;69(5):1074-81.
93. Lerner EB, Cone DC, Weinstein ES, Schwartz RB, Coule PL, Cronin M, et al. Mass casualty triage: an evaluation of the science and refinement of a national guideline. Disaster Med Public Health Prep. 2011 Jun;5(2):129-37.
94. Cone DC, Serra J, Burns K, MacMillan DS, Kurland L, Van Gelder C. Pilot test of the SALT mass casualty triage system. Prehosp Emerg Care. 2009 Oct;13(4):536–40.
95. Deluhery MR, Lerner EB, Pirrallo RG, Schwartz RB. Paramedic accuracy using SALT triage after a brief initial training. Prehosp Emerg Care. 2011 May;15(4):526–32.
96. Nilsson A, Åslund K, Lampi M, Nilsson H, Jonson CO. Improved and sustained triage skills in firemen after a short training intervention. Scand J Trauma Resusc Emerg Med. 2015 Oct 17;23(1):81–87.
97. Cone DC, Serra J, Kurland L. Comparison of the SALT and Smart triage systems using a virtual reality simulator with paramedic students. Eur J Emerg Med. 2011 Dec;18(6):314–21.
98. Wallis LA, Carley S. Validation of the Paediatric Triage Tape. Emerg Med J. 2006 Jan;23(1):47–50.

99. Cross KP, Cicero MX. Independent application of the Sacco Disaster Triage Method to pediatric trauma patients. Prehosp Disaster Med. 2012 Aug;27(4):306–11.
100. Knotts KE, Etengoff S, Barber K, Golden IJ. Casualty collection in mass-casualty incidents: a better method for finding proverbial needles in a haystack. Prehosp Disaster Med. 2006 Nov;21(6):459–64.
101. Lehmann R, Brounts L, Lesperance K, Eckert M, Casey L, Beekley A, et al. A simplified set of trauma triage criteria to safely reduce overtriage: a prospective study. Arch Surg. 2009 Sep;144(9):853–8.
102. Haukoos JS, Byyny RL, Erickson C, Paulson S, Hopkins E, Sasson C, et al. Validation and refinement of a rule to predict emergency intervention in adult trauma patients. Ann Emerg Med. 2011 Aug;58(2):164–71.
103. Waggoner J, Carline JD, Durning SJ. Is there a consensus on consensus methodology? descriptions and recommendations for future consensus research. Acad Med. 2016 May;91(5):663–8.
104. Gracht von der HA. Consensus measurement in Delphi studies: review and implications for future quality assurance. Technological Forecasting and Social Change. 2012 Oct;79(8):1525–36.
105. Clancy M, Kilroy D, Driscoll P. Content prioritisation of the College of Emergency Medicine specialty curriculum: an exploratory study using a modified Delphi approach. Emerg Med J. 2009 Mar;26(3):180–2.
106. Hinchliffe RJ, Ribbons T, Ulug P, Powell JT. Transfer of patients with ruptured abdominal aortic aneurysm from general hospitals to specialist vascular centres: results of a Delphi consensus study. Emerg Med J. 2013 Jun;30(6):483-6.
107. Williams PL, Webb C. The Delphi technique: a methodological discussion. J Adv Nurs. 1994 Jan;19(1):180–6.
108. Beniuk K, Boyle AA, Clarkson PJ. Emergency department crowding: prioritising quantified crowding measures using a Delphi study. Emerg Med J. 2012 Oct;29(11):868–71.
109. Bisson JI, Tavakoly B, Witteveen AB, Ajdukovic D, Jehel L, Johansen VJ, et al. TENTS guidelines: development of post-disaster psychosocial care guidelines through a Delphi process. Br J Psychiatry 2010 Jan;196(1): 69–74.
110. Baxt WG, Jones G, Fortlage D. The trauma triage rule: a new, resource-based approach to the prehospital identification of major trauma victims. Ann Emerg Med. 1990;19(12):1401–6.
111. Boulkedid R, Abdoul H, Loustau M, Sibony O, Alberti C. Using and reporting the Delphi method for selecting healthcare quality indicators: a systematic review. PLoS One. 2011; 6(6):e20476–9.
112. Stordahl H, Passas E, Hopland A, Nielsen EW. Nine out of ten trauma calls to a Norwegian hospital are avoidable: a retrospective analysis. BMC Emerg Med. 2015 Feb 3;15(1):1.
113. Robinson JB, Smith MP, Gross KR, Sauer SW, Geracci JJ, Day CD, et al. Battlefield documentation of tactical combat casualty care in Afghanistan. US Army Med Dep J. 2016 Apr;(2-16):87–94.
114. Field A. Discovering statistics using IBM SPSS statistics. Fourth Edition. London: SAGE; 2014.

