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Research Article

Statistical Analysis to Quantify the Usefulness of Triage Criteria in Predicting Seriously Injured Patients in Order to Refine Criteria for Activating Level One or Level Two Trauma Calls

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Abstract

Background: A trauma triage system uses numerous variables to activate trauma calls and is important for facilitating rapid diagnosis and treatment whilst ensuring optimal resource allocation. This project involved the use of retrospective statistical analysis to quantify the usefulness of various triage criteria in predicting severely injured patients. Following this, the objective was to refine the criteria for activating level one or level two trauma calls in the Wessex Trauma Network (WTN).

Methods: All patients directly admitted to hospitals in the WTN either with or without Trauma Team Activation (TTA) were investigated retrospectively from 2013-2014 (n=4267). Different TTA criteria were analyzed with respect to sensitivity, under-triage, specificity, positive/negative predictive values and over-triage. The current triage criteria were compared to a proposed revised set of criteria.

Results: For the TTA criteria currently in use at UHS, the sensitivity was 87.42% and the over-triage 45.23% when using ISS>15 as a standard of reference for major trauma. In general, physiological criteria were the most powerful predictors of severe injury, with mechanism of injury (MOI) criteria contributing the most to over-triage. The proposed revised set of criteria was retrospectively applied to the data for patients directly admitted to UHS in 2013/14(n=800), resulting in a sensitivity of 85.31% and over-triage of 30.75%.

Conclusion: Findings showed that a simplified revised set of TTA criteria utilizing predominantly physiological and anatomical criteria can safely reduce over-triage without a substantial decrease in sensitivity. There will always be a degree of under-triage, however it is possible to minimize it.

ABBREVIATIONS

TARN: Trauma Audit and Research Network) - a national organisation that collects and processes data on moderately and severely injured patients in England and Wales; WTN: Wessex Trauma Network - a regional network comprising all hospitals in the Wessex area along with the region's ambulance trusts; MTC: Major Trauma Centre – a hospital equipped and staffed to provide care for patients suffering from major traumatic injuries; UHS - University Hospital of Southampton; MOI: Mechanism of Injury – the circumstance in which an injury occurs, for example, high fall, road traffic collision, penetrating injury; GCS: Glasgow Coma Scale– the summation of scores for eye, verbal and motor responses, used to describe the level of consciousness of a person following traumatic brain injury; ED: Emergency Department; ISS: Injury Severity Score - is an anatomical scoring system that provides an overall score for patients with multiple injuries

INTRODUCTION

In England, trauma is the leading cause of death in people under the age of 40, highlighting the importance for the need of high quality of care from multiple specialists [1]. Major trauma networks are structured groups of personnel and services with the objective of reducing mortality and morbidity following trauma. They have improved the quality of care for severely injured patients since they allow patients to be seen by the most appropriate personnel immediately upon admission.

The involvement of the correct personnel enables hospitals to reach patient care standards and hence generate more income. Regional trauma networks were first introduced in the UK in 2012 facilitating safe and efficient delivery of patients to designated Major Trauma Centres (MTC) in the country, the University Hospital of Southampton (UHS) being one of these. The Wessex trauma network (WTN) includes eight hospitals in the Wessex region and all of the ambulance and air ambulance trusts [2].

An independent audit by the 'Trauma Audit and Research Network' (TARN) showed that following the introduction of MTC's, 1 in 5 patients who would have died from severe injuries are now surviving, a 20 per cent improvement [1]. Trauma triage systems seek to provide this level of care to those requiring it whilst preventing the inappropriate use of financial and personnel resources. The activation of a multi-disciplinary team is an integral part of the trauma care system and has been shown to improve outcomes. The current Adult Major Trauma Team Activation System at the University Hospital Southampton, and in fact all other hospitals in the network, work on a two-tier response to trauma calls. The generation of a level one trauma call will alert a full trauma team response, whereas a level two trauma call for less severe trauma, will alert the Emergency Department trauma team alone. Hence, the primary reason for stratifying is to minimise the unnecessary disruption to other emergency work taking place. For every level one trauma call that is made, orthopaedic, general and anaesthetic specialists along with numerous other healthcare professionals, must attend therefore causing inevitable disruption and impact to other on-call workload.

The Injury Severity Score (ISS) is a complex scale used to assess the severity of trauma. It was designed by the 'Abbreviated Injury Scale (AIS) committee of the Association for the Advancement of Automotive Medicine' using consensus data. A major trauma or a poly-trauma is classified by the ISS exceeding a score of 15 [3-5].

Trauma team activations (TTA) are based upon information passed to the Emergency department in a pre-alert and aid the department in deciding which call to put out (level one or two). There are a series of criteria that activate a level one trauma call involving physiological, anatomical and mechanism of injury, criteria of which are numerous (e.g.: GCS <10 or Road traffic accident etc). If pre-hospital information meets at least one of the TTA criteria then the trauma team will be activated [6]. Several studies have investigated the criteria for TTA [8-15]. However it has often been challenging to define an optimal set of criteria since there are many factors which play a determining role: pre-morbidity, mechanism of injury, the extent of injury, patient heterogeneity) [7-16]. Many systems use a variation of the recommended field triage criteria in the guidelines of the 'American College of Surgeons - Committee on Trauma', including physiological, mechanism of injury and anatomical criteria. Mechanism of injury criteria allows identification of additional severely injured patients that may not display physiological signs so hence would not have been picked up otherwise. However the use of MOI criteria has a tendency to over-triage and incorrectly identify patients as severely injured [17]. Ideal trauma team activation criteria should work effectively to initiate the appropriate level of trauma response by activating either a level one or level two trauma call. It is therefore important that the criteria is sensitive in order to minimise under triage but also specific in order to minimise over triage also. The use of triage activation criteria brings about a trade off between over-triaging (activating a level one trauma call when not entirely necessary) and under-triaging (not activating the call when the patient would have needed or benefited from it). 'The American College of Surgery – Committee on Trauma' state in their guidelines that in general, priority should be given to decreasing under-triage since it can result in preventable mortality or morbidity resulting from delays in definitive care. Under-triaging can delay diagnosis and treatment of severely injured patients and hence worsen prognosis and increase mortality. There will always be an element of over-triaging which is very disruptive, especially in smaller hospitals with fewer staff and resources. The predominant problem with over-triaging is resource allocation, since members of the multi-disciplinary trauma team will be diverted away from the work load of their day to day specialities, which can in turn compromise the care of other patients and increase hospital costs. Unfortunately, attempts to decrease over-triage are likely to come at the cost of an increase in under-triage. Therefore it is necessary that trauma centres find a balance between utilising scarce resources and the requirement for acute care in severely injured patients [7-11,17].

