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THE CIVILIAN VALIDATION OF THE MODIFIED PHYSIOLOGICAL TRIAGE TOOL (MPTT), AN EVIDENCE BASED APPROACH TO PRIMARY MAJOR INCIDENT TRIAGE.

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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) demonstrated improved performance at predicting the need for LSI. Using a civilian trauma registry, this study aimed to validate the MPTT in a civilian environment.

METHODS:

A retrospective database review was undertaken of the Trauma Audit Research Network (TARN) database for all adult patients ($\geq$18 years) between 2006-2014. Patients were defined as Priority One if they received one or more life-saving interventions from a previously defined list. Using first recorded hospital physiological data, patients were categorised by the MPTT and existing primary physiological triage tools. Only patients with complete physiological data were included in the analysis. Performance characteristics were evaluated using sensitivity, specificity and AUROC.

RESULTS:

During the study period 218,985 adult patients were included in the TARN database. 127,233 (58.1%) had complete data and were included in the final analysis: 55.6% were male, aged 61.4 (IQR 43.1-80.0 years), ISS 9 (IQR 9-16), 96.5% suffered blunt trauma and 24,791 (19.5%) were Priority One.

The MPTT (sensitivity 57.6%, 95% CI 0.569-0.582, specificity 71.5%, 95% CI 0.712-0.718) outperformed all existing triage methods with a 44.7% absolute reduction in under-triage compared to existing UK civilian methods. Comparison of the AUROC demonstrated statistical significance supporting the use of the MPTT over other tools (χ^2=484.55, p<0.001.

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 civilian trauma registry population. We recommend that its use within a civilian major incident context be considered.

KEYWORDS:

Triage, major incidents, life-saving interventions, physiological parameters

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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 (MTFAs), 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 1 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 under-triage rate of 50%. [11]

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 under-triage (30.1%) whilst minimising rates of over-triage (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).

Method	1st Assessment	2nd Assessment	3rd Assessment	4th Assessment
START (United States)	Walking?	Breathing? Rate >29	Palpable Pulse?[1]	Obeys Commands?[2]
Careflight (Australia)	Walking?	Obeys Commands?[2]	Breathing? Palpable Radial Pulse?[1]	
Triage Sieve (UK & International)	Walking?	Breathing? <10 Rate >30	Heart Rate >120	
Military Sieve (United Kingdom)	Walking?	Breathing? <10 Rate >30	Heart Rate >120	Unconscious?[2]
Modified Physiological Triage Tool	Walking?	Breathing? <12 Rate $\geq$ 22	Heart Rate $\geq$ 100	GCS < 14
A patient is designated as Priority 1 if the patient is unable to walk, and if any of the assessments conducted afterwards are positive.				

Table 1: Comparison of existing triage tools [5,12]

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; whilst 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.

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[1] A systolic blood pressure measurement of 90mmHg was used as a surrogate measure to represent presence of a palpable pulse

[2] A GCS < 13 was used as a surrogate for unconsciousness or the inability to obey commands.

METHODS:
A retrospective database review was undertaken using the TARN database from 1 January 2006 to 31 December 2014. All adult ($\geq$18 years) trauma patients 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, Wales and the Republic of Ireland. 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 trauma patients admitted to hospital $\geq$ 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. 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 heart rate > 170 beats per minute, respiratory rate > 45 breathes per minute, systolic blood pressure > 206mmHg 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. [7] Using first recorded Emergency Department 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 (**supplementary table 2**). 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 90mmHg was used to 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, under-triage (1-sensitivity) and over-triage (1-positive predictive value) with 95% confidence intervals were calculated. Using a McNemar test, tools with similar performance characteristics were evaluated for any statistically significant difference in performance. [15] Receiver operator characteristic (ROC) curves were mapped for all tools with calculation of the area under the ROC curve (AUROC). Tools with similar AUROC were compared using the method of DeLong et al. [16]

Statistical Package for the Social Sciences (SPSS) Version 23.0 (SPSS Inc., Chicago, Illinois, USA) and STATA Version 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, 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 imputation under a missing at random (MAR) assumption using chained equations. [17] A comparative analysis was performed on the imputed data set. 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 5 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 2 breakdown). Median age was 61.4 years (IQR 43.1-80.0 years) with males accounting for 55.6% cases (n=70,747).