115. Overbay A, Osborne JW. The power of outliers (and why researchers should ALWAYS check for them). Practical Assessment, Research & Evaluation. 2004 Mar;9(6):1–8.
116. Poulton TJ. ATLS paradigm fails. Ann Emerg Med. 1988 Jan;17(1):107.
117. Deakin CD, Low JL. Accuracy of the Advanced Trauma Life Support guidelines for predicting systolic blood pressure using carotid, femoral, and radial pulses: observational study. BMJ. 2000 Sep;321(7262):673–4.
118. Rossaint R, Bouillon B, Cerny V, Coats TJ, Duranteau J, Fernández-Mondéjar E, et al. The European guideline on management of major bleeding and coagulopathy following trauma: fourth edition. Crit Care. 2016 Apr;20(1):100.
119. Hasler RM, Nuesch E, Jüni P, Bouamra O, Exadaktylos AK, Lecky F. Systolic blood pressure below 110 mm Hg is associated with increased mortality in blunt major trauma patients: multicentre cohort study. Resuscitation. 2011 Sep;82(9):1202–7.
120. Hasler RM, Nuesch E, Jüni P, Bouamra O, Exadaktylos AK, Lecky F. Systolic blood pressure below 110 mmHg is associated with increased mortality in penetrating major trauma patients: Multicentre cohort study. Resuscitation. 2012 Apr;83(4):476–81.
121. Shi Q, Pavey ES, Carter RE. Bonferroni-based correction factor for multiple, correlated endpoints. Pharm Stat. 2012 Jul;11(4):300–9.
122. Armstrong RA. When to use the Bonferroni correction. Ophthalmic Physiol Opt. 2014 Sep;34(5):502–8.
123. Vassallo J, Beavis J, Smith JE, Wallis LA. Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT). Injury. 2017 May;48(5):992–9.
124. Eastridge BJ, Salinas J, Mcmanus JG, Blackburn L, Bugler EM, Cooke WH, et al. Hypotension begins at 110 mm Hg: redefining "hypotension" with data. J Trauma. 2007 Aug; 63(2):291–7.
125. Rehn M, Eken T, Krüger AJ, Steen PA, Skaga NO, Lossius HM. Precision of field triage in patients brought to a trauma centre after introducing trauma team activation guidelines. Scand J Trauma Resusc Emerg Med. 2009 Jan;17(1):1.
126. Kehoe A, Smith JE, Edwards A, Yates D, Lecky F. The changing face of major trauma in the UK. Emerg Med J. 2015 Dec;32(12):911–5.
127. Vassallo J, Smith J, Bouamra O, Lecky F, Wallis LA. The civilian validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to primary major incident triage. Emerg Med J. 2017 Dec;34(12):810-815.
128. Royston P. Multiple imputation of missing values: further update of ice, with an emphasis on interval censoring. The Stata Journal. 2007 Dec; 7 (4):445-464.
129. Vassallo J, Horne S, Smith JE, Wallis LA. The prospective validation of the Modified Physiological Triage Tool (MPTT): an evidence-based approach to major incident triage. J R Army Med Corps. 2017 Dec; 163(6):383-387.
130. Vassallo J, Smith JE, Wallis LA. Investigating the effects of under-triage by existing major incident triage tools. Eur J Emerg Med. 2017 Nov. doi: 10.1097/MEJ.0000000000000513.