A repeating trend amongst other studies assessing efficacy of activation criteria in predicting major trauma is that Mechanism of injury(MOI) criteria has a lower predictive value and sensitivity, contributing the most to over-triage and an unnecessary use of resources [7,9,10,12]. However, this does not rule out the possibility that some individual MOI criteria might possess significant predictive power alone [9]. A study conducted by the American college of surgeons discovered that physiological criteria was the most powerful at predicting severely injured patients (ISS >15) [10]. On the contrary, multiple studies have found that the frequently used physiological variable of heart rate is not a powerful predictor of severely injured patients. It is likely that this is due to the large number of associating factors that can influence heart rate (e.g.: level of fitness, fever, alcohol use, etc [12,19].

The aim of this report is to use retrospective statistical analysis to quantify the usefulness of various triage criteria in predicting seriously injured patients. This is in order to refine criteria for activating level one or level two trauma calls within the Wessex Trauma Network (WTN), with the overall intention being to lead to an improvement in the efficiency of trauma care within the region. Compared to many of the other similar studies, the sample size for this project is comparatively several times larger at 4,267 patients. A two tiered trauma response system has been developed and implemented in the University Hospital of Southampton, whereas some of the similar studies took place in only one tiered trauma systems.

MATERIALS AND METHODS

This study involved retrospective statistical analysis of all patients directly admitted to hospitals in the WTN in 2013 and 2014 (n=4267) , both with a pre-alert and without a pre-alert. Data was requested from the Trauma Audit and Research Network database regarding patients admitted to the hospitals in the WTN in 2013/14 and their corresponding ISS's and injuries. Additional data on these specific patients was also obtained through the NHS server via a secure login. This involved recording relevant information from the patient notes such as physiological observations both pre hospital and in the emergency department.

The various TTA criteria being statistically analysed were retrospectively applied to the cohort of patients to see how many of the patients admitted with particular ISS's fulfilled or activated these criteria either at the scene of the incident or in the emergency department. A table was constructed (Figure 1) formatting the number of patients that activated each individual criteria being examined, the ISS bracket they fell under, and whether the hospital was pre-alerted in each instance or not.

There were some limitations in regards to the accessibility of certain information in the data collection process. For certain activation criteria, namely the physiological and intubation criterion, data for 2014 was only available to access for University Hospital Southampton due to login restrictions. It is relevant to mention that the UHS comprises a significant proportion of the patient population in this study. Therefore this limitation would not affect the validity of the results as it merely means that for certain criteria the sample size is partially decreased. There were also several criteria for which only 2013 data was available, these being multiple blunt injuries, spinal cord injury and crushed/degloved/amputated limbs. However this was not an issue with all remaining criteria for which data was available from all of the hospitals in the WTN for both 2013 and 2014.

Following full collection of the data and the completion of the table comprising all patients admitted with ISS ranging from 1 to 65, it was then possible to begin conducting statistical tests on the data. Numerous outcomes were calculated for each criteria including sensitivity, under triage, specificity, over triage and positive and negative predictive values (Figure 2). Specificity is defined as the probability of no TTA amongst patients with minor injury. Whilst 'Negative Predictive Value (NPV)' refers to the probability of minor injury amongst all patients that did not activate a pre-alert. The outcomes remain in the table for completeness, however it was decided that the 'specificity' and 'NPV' were of limited value since most patients with minor injury are never even considered for the activation of the trauma team.

The findings were then utilised with the aim of creating a more refined and optimal set of TTA criteria. This new refined set of criteria was then applied retrospectively to the same TARN and NHS data from 2013/14, in order to observe how many severely injured patients would have been missed had this revised set of data been in use.

RESULTS AND DISCUSSION

Following statistical analysis it can be observed that in general, physiological criteria tend to have a higher sensitivity and hence are more powerful predictors of severe injury. However, it should be noted that there are certain physiological criteria which are not as powerful predictors of major trauma: 'ED respiratory rates' and 'ED/pre hospital GCS 10-12' are amongst these (Figure 3).