Figure 1: Study flow diagram

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

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

With an absolute increase in AUROC of 0.035, comparison of the AUROC indicated statistically significant improvement in performance of the MPTT over the Military Sieve (χ^2=484.55, p<0.001). Using a McNemar test with Bonferroni correction, a statistically significant difference in performance was again observed between the MPTT and the Military Sieve (χ^2=30,405, p<0.001) and the MPTT and the Triage Sieve (χ^2= 36,804, p<0.001).

No of patients	127,233
Gender (n (%))	
Male	70747 (55.6%)
Female	56486 (44.4%)
ISS (Median (IQR))	9 (9-16)
Age (years) (Median (IQR))	61.4 (43.1-80.0)
30 Day Outcome (n (%))	
Alive	119967 (94.3%)
Dead	7266 (5.7%)
Mode of Injury (n (%))	
Blunt	122802 (96.5%)
Penetrating	4431(3.5%)
Mechanism of injury (n (%))	
RTC	27915 (21.9%)
Crush	935 (0.7%)
Amputation (Total + Partial)	123 (0.1%)
Fall > 2m	18141 (14.3%)
Fall < 2m	68354 (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	13402 (7.1%)
Head	30167 (15.9%)
Limb	73755 (38.9%)
Spine	28942 (15.3%)
Thorax	31499 (16.6%)
Other	3731 (2.0%)
Priority One (N (%))	
Priority One	24791 (19.5%)
Not Priority One	102442 (80.5%)
LSI by type (n (% total LSI))	42610
Intubation and ventilatory support	8813 (20.7%)
Blood Administration ($\geq$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	1503 (3.5%)
Spinal Nursing	3114 (7.3%)
Seizure termination	390 (0.9%)
Low BM correction	83 (0.2%)
Re-Warming	471 (1.1%)

Table 2: Characteristics of Study Population

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%)

Table 3: Triage tool summary of results

Model	AUROC (95% CIs)	Sensitivity (95% CIs)	Specificity (95% CIs)	PPV	NPV	Under-triage (1-sens)	Over-triage (1-ppv)
MPTT	0.645 (0.642-0.649)	57.6% (56.9-58.2%)	71.5% (71.2-71.8%)	32.9% (32.4-33.3%)	87.4% (87.2-87.7%)	42.4%	67.1%
Military Sieve	0.610 (0.608-0.613)	28.0% (27.5-28.6%)	94.1% (93.9-94.2%)	53.3% (52.5-54.2%)	84.4% (84.2-84.6%)	72.0%	56.7%
Triage Sieve	0.548 (0.546-0.550)	12.9% (12.5-13.4%)	96.7% (96.5-96.8%)	48.4% (47.2-49.6%)	82.1% (81.9-82.3%)	87.1%	51.6%
START	0.616 (0.613-0.618)	28.8% (28.2-29.4%)	94.3% (94.2-94.4%)	55.0% (54.2-55.9%)	84.6% (84.3-84.8%)	71.2%	45.0%
Careflight	0.597 (0.595-0.600)	23.6% (23.1-24.1%)	95.9% (95.7-96.0%)	57.9% (57.0-58.9%)	83.8% (83.6-84.0%)	76.4%	42.1%

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*

Table 4: Test characteristics

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 vs complete (55 vs 61 years and 62.2% vs 55.6% male). 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 is provided as **supplementary table 1.**

SUBGROUP ANALYSIS

Injury Type

Patients sustaining penetrating trauma received a greater number of life-saving interventions when compared to blunt trauma (62.7% vs. 17.9%). Rates of under-triage 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 under-triage, with the highest over-triage 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 <2m 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 under and over-triage throughout all age groups, with the MPTT having the lowest rate of under-triage across all age groups, albeit at the expense of over-triage. (**Supplementary Figure 1: Relationship between triage tool performance and age range.)**

Gender

Large differences in over-triage rates were observed for all triage tools, ranging from an additional 15.5% (MPTT) to 19.2% (Careflight). By comparison, under-triage 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.

Whilst 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 recognize 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 in table 1 are recorded as variables in the TARN database, requiring us to use a number of surrogates in order to conduct the study **(supplementary table 2)**. These surrogates were chosen to represent the closest approximation to the life-saving interventions required. Whilst our final study population is large (127,233 patients), we acknowledge that an additional limitation is the exclusion of those with incomplete physiological data. Whilst 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 (8 and 2 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]

Whilst 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 observed.