131. Gill M, Martens K, Lynch EL, Salih A, Green SM. Interrater reliability of 3 simplified neurologic scales applied to adults presenting to the emergency department with altered levels of consciousness. Ann Emerg Med. 2007 Apr;49(4):403–407.
132. McNarry AF, Goldhill DR. Simple bedside assessment of level of consciousness: comparison of two simple assessment scales with the Glasgow Coma scale. Anaesthesia. 2004 Jan;59(1):34–7.
133. HM Coroner's Office. Coroner's Inquests into the London Bombings of 7 July 2005. The Rt. Hon. Lady Justice Hallett. May 2011. http://webarchive.nationalarchives.gov.uk/20120216072447/http://7julyinquests.independent.gov.uk/docs/orders/rule43-report.pdf (accessed Jan 2017)
134. Vassallo J, Smith JE, Wallis LA. Major incident triage and the implementation of a new triage tool, the MPTT-24. J R Army Med Corps. 2017 Oct: doi: 10.1136/jramc-2017-000819.
135. Glas AS, Lijmer JG, Prins MH, Bonsel GJ, Bossuyt PM. The diagnostic odds ratio: a single indicator of test performance. J Clin Epidemiol. 2003 Nov;56(11):1129–35.
136. Mølgaard RR, Larsen P, Håkonsen SJ. Effectiveness of respiratory rates in determining clinical deterioration: a systematic review protocol. JBI Database System Rev Implement Rep. 2016 Jul;14(7):19–27.
137. Craigie R J, Farrelly P J, Santos R, Smith S R, Pollard J S, Jones D J. Manchester Arena bombing: lessons learnt from a mass casualty incident. J R Army Med Corps. 2018. Epub ahead of print: 10 April 2018. Doi:10.1136/jramc-2018-000930
138. Little RA, Kirkman E, Driscoll P, Hanson J, Mackway-Jones K. Preventable deaths after injury: why are the traditional "vital" signs poor indicators of blood loss? J Accid Emerg Med. 1995 Mar;12(1):1–14.

Appendix 1: TARN inclusion criteria

2. Standards of practice

2.1 INCLUSION CRITERIA

The decision to include a patient should be based on the following points:

A. ALL TRAUMA PATIENTS IRRESPECTIVE OF AGE

B. WHO FULFILL THE FOLLOWING LENGTH OF STAY CRITERIA

DIRECT ADMISSIONS	PATIENTS TRANSFERRED IN
Trauma admissions whose length of stay is 72 hours or more OR Trauma patients admitted to a High Dependency Area regardless of length of stay OR Deaths of trauma patients occurring in the hospital including the Emergency Department (even if the cause of death is medical) OR Trauma patients transferred to other hospital for specialist care or for an ICU/HDU bed.	Trauma patients transferred into your hospital for specialist care whose combined hospital stay at both sites is 72 hours or more OR Trauma admissions to a ICU/HDU area regardless of length of stay OR Trauma patients who die from their injuries (even if the cause of death is medical) OR Patients transferred in for rehabilitation only do not need to be submitted to TARN.

C. AND WHOSE INJURIES MEET THE FOLLOWING CRITERIA

INJURY	INCLUDED	EXCLUDED
BURN	Any full thickness burn. Partial or superficial burn ≥10% body surface area.	Partial or superficial burn <10% body surface area.
FACIAL FRACTURE	Documented as displaced, open, compound or comminuted.	Simple, stable fracture.
FEMORAL FRACTURE	Shaft, condyle, supracondylar or head. Neck of femur < 65 years old.	Neck of femur ≥65 years.
FOOT OR TOE: JOINT OR BONE	Massive destruction or crush injury.	Any combination of the following: Foot fracture, any number of fractured toes, metatarsals &/or tarsals, dislocated phalanges or inter-phalangeal joints, subtalar, transtarsal or transmetatarsal joints.