In overview, both MOI and Anatomical criteria tended to be less sensitive predictors however there were exceptions to this trend, the most significant being the 'penetrating injury' and 'Long bone fractures in multiple limbs' criterion. Penetrating injury in fact turned out to be the most powerful of all of the TTA criteria in terms of sensitivity (90.91%), and ability to predict severe injury. However it must be noted that this is of limited significance in a region such as Wessex, since the incidence of penetrating injury is relatively low in comparison to other mechanisms of trauma. Penetrating injury in fact also turned out to be the TTA criteria that contributed the most to over-triage (62.96%). Under triage

Table 1 – All patients directly admitted to hospitals in the Wessex Trauma Network in 2013/2014

ISS Band	Pre-Alerted	All Patients (WTN)	All patients (UHS)	High Fall (>2m)	RTC (all)	RTC Pedestrian	RTC Cyclist	RTC Motorcyclist	Intubated Pre-Hospital	Intubated in ED	Flail Chest	Pneumothorax	Pelvis/Acetabulum Fracture	Long Bone Fractures in Multiple Limbs
ISS 1-8	No	660	93	104	98	7	17	9	0	1	0	0	225	34
	Yes	192	86	40	73	11	5	9	2	5	0	0	37	8
ISS 9-15	No	1648	150	165	150	13	25	19	1	5	0	80	47	239
	Yes	450	241	67	192	14	16	45	11	30	0	47	22	40
ISS 16-25	No	514	47	68	75	11	9	10	4	23	45	63	50	7
	Yes	416	213	87	145	21	14	18	31	66	25	50	49	21
ISS 26-35	No	74	9	13	10	1	2	2	1	12	5	10	9	2
	Yes	197	112	41	76	13	8	16	19	39	14	38	40	18
ISS 36-49	No	11	1	2	7	1	1	2	1	2	2	8	7	1
	Yes	79	57	16	50	7	4	8	24	33	18	39	27	7
ISS 50-65	No	11	0	1	9	4	1	1	4	7	2	7	4	1
	Yes	15	14	0	12	1	2	1	4	6	3	3	6	2

ISS Band	Pre-Alerted	Pre-hospital								
		Resp Rate <10 or =>30	Resp Rate <15 or >25	Oxygen Sat <90	GCS 13-15	GCS 10-12	GCS <10	GCS Motor <5	Adult Systolic BP <90	Pulse <50 or >130
ISS 1-8	No	7	38	13	308	1	0	1	5	11
	Yes	2	24	9	105	3	5	5	3	10
ISS 9-15	No	25	112	38	811	2	8	7	12	24
	Yes	13	53	16	233	8	23	21	11	15
ISS 16-25	No	7	40	12	210	12	13	9	2	7
	Yes	20	61	31	154	20	70	62	18	23
ISS 26-35	No	0	9	2	30	3	8	5	0	2
	Yes	9	23	5	77	7	31	29	3	10
ISS 36-49	No	0	2	1	7	0	1	1	0	0
	Yes	6	13	7	24	6	23	22	7	6
ISS 50-65	No	4	6	2	1	0	9	8	2	3
	Yes	2	3	2	3	1	3	3	0	4

ISS Band	Pre-Alerted	ED							
		Resp Rate <10 or =>30	Resp Rate <15 or >25	Oxygen Sat <90	GCS 13-15	GCS 10-12	GCS <10	Adult Systolic BP <90	Pulse <50 or >130
ISS 1-8	No	3	51	11	352	0	0	6	6
	Yes	6	20	2	101	3	5	4	7
ISS 9-15	No	18	190	32	843	3	4	6	24
	Yes	16	62	7	242	7	11	8	13
ISS 16-25	No	9	58	5	243	9	12	7	4
	Yes	15	48	7	168	14	60	23	16
ISS 26-35	No	2	10	0	29	2	9	1	1
	Yes	1	19	2	72	10	25	10	14
ISS 36-49	No	0	0	1	9	0	1	0	0
	Yes	5	5	6	21	2	13	9	8
ISS 50-65	No	1	2	0	2	0	5	3	2
	Yes	0	1	1	3	0	2	0	2

Table 2 - All patients directly admitted to hospitals in the Wessex Trauma Network in 2013 only

ISS Band	Pre-Alerted	Crushed/Degloved/Amputated Limb	Multiple Blunt Injuries	Spinal Cord Injury
ISS 1-8	No	2	371	-
	Yes	3	75	-
ISS 9-15	No	4	14	48
	Yes	5	7	10
ISS 16-25	No	1	28	11
	Yes	1	34	16
ISS 26-35	No	1	9	3
	Yes	3	40	16
ISS 36-49	No	-	10	2
	Yes	2	35	6
ISS 50-65	No	2	10	1
	Yes	-	4	1

Table 3 - All patient admitted to hospitals in the Wessex Trauma Network in 2013/2014

ISS Band	Pre-Alerted	Age >50	Age >60	Age >70	Age >80
ISS 1-8	No	516	466	382	276
	Yes	96	65	51	33
ISS 9-15	No	1375	1166	906	658
	Yes	242	189	122	71
ISS 16-25	No	344	289	235	166
	Yes	234	168	114	67
ISS 26-35	No	141	122	104	73
	Yes	108	86	64	32
ISS 36-49	No	1	1	0	0
	Yes	36	25	15	7
ISS 50-65	No	0	0	0	0
	Yes	4	4	2	0

Figure 1 Table of the data showing the number of patients that fulfilled each TTA criteria

This table contains the data obtained following interpretation of the data sent from TARN and using the secure NHS database. The table shows all of the patients directly admitted to hospitals in the WTN in 2013/14, the ISS bracket they fall under and the number of patients that fulfilled each TTA criteria. The table also specifies as to whether a pre-alert was made to the hospital beforehand or not. See appendices for enlarged version of the table.