	Current Study	Derivation Study	Garner	Challen	Horne
Triage Sieve – Sens/Spec	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 – Sens/Spec	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 – Sens/Spec	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 Sens/Spec	28% (28-29%) 94% (94-94%)	44% (42-46%) 94% (92-95%)			63% (57-70%) 82% (76-89%)
MPTT – Sens/Spec	58% (57-58%) 72% (71-72%)	70% (68-72%) 65% (63-68%)			

Table 4: Comparative analysis by study[5,9,12,20]

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 (over-triage) or lower (under-triage) 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 over and under-triage.

The MPTT, derived using individual logistical regression models for each physiological parameter, had the lowest rate of under-triage and approximately equal rates of over and under-triage (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 (under/over-triage). Whilst the effects of under-triage are clearly apparent (failing to identify a patient in need of a life-saving intervention), over-triage in itself can be harmful as well. Previous studies have shown that a consequence of over-triage is the potential to overwhelm hospital resources, with a direct association between over-triage and critical mortality. [21,22] This is a key difference between major incidents and routine clinical practice, where a form of triage occurs for every patient in the emergency department (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 over-triage).

Current guidance for major incident triage simply states that rates of under and over-triage should be kept as low as possible. [23] By contrast, for the triage of individual patients to major trauma centres, a threshold of 35% over-triage and 5% under-triage is recommended. [23] 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. Whilst the rate of under-triage demonstrated by the MPTT is the lowest of all existing triage tools, it does come at the expense of increased over-triage. Although the highest of all triage tools (67.1%), the MPTT's over-triage rate is comparable to that encountered overall following the London 7/7 bombings (64%). [21] However, whilst this level of over-triage 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 and in those settings with a less developed EMS response.[24]

The MPTT showed the highest sensitivity 57.6% (95% CI 56.9-58.2%) at predicting the need for life-saving intervention with an absolute increase of 44.7% over the existing Triage Sieve 12.9% (95% CI 12.5-13.4%). Throughout the subgroup analysis, the performance of the MPTT was superior to all existing triage tools in terms of minimising under-triage. A reduction in MPTT sensitivity is observed when compared to the derivation study (42.4% vs. 35.1%). This is likely to be multi-factorial, 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 under-triage, whilst maintaining an acceptable level of over-triage. 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.

1 Lennquist S. Medical Response to Major Incidents and Disasters. In: Lennquist S, ed. *Chapter 2: Major Incidents: Examples and Experiences*. Berlin, Heidelberg: : Berlin Heidelberg 2012.

2 Advanced Life Support Group, Carley S, Mackway-Jones K, editors. Triage. In: *Major Incident Medical Management And Support*. 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.* MacLachlan Stewart and Co. Edinburgh. 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**:424–430.

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 (2008). *Comparative validation of major incident triage systems. MRes thesis.* University of Manchester.

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**(5):992-999.

13 Kehoe A, Smith JE, Edwards A, *et al.* The changing face of major trauma in the UK. *Emergency Medicine Journal* 2015;**32**:911–5.

14 Clinical Guidelines for Operations. 2012;:1–244.

15 Hazra A, Gogtay N. Biostatistics series module 4: Comparing groups - categorical variables. *Indian J Dermatol* 2016;**61**:385–9.

16 N S, Islam A, Hossain A. Evaluation and computation of diagnostic tests: a simple alternative. *Bulletin of the Malyasian Mathematical Society* 2012;**37**:411–

23.

17 Press S. The Stata Journal. 2007;:1–11.

18 Cross KP, Cicero MX. Head-to-Head Comparison of Disaster Triage Methods in Pediatric, Adult, and Geriatric Patients. *YMEM* 2013;**61**:668–676.

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 Horne S, Vassallo J, Read J, *et al.* UK triage--an improved tool for an evolving threat. *Injury* 2013;**44**:23–8.

21 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.

22 Frykberg ER, Tepas JJ. Terrorist bombings. Lessons learned from Belfast to Beirut. *Ann Surg* 1988;**208**:569–76.

23 American College of Sureons. *Resources for optimal care of the injured patient*. Chicago, IL. American College of Surgeons 2014.

24 Frykberg ER. Medical management of disasters and mass casualties from terrorist bombings: how can we cope? *J Trauma* 2002;**53**:201–12.