HAND OR FINGER: JOINT OR BONE	Massive destruction or crush injury.	Any combination of the following: Fractured hand, any number of fractured fingers, carpal or metacarpal, carpel-metacarpal, metacarpal-phalangeal or interphalangeal dislocation.
INHALATION	All included	
JOINTS (excluding hands or feet)	Dislocation, with or without fracture.	Sprain, contusion or laceration to joint.
LIMB FRACTURE (excluding femur)	Documented as displaced, open, compound or comminuted.	Simple stable fracture.
MUSCLE, TENDON OR LIGARMENT		All injuries to muscles, tendons & ligaments, alone or in combination with other muscles, tendons, ligaments injuries.
NERVE	Any injury to sciatic, facial, femoral or cranial nerve.	All other nerve injuries, single or multiple.
PELVIS	Sacrum, coccyx, acetabulum, ilium, ischium, sacro-ilium or symphysis pubis or pubic rami fractures.	Single pubic rami fracture ≥65 years old.
SKIN	Laceration or penetrating skin injuries with blood loss >20% (1litre) or with damage to underlying vessel, bone or organ. Degloving injury.	Simple skin lacerations or penetrating injuries with blood loss < 20% (1litre) and no damage to internal organs or vessels: single or multiple. Contusions or abrasions: single or multiple.
SPINE	Cord injury, fracture, dislocation or nerve root injury.	Spinal strain or sprain.
VESSEL	Any injury to femoral, neck, facial or cranial vessel. Transection or major laceration. Any other vessel injury with blood loss >20%.	Intimal tear or superficial laceration or perforation of any other vessel with <20% blood loss.

The above examples are shown for clarity and apply to injuries in isolation (except where highlighted in red) or where accompanied by skin injuries only.

Appendix 2: University of Cape Town HREC original approval

UNIVERSITY OF CAPE TOWN

Faculty of Health Sciences
Human Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • **Facsimile** [021] 406 6411
e-mail: lamees.emjedi@uct.ac.za
Website address: http://www.health.uct.ac.za/research/humanethics/forms/

28 May 2013

HREC REF: 285/2013

Dr J Vassallo
Emergency Medicine
J Floor
Surgery

Dear Dr Vassallo

PROJECT TITLE: MAJOR INCIDENT TRIAGE: DEVELOPMENT AND VALIDATION OF A MODIFIED PRIMARY TRIAGE TOOL

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee

It is a pleasure to inform you that the Ethics Committee has **formally approved** the above-mentioned study.

Approval is granted until 28 May 2014.

Please submit to the HREC a Progress Report Form if the study continues beyond the approval period. Please submit a Closure Report Form on completion of the study. (Forms can be found on our website: http://www.health.uct.ac.za/research/humanethics/forms/

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please quote the REC. REF in all your correspondence.

Yours sincerely

PROFESSOR MARC BLOCKMAN
CHAIRPERSON, FHS human research ethics committee

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

Lemjedi

Appendix 3: NHS England Clinical Guidelines for Major Incidents (Adult triage)

Casualty triage (adult)

Introduction

- The aim of primary major incident triage is to identify those in need of life-saving intervention (see table overleaf).
- When using Modified Physiological Triage Tool 24 (MPTT-24), some casualties will be over-triaged and early secondary assessment from a senior clinician is required.