Example	ISS>15	ISS<=15	Total
Pre-Alert	a	b	(a+b)
No Pre-Alert	c	d	(c+d)
Total	(a+c)	(b+d)	

Sensitivity = a/(a+c)
Undertriage = 1 - sensitivity = c/(a+c)
Specificity = d/(b+d)

Positive Predictive Value = a/(a+b)
Overtriage = 1-PPV = b/(a+b)
Negative Predictive Value = d/(c+d)

All patients directly admitted to UHS in 2013/14	ISS>15	ISS<=15	Total
Pre Alert	396	327	723
No Pre Alert	57	243	300
Total	453	570	
Sensitivity		87.42%	
Undertriage		12.58%	
Specificity		42.63%	
PPV		54.77%	
Overtriage		45.23%	
NPV		81.00%	

High Fall	ISS>15	ISS<=15	Total
Pre Alert	144	107	251
No Pre Alert	84	269	353
Total	228	376	
Sensitivity		63.16%	
Undertriage		36.84%	
Specificity		71.54%	
PPV		57.37%	
Overtriage		42.63%	
NPV		76.20%	

RTC (All)	ISS>15	ISS<=15	Total
Pre Alert	283	107	390
No Pre Alert	101	269	370
Total	384	376	
Sensitivity		73.70%	
Undertriage		26.30%	
Specificity		71.54%	
PPV		72.56%	
Overtriage		27.44%	
NPV		72.70%	

RTC (Pedestrian)	ISS>15	ISS<=15	Total
Pre Alert	42	25	67
No Pre Alert	17	20	37
Total	59	45	
Sensitivity		71.19%	
Undertriage		28.81%	
Specificity		44.44%	
PPV		62.69%	
Overtriage		37.31%	
NPV		54.05%	

Intubated Pre Hospital	ISS>15	ISS<=15	Total
Pre Alert	78	13	91
No Pre Alert	10	1	11
Total	88	14	
Sensitivity		88.64%	
Undertriage		11.36%	
Specificity		7.14%	
PPV		85.71%	
Overtriage		14.29%	
NPV		9.09%	

Intubated in ED	ISS>15	ISS<=15	Total
Pre Alert	144	35	179
No Pre Alert	44	6	50
Total	188	41	
Sensitivity		76.60%	
Undertriage		23.40%	
Specificity		14.63%	
PPV		80.45%	
Overtriage		19.55%	
NPV		12.00%	

Flail Chest	ISS>15	ISS<=15	Total
Pre Alert	60	0	60
No Pre Alert	54	0	54
Total	114	0	
Sensitivity		52.63%	
Undertriage		47.37%	
Specificity		N/A	
PPV		100.00%	
Overtriage		0.00%	
NPV		0.00%	

Pneumothorax	ISS>15	ISS<=15	Total
Pre Alert	130	47	177
No Pre Alert	88	80	168
Total	218	127	
Sensitivity		59.63%	
Undertriage		40.37%	
Specificity		62.99%	
PPV		73.45%	
Overtriage		26.55%	
NPV		47.62%	

RTC (Cyclist)	ISS>15	ISS<=15	Total
Pre Alert	28	21	49
No Pre Alert	13	42	55
Total	41	63	
Sensitivity		68.29%	
Undertriage		31.71%	
Specificity		66.67%	
PPV		57.14%	
Overtriage		42.86%	
NPV		76.36%	

RTC (Motorcyclist)	ISS>15	ISS<=15	Total
Pre Alert	43	54	97
No Pre Alert	15	28	43
Total	58	82	
Sensitivity		74.14%	
Undertriage		25.86%	
Specificity		34.15%	
PPV		44.33%	
Overtriage		55.67%	
NPV		65.12%	

Penetrating Injury	ISS>15	ISS<=15	Total
Pre Alert	10	17	27
No Pre Alert	1	11	12
Total	11	28	
Sensitivity		90.91%	
Undertriage		9.09%	
Specificity		39.29%	
PPV		37.04%	
Overtriage		62.96%	
NPV		91.67%	

Pre hosp GCS <10	ISS>15	ISS<=15	Total
Pre Alert	127	28	155
No Pre Alei	31	8	39
Total	158	36	
Sensitivity		80.38%	
Undertriage		19.62%	
Specificity		22.22%	
PPV		81.94%	
Overtriage		18.06%	
NPV		20.51%	

Pelvis/Acetabulum fracture	ISS>15	ISS<=15	Total
Pre Alert	122	59	181
No Pre Alert	70	272	342
Total	192	331	
Sensitivity		63.54%	
Undertriage		36.46%	
Specificity		82.18%	
PPV		67.40%	
Overtriage		32.60%	
NPV		79.53%	

Long bone fractures in multiple limbs	ISS>15	ISS<=15	Total
Pre Alert	48	48	96
No Pre Alert	11	273	284
Total	59	321	
Sensitivity		81.36%	
Undertriage		18.64%	
Specificity		85.05%	
PPV		50.00%	
Overtriage		50.00%	
NPV		96.13%	

Pre hosp Resp Rate <10 or >30	ISS>15	ISS<=15	Total
Pre Alert	37	15	52
No Pre Alert	11	32	43
Total	48	47	
Sensitivity		77.08%	
Undertriage		22.92%	
Specificity		68.09%	
PPV		71.15%	
Overtriage		28.85%	
NPV		74.42%	

Pre hosp GCS motor <5	ISS>15	ISS<=15	Total
Pre Alert	116	26	142
No Pre Alei	23	8	31
Total	139	34	
Sensitivity		83.45%	
Undertriage		16.55%	
Specificity		23.53%	
PPV		81.69%	
Overtriage		18.31%	
NPV		25.81%	

Pre hosp Oxygen Sat <90	ISS>15	ISS<=15	Total
Pre Alert	45	25	70
No Pre Alert	17	51	68
Total	62	76	
Sensitivity		72.58%	
Undertriage		27.42%	
Specificity		67.11%	
PPV		64.29%	
Overtriage		35.71%	
NPV		75.00%	

Pre hosp GCS 13-15	ISS>15	ISS<=15	Total
Pre Alert	258	338	596
No Pre Alert	248	1119	1367
Total	506	1457	
Sensitivity		50.99%	
Undertriage		49.01%	
Specificity		76.80%	
PPV		43.29%	
Overtriage		56.71%	
NPV		81.86%	

Pre hosp GCS 10-12	ISS>15	ISS<=15	Total
Pre Alert	34	11	45
No Pre Alert	15	3	18
Total	49	14	
Sensitivity		69.39%	
Undertriage		30.61%	
Specificity		21.43%	
PPV		75.56%	
Overtriage		24.44%	
NPV		16.67%	

Pre hosp Adult Systolic BP <90	ISS>15	ISS<=15	Total
Pre Alert	28	14	42
No Pre Alei	4	17	21
Total	32	31	
Sensitivity		87.50%	
Undertriage		12.50%	
Specificity		54.84%	
PPV		66.67%	
Overtriage		33.33%	
NPV		80.95%	

Pre hosp Resp Rate <15 or >25	ISS>15	ISS<=15	Total
Pre Alert	100	77	177
No Pre Alert	57	150	207
Total	157	227	
Sensitivity		63.69%	
Undertriage		36.31%	
Specificity		66.08%	
PPV		56.50%	
Overtriage		43.50%	
NPV		72.46%	

ED Resp Rate <10 or >30	ISS>15	ISS<=15	Total
Pre Alert	21	22	43
No Pre Alert	12	21	33
Total	33	43	
Sensitivity		63.64%	
Undertriage		36.36%	
Specificity		48.84%	
PPV		48.84%	
Overtriage		51.16%	
NPV		63.64%	

ED Resp Rate <15 or >25	ISS>15	ISS<=15	Total
Pre Alert	73	82	155
No Pre Alert	70	241	311
Total	143	323	
Sensitivity		51.05%	
Undertriage		48.95%	
Specificity		74.61%	
PPV		47.10%	
Overtriage		52.90%	
NPV		77.49%	

ED Oxygen Sat <90	ISS>15	ISS<=15	Total
Pre Alert	16	9	25
No Pre Alert	6	43	49
Total	22	52	
Sensitivity		72.73%	
Undertriage		27.27%	
Specificity		82.69%	
PPV		64.00%	
Overtriage		36.00%	
NPV		87.76%	

Pre hosp Pulse <50 or >130	ISS>15	ISS<=15	Total
Pre Alert	43	25	68
No Pre Alert	12	35	47
Total	55	60	
Sensitivity		78.18%	
Undertriage		21.82%	
Specificity		58.33%	
PPV		63.24%	
Overtriage		36.76%	
NPV		74.47%	

ED Adult Systolic BP <90	ISS>15	ISS<=15	Total
Pre-Alert	42	12	54
No Pre-Alert	11	12	23
Total	53	24	
Sensitivity		79.25%	
Undertriage		20.75%	
Specificity		50.00%	
PPV		77.78%	
Overtriage		22.22%	
NPV		52.17%	

ED Pulse <50 or >130	ISS>15	ISS<=15	Total
Pre-Alert	40	20	60
No Pre-Alert	7	30	37
Total	47	50	
Sensitivity		85.11%	
Undertriage		14.89%	
Specificity		60.00%	
PPV		66.67%	
Overtriage		33.33%	
NPV		81.08%	

(2013) Crushed/Degloved/Amputated Limb	ISS>15	ISS<=15	Total
Pre-Alert	6	8	14
No Pre-Alert	4	6	10
Total	10	14	
Sensitivity		60.00%	
Undertriage		40.00%	
Specificity		42.86%	
PPV		42.86%	
Overtriage		57.14%	
NPV		60.00%	

ED GCS motor<5	ISS>15	ISS<=15	Total
Pre-Alert	76	15	91
No Pre-Alert	15	4	19
Total	91	19	
Sensitivity		83.52%	
Undertriage		16.48%	
Specificity		21.05%	
PPV		83.52%	
Overtriage		16.48%	
NPV		21.05%	

ED GCS 13-15	ISS>15	ISS<=15	Total
Pre Alert	264	343	607
No Pre Alert	283	1195	1478
Total	547	1538	
Sensitivity		48.26%	
Undertriage		51.74%	
Specificity		77.70%	
PPV		43.49%	
Overtriage		56.51%	
NPV		80.85%	

ED GCS 10-12	ISS>15	ISS<=15	Total
Pre Alert	26	10	36
No Pre Alert	11	3	14
Total	37	13	
Sensitivity		70.27%	
Undertriage		29.73%	
Specificity		23.08%	
PPV		72.22%	
Overtriage		27.78%	
NPV		21.43%	

ED GCS <10	ISS>15	ISS<=15	Total
Pre Alert	100	16	116
No Pre Alert	27	4	31
Total	127	20	
Sensitivity		78.74%	
Undertriage		21.26%	
Specificity		20.00%	
PPV		86.21%	
Overtriage		13.79%	
NPV		12.90%	

Age > 50	ISS>15	ISS<=15	Total
Pre-Alert	382	338	720
No Pre-Alert	486	1891	2377
Total	868	2229	
Sensitivity		44.01%	
Undertriage		55.99%	
Specificity		84.84%	
PPV		53.06%	
Overtriage		46.94%	
NPV		79.55%	

Age >60	ISS>15	ISS<=15	Total
Pre-Alert	283	254	537
No Pre-Alert	412	1632	2044
Total	695	1886	
Sensitivity		40.72%	
Undertriage		59.28%	
Specificity		86.53%	
PPV		52.70%	
Overtriage		47.30%	
NPV		79.84%	