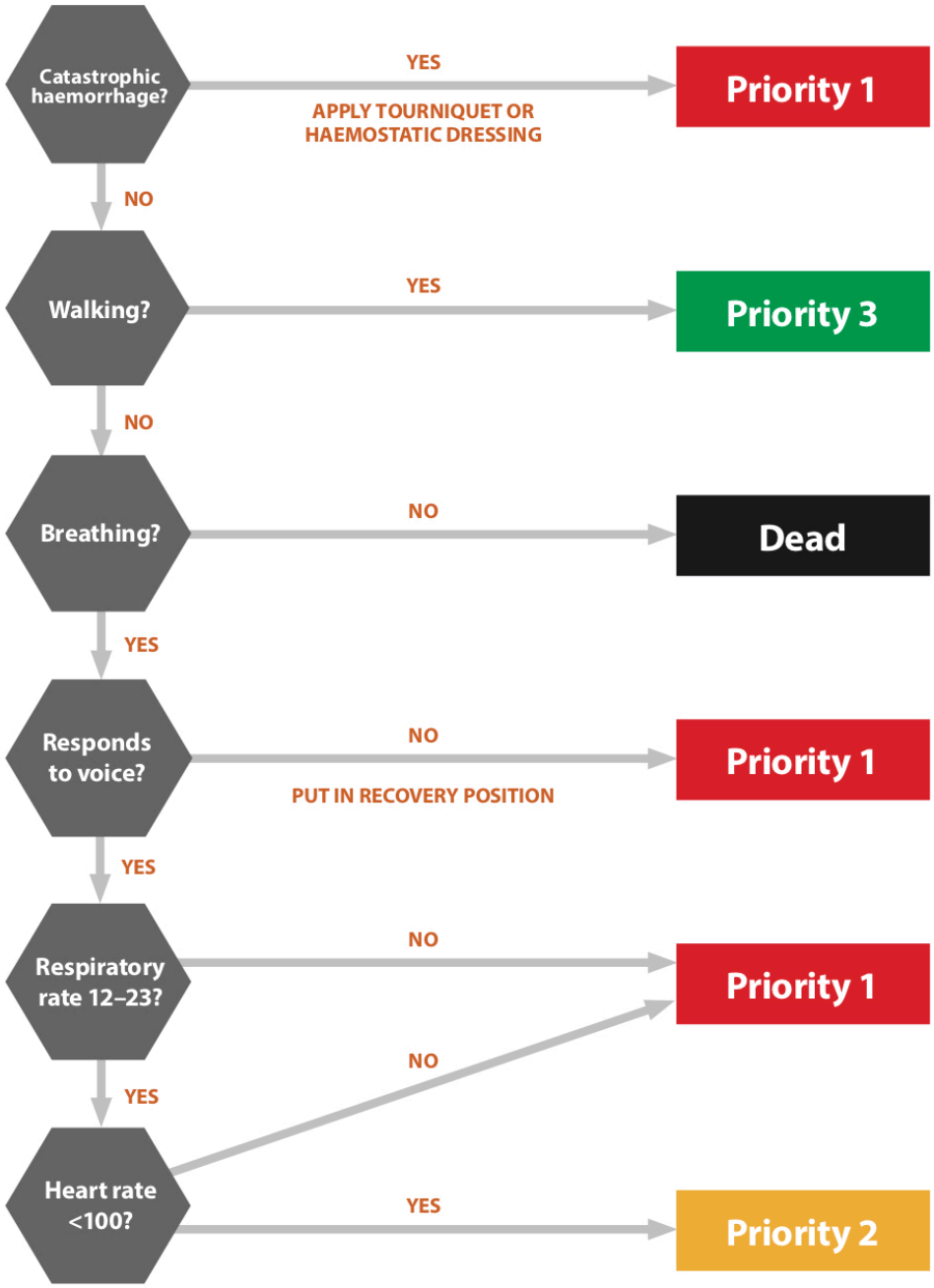


Figure 1: Modified Physiological Triage Tool 24 (MPTT-24). Vassallo 2017 CC BY 4.0

Rationale for the MPTT-24

- Can be completed by inexperienced personnel in 30 seconds
- The MPTT-24 is designed to **minimise under-triage**.

Casualty triage (adult)

1	Intubation for actual or impending airway obstruction
2	Surgical airway for actual or impending airway obstruction
3	Thoracostomy (needle/finger/tube)
4	Application of a chest seal (commercial/improvised)
5	Positive pressure ventilation for ventilatory inadequecy
6	Application of a tourniquet for haemorrhage control
7	Use of haemostatic agents for haemorrhage control
8	Insertion of an intra-osseous device for resuscitation purposes
9	Receiving un-crossmatched blood
10	Recieving ≥4 units of blood/blood products
11	Administration of tranexamic acid
12	Laparotomy for trauma
13	Thoracotomy or pericardial window
14	Surgery to gain proximal vascular control
15	Interventional radiology for haemorrhage control
16	Application of a pelvic binder
17	ALS/ALS for a patient in a peri-arrest/cardiac arrest situation
18	Neurosurgery for the evacuation of an intra-cranial haematoma
19	Craniotomy/Burr hole insertion
20	Spinal nursing for a C1–3 fracture
21	Administration of a seizure-terminating medication
22	Active/passive rewarming for initial core temp <32ºC
23	Correction of low blood glucose
24	Administration of chemical antidotes

Evidence shows that the NARU Sieve and MIMMS Triage Sieve have poor sensitivity at predicting the need for life-saving intervention resulting in high numbers of casualties being under-triaged as Priority 2.

The MPTT was derived specifically to identify those in need of life-saving intervention and is a combination of Heart Rate (>100), Respiratory Rate (<12 or >=22) and Glasgow Coma Scale (<14).

Calculating a GCS can be time-consuming and its success is reliant on user familiarity and experience. The AVPU scale is a quicker assessment, and studies have shown that 'responds to voice' correlates to a median GCS of 13 (the original MPTT used GCS <14).