Age >70	ISS>15	ISS<=15	Total
Pre-Alert	195	173	368
No Pre-Alert	339	1288	1627
Total	534	1461	
Sensitivity		36.52%	
Undertriage		63.48%	
Specificity		88.16%	
PPV		52.99%	
Overtriage		47.01%	
NPV		79.16%	

Age >80	ISS>15	ISS<=15	Total
Pre-Alert	106	104	210
No Pre-Alert	239	934	1173
Total	345	1038	
Sensitivity		30.72%	
Undertriage		69.28%	
Specificity		89.98%	
PPV		50.48%	
Overtriage		49.52%	
NPV		79.62%	

(2013 only) Multiple Blunt Injury	ISS>15	ISS<=15	Total
Pre-Alert	113	82	195
No Pre-Alert	57	14	71
Total	170	96	
Sensitivity		66.47%	
Undertriage		33.53%	
Specificity		14.58%	
PPV		57.95%	
Overtriage		42.05%	
NPV		19.72%	

(2013 only) Spinal Cord Injury	ISS>15	ISS<=15	Total
Pre-Alert	39	10	49
No Pre-Alert	17	48	65
Total	56	58	
Sensitivity		69.64%	
Undertriage		30.36%	
Specificity		82.76%	
PPV		79.59%	
Overtriage		20.41%	
NPV		73.85%	

Figure 2 The statistical outcomes calculated for each individual criterion

Sensitivity = a/ (a+c), under-triage = 1- sensitivity = c/a+c, specificity = d/ (b+d), PPV = a/ (a+b), over-triage = 1-PPV = b/ (a+b), NPV = d/(c+d). Specificity and NPV are highlighted since they were decided to be of limited value to the study but have been included for completeness.

Activation Criteria	Sensitivity
Penetrating Injury	90.91%
Intubated pre hosp	88.64%
Pre hosp Adult Systolic BP <90	87.50%
ED Pulse <50 or >130	85.11%
ED GCS motor<5	83.52%
Pre hosp GCS motor <5	83.45%
Long bone fractures in multiple limbs	81.36%
Pre hosp GCS <10	80.38%
ED Adult Systolic BP <90	79.25%
ED GCS <10	78.74%
Pre hosp Pulse <50 or >130	78.18%
Pre hosp Resp Rate <10 or >30	77.08%
Intubated in ED	76.60%
RTC (Motorcyclist)	74.14%
RTC (All)	73.70%
ED Oxygen Sat <90	72.73%
Pre hosp Oxygen Sat <90	72.58%
RTC (Pedestrian)	71.19%
ED GCS 10-12	70.27%
Spinal Cord Injury	69.64%
Pre hosp GCS 10-12	69.39%
RTC (Cyclist)	68.29%
Multiple Blunt Injury	66.47%
Pre hosp Resp Rate <15 or >25	63.69%
ED Resp Rate <10 or >30	63.64%
Pelvis/Acetabulum fracture	63.54%
High Fall	63.16%
Crushed/Degloved/Amputated Limb	60.00%
Pneumothorax	59.63%
Flail Chest	52.63%
ED Resp Rate <15 or >25	51.05%
Pre hosp GCS 13-15	50.99%
ED GCS 13-15	48.26%
Age > 50	44.01%
Age > 60	40.72%
Age >70	36.52%
Age >80	30.72%

Activation Criteria	Undertriage
Penetrating Injury	9.09%
Intubated pre hosp	11.36%
Pre hosp Adult Systolic BP <90	12.50%
ED Pulse <50 or >130	14.89%
ED GCS motor<5	16.48%
Pre hosp GCS motor <5	16.55%
Long bone fractures in multiple limbs	18.64%
Pre hosp GCS <10	19.62%
ED Adult Systolic BP <90	20.75%
ED GCS <10	21.26%
Pre hosp Pulse <50 or >130	21.82%
Pre hosp Resp Rate <10 or >30	22.92%
Intubated in ED	23.40%
RTC (Motorcyclist)	25.86%
RTC (All)	26.30%
ED Oxygen Sat <90	27.27%
Pre hosp Oxygen Sat <90	27.42%
RTC (Pedestrian)	28.81%
ED GCS 10-12	29.73%
Spinal Cord Injury	30.36%
Pre hosp GCS 10-12	30.61%
RTC (Cyclist)	31.71%
Multiple Blunt Injury	33.53%
Pre hosp Resp Rate <15 or >25	36.31%
ED Resp Rate <10 or >30	36.36%
Pelvis/Acetabulum fracture	36.46%
High Fall	36.84%
Crushed/Degloved/Amputated Limb	40.00%
Pneumothorax	40.37%
Flail Chest	47.37%
ED Resp Rate <15 or >25	48.95%
Pre hosp GCS 13-15	49.01%
ED GCS 13-15	51.74%
Age > 50	55.99%
Age > 60	59.28%
Age > 70	63.48%
Age > 80	69.28%

Activation Criteria	Specificity
Flail Chest	N/A
Age > 80	89.98%
Age > 70	88.16%
Age > 60	86.53%
Long bone fractures in multiple limbs	85.05%
Age > 50	84.84%
Spinal Cord Injury	82.76%
ED Oxygen Sat <90	82.69%
Pelvis/Acetabulum fracture	82.18%
ED GCS 13-15	77.70%
Pre hosp GCS 13-15	76.80%
ED Resp Rate <15 or >25	74.61%
RTC (All)	71.54%
High Fall	71.54%
Pre hosp Resp Rate <10 or >30	68.09%
Pre hosp Oxygen Sat <90	67.11%
RTC (Cyclist)	66.67%
Pre hosp Resp Rate <15 or >25	66.08%
Pneumothorax	62.99%
ED Pulse <50 or >130	60.00%
Pre hosp Pulse <50 or >130	58.33%
Pre hosp Adult Systolic BP <90	54.84%
ED Adult Systolic BP <90	50.00%
ED Resp Rate <10 or >30	48.84%
RTC (Pedestrian)	44.44%
Crushed/Degloved/Amputated Limb	42.86%
Penetrating Injury	39.29%
RTC (Motorcyclist)	34.15%
Pre hosp GCS motor <5	23.53%
ED GCS 10-12	23.08%
Pre hosp GCS <10	22.22%
Pre hosp GCS 10-12	21.43%
ED GCS motor<5	21.05%
ED GCS <10	20.00%
Intubated in ED	14.63%
Multiple Blunt Injury	14.58%
Intubated pre hosp	7.14%

Activation Criteria	PPV
Flail Chest	100.00%
ED GCS <10	86.21%
Intubated pre hosp	85.71%
ED GCS motor<5	83.52%
Pre hosp GCS <10	81.94%
Pre hosp GCS motor <5	81.69%
Intubated in ED	80.45%
Spinal Cord Injury	79.59%
ED Adult Systolic BP <90	77.78%
Pre hosp GCS 10-12	75.56%
Pneumothorax	73.45%
RTC (All)	72.56%
ED GCS 10-12	72.22%
Pre hosp Resp Rate <10 or >30	71.15%
Pelvis/Acetabulum fracture	67.40%
ED Pulse <50 or >130	66.67%
Pre hosp Adult Systolic BP <90	66.67%
Pre hosp Oxygen Sat <90	64.29%
ED Oxygen Sat <90	64.00%
Pre hosp Pulse <50 or >130	63.24%
RTC (Pedestrian)	62.69%
Multiple Blunt Injury	57.95%
High Fall	57.37%
RTC (Cyclist)	57.14%
Pre hosp Resp Rate <15 or >25	56.50%
Age > 50	53.06%
Age > 70	52.99%
Age > 60	52.70%
Age > 80	50.48%
Long bone fractures in multiple limbs	50.00%
ED Resp Rate <10 or >30	48.84%
ED Resp Rate <15 or >25	47.10%
RTC (Motorcyclist)	44.33%
ED GCS 13-15	43.49%
Pre hosp GCS 13-15	43.29%
Crushed/Degloved/Amputated Limb	42.86%
Penetrating Injury	37.04%

Activation Criteria	Overtriage
Flail Chest	0.00%
ED GCS <10	13.79%
Intubated pre hosp	14.29%
ED GCS motor<5	16.48%
Pre hosp GCS <10	18.06%
Pre hosp GCS motor <5	18.31%
Intubated in ED	19.55%
Spinal Cord Injury	20.41%
ED Adult Systolic BP <90	22.22%
Pre hosp GCS 10-12	24.44%
Pneumothorax	26.55%
RTC (All)	27.44%
ED GCS 10-12	27.78%
Pre hosp Resp Rate <10 or >30	28.85%
Pelvis/Acetabulum fracture	32.60%
ED Pulse <50 or >130	33.33%
Pre hosp Adult Systolic BP <90	33.33%
Pre hosp Oxygen Sat <90	35.71%
ED Oxygen Sat <90	36.00%
Pre hosp Pulse <50 or >130	36.76%
RTC (Pedestrian)	37.31%
Multiple Blunt Injury	42.05%
High Fall	42.63%
RTC (Cyclist)	42.86%
Pre hosp Resp Rate <15 or >25	43.50%
Age > 50	46.94%
Age > 70	47.01%
Age > 60	47.30%
Age > 80	49.52%
Long bone fractures in multiple limbs	50.00%
ED Resp Rate <10 or >30	51.16%
ED Resp Rate <15 or >25	52.90%
RTC (Motorcyclist)	55.67%
ED GCS 13-15	56.51%
Pre hosp GCS 13-15	56.71%
Crushed/Degloved/Amputated Limb	57.14%
Penetrating Injury	62.96%

Activation Criteria	NPV
Long bone fractures in multiple limbs	96.13%
Penetrating Injury	91.67%
ED Oxygen Sat <90	87.76%
Pre hosp GCS 13-15	81.86%
Pre hosp Adult Systolic BP <90	80.95%
ED GCS 13-15	80.85%
Age > 60	79.84%
Age > 80	79.62%
Age > 50	79.55%
Pelvis/Acetabulum fracture	79.53%
Age > 70	79.16%
ED Resp Rate <15 or >25	77.49%
RTC (Cyclist)	76.36%
High Fall	76.20%
Pre hosp Oxygen Sat <90	75.00%
ED Pulse <50 or >130	74.47%
Pre hosp Pulse <50 or >130	74.47%
Pre hosp Resp Rate <10 or >30	74.42%
Spinal Cord Injury	73.85%
RTC (All)	72.70%
Pre hosp Resp Rate <15 or >25	72.46%
RTC (Motorcyclist)	65.12%
ED Resp Rate <10 or >30	63.64%
Crushed/Degloved/Amputated Limb	60.00%
RTC (Pedestrian)	54.05%
ED Adult Systolic BP <90	52.17%
Pneumothorax	47.62%
Pre hosp GCS motor <5	25.81%
ED GCS 10-12	21.43%
ED GCS motor<5	21.05%
Pre hosp GCS <10	20.51%
Multiple Blunt Injury	19.72%
Pre hosp GCS 10-12	16.67%
ED GCS <10	12.90%
Intubated in ED	12.00%
Intubated pre hosp	9.09%
Flail Chest	0.00%