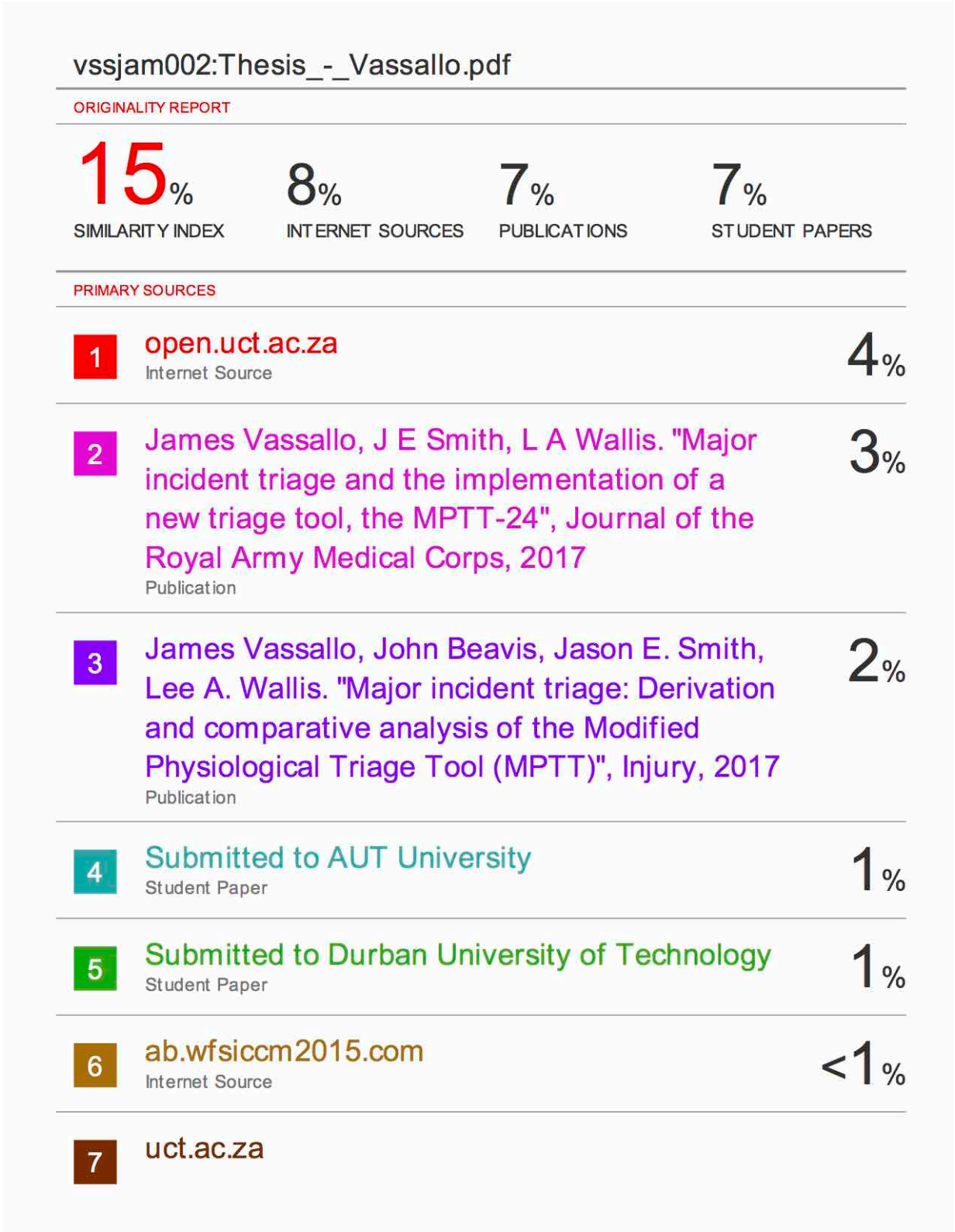
The MPTT-24 (Figure 1) is a pragmatic application of the MPTT and incorporates an assessment of catastrophic haemorrhage, a higher upper respiratory rate threshold and a conscious level assessment using the AVPU scale.

These changes allow the triage tool to be more easily calculable in a shorter period of time (within 30 seconds) and also allows the tool to be used by those with little clinical experience.

Whilst the MPTT-24 demonstrates optimum performance at identifying those in need of life-saving intervention with considerably lower rates of under-triage, this does come at the expense of OVER-TRIAGE.

A greater proportion of casualties will be categorised as Priority 1 – therefore at the earliest opportunity, within a permissive setting, early secondary assessment by a senior decision maker is required to review those categorised as Priority 1 by the MPTT-24.

Appendix 4: Turnitin originality report



vssjam002:Thesis_-_Vassallo.pdf

ORIGINALITY REPORT

15%	8%	7%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	open.uct.ac.za Internet Source	4%
2	James Vassallo, J E Smith, L A Wallis. "Major incident triage and the implementation of a new triage tool, the MPTT-24", Journal of the Royal Army Medical Corps, 2017 Publication	3%
3	James Vassallo, John Beavis, Jason E. Smith, Lee A. Wallis. "Major incident triage: Derivation and comparative analysis of the Modified Physiological Triage Tool (MPTT)", Injury, 2017 Publication	2%
4	Submitted to AUT University Student Paper	1%
5	Submitted to Durban University of Technology Student Paper	1%
6	ab.wfsiccm2015.com Internet Source	<1%
7	uct.ac.za	

Prof. Lee A. Wallis

16th February 2018

	Internet Source	<1%
8	Submitted to University of Cape Town Student Paper	<1%
9	www.epu.jpm.my Internet Source	<1%
10	ccforum.com Internet Source	<1%
11	mebe3.iespana.es Internet Source	<1%
12	"8-K: Vicor Technologies, Inc.", EDGAR Online-8-K Glimpse, August 6 2010 Issue Publication	<1%
13	"New Injury Research Findings from J. Vassallo and Co-Researchers Reported (UK Triage the validation ", Health & Medicine Week, March 6 2015 Issue Publication	<1%
14	Submitted to Anglia Ruskin University Student Paper	<1%
15	www.svhm.org.au Internet Source	<1%
16	library.wur.nl Internet Source	<1%

Prof. Lee A. Wallis

16th February 2018

17	env-shuenwan.com Internet Source	<1%
18	Submitted to University of Cumbria Student Paper	<1%
19	www.researchgate.net Internet Source	<1%
20	arrow.monash.edu.au Internet Source	<1%
21	www.biomedcentral.com Internet Source	<1%
22	Submitted to University of Salford Student Paper	<1%
23	www.amr.net Internet Source	<1%
24	"Researchers at Oregon Health & Science University, Center for Policy and Research in Emergency Medic", Biotech Week, Sept 3 2008 Issue Publication	<1%
25	xa.yimg.com Internet Source	<1%
26	www.samj.org.za Internet Source	<1%
	arldocdel.iii.com	

Prof. Lee A. Wallis

16th February 2018

27	Internet Source	<1%
28	Aylwin, Christopher J. Konig, Thomas C. . "Reduction in critical mortality in urban mass casualty incidents: analysis of triage, surge, and res", The Lancet, Dec 23 2006 Issue Publication	<1%
29	Nikolov, Boyan(Raschke, Michael J.). "Übersetzung der verletzungsbezogenen Kodes des XIX. Kapitels der ICD-10-GM 2008 in AIS 2005", Münster University, Germany, Document Server, 2010. Publication	<1%
30	www.dmphp.org Internet Source	<1%
31	pdm.medicine.wisc.edu Internet Source	<1%
32	www.e-semble.com Internet Source	<1%
33	www.tsgassociates.co.uk Internet Source	<1%
34	Paz-Garcia, David A. Chavez-Romo, Hector. "Genetic connectivity patterns of corals Pocillopora damicornis and Porites panamensis (anthozoa: scl", Pacific Science, Jan 2012 Issue Publication	<1%

Prof. Lee A. Wallis

16th February 2018

35	"New Medical Research Data Have Been Reported by Investigators at Uniformed Services University of th", Health & Medicine Week, June 3 2016 Issue Publication	<1%

Exclude quotes	On	Exclude matches	< 12 words
Exclude bibliography	On		

Prof. Lee A. Wallis

16th February 2018