Figure 3 Tables depicting the performance of various TTA criteria being analysed

The table demonstrates the performance of the various TTA criteria at predicting severe injury (ISS >15) using all patients admitted to hospitals in the WTN in 2013/14.

tended to follow the same trend with the most sensitive criteria contributing the least to under-triage. Therefore the findings demonstrate that MOI/Anatomical criteria are likely to result in a greater proportion of severely injured patients not being correctly identified as such, which can result in devastating and fatal outcomes. However the advantage of also incorporating MOI/Anatomical criteria is that despite higher levels of under-triage when taken independently, they do identify some degree of patients that may have been missed by just physiological criteria. Hence the criteria can still be of use but only when taken in combination with physiological criteria. Although, it is relevant to mention that with the use of MOI and anatomical criteria, often come higher rates of over-triage, the implications of which have been previously discussed.

The positive predictive value can be defined as the probability of the patient in question actually being severely injured (ISS>15) when the criteria is activated (pre-alert). Being the converse of this, over-triage is hence defined as '1-PPV'. In general, MOI criteria tended to contribute the most to over-triage (Penetrating injury and Crushed/Degloved/Amputated limb contributing the most). Therefore on the whole, anatomical and physiological criteria tended to contribute less so to over-triage with the criteria of 'Flail chest' in fact contributing 0% to over-triage since the mere occurrence directly implies severe injury.

This study reports that MOI criteria in general have a lower predictive power than physiological and anatomical criteria in terms of ability to predict severe injury. This theme seems to be consistent with the results of previously conducted studies [7,9,10,12]. Another common theme amongst other studies is that MOI criteria tend to contribute the most to over-triage. This is re-enforced by this study with 'Penetrating Injury' and 'Crushed/degloved/amputated limb' being the two criteria contributing the most to over-triage, with over-triage rates of 62.96% and 57.14% respectively (Figure 3).

The findings of the study showed that the mechanism of injury criteria of 'Penetrating injury' in fact turned out to be the criteria with both the greatest predictive power and also the largest rate of over-triage. It is significant to mention that the 'Penetrating injury' criteria is likely to be more relevant to other geographical regions, which have a greater incidence of penetrating injury, for example the inner cities of major urban areas. Penetrating injury can encompass a somewhat widespread variety of injuries, many of which include more minor stab wounds or air powered rifle wounds. Therefore, it would be advisable that a more specific and localised criteria would be more useful. This perhaps would be achieved by including the anatomical location of the penetrating injury, e.g.: to the chest/vital organ zone on the torso.

Patterns of trauma can vary significantly between different regions and other studies have even shown that trauma patterns can still be variable amongst hospitals in the same region [8]. Hence this could affect the applicability of the proposed revised set of trauma activation criteria in relation to other regions.

The statistical analysis in this study involved including age as a criterion in order to observe if there was any significant trend related to age as a factor in the trauma triage protocol. The findings indicate that there is an inverse correlation between sensitivity and age, since sensitivity decreases as age increases. Conversely there was a positive relationship between age and the rate of over-triage, since over-triage increases as age increases. It is believed that perhaps these trends may be due to symptoms often being somewhat more covert and masked in the elderly population due to the greater likelihood of existing co-morbidities.

In order to minimise any increase in under-triage that might result from the removal of certain criteria, only the specific criteria with both a low predictive power and a high contribution to over-triage were removed in the formation of the revised set of activation criteria. It is relevant to mention that although information recorded in the ED can be useful for comparison, it is only pre hospital observations that are of significance for inclusion in the revised TTA criteria. This is since only information known prior to the patient arriving at the hospital can be used to decide whether a level one trauma call should be activated or not.

The findings from the statistical analysis were used and several modifications to the revised set of TTA criteria were made. 'Flail chest' along with the top 6 most sensitive pre hospital physiological criteria were taken as an initial sample to be retrospectively applied to the 2013/14 patient data. This therefore included 'flail chest', 'intubated pre hospital', 'pre hospital adult systolic BP <90', 'pre hospital GCS motor <5', 'pre hospital GCS <10', 'pre hospital pulse <50 or >130' and 'pre hospital resp rate <10 or >30'. As discussed previously, the criterion of 'flail chest' has an over-triage rate of 0%, so although it may not have a particularly high sensitivity, it will not contribute to over-triage so is hence worth including. This is likely to be the case since it would be rare for a flail chest to occur in isolation; hence it is very probable that other traumas will have occurred simultaneously.

Following retrospective application to a sample of 134 severely injured patients directly admitted to UHS in 2013/14, it was found that only 90 (67%) of these would have been correctly identified as severely injured had this set of TTA criteria been in use. Consequently this prompted some alterations to be made to the proposed criteria (See figure 4). Amongst these modifications were the adjustment of the parameters of certain activation criteria (Resp rate <15 or >25, Pulse rate <50 or >120). As shown in Figure 4, implementation of these changes, raised the sensitivity of the proposed criteria to 76% (133 of 174 severely injured patients being identified).

However, as depicted in Figure 6, the TTA criteria currently in use in UHS had a sensitivity of 87.42% and over-triage rate of 45.23% over 2013/14. Consequently with this in consideration, several modifications were implemented, namely the inclusion of 'pre hospital O2 saturation on air <92%' as a criteria, along with adjustments of the parameters for 'GCS (changed to <12)' and 'Pulse rate (changed to <60 or >110).

It is relevant to mention that there were some limitations in relation to the retrospective application of the revised criteria. Due to restrictions regarding the accessibility of data, the criteria could only be applied to those patients directly admitted to UHS (n=800).

First proposed set
Flail chest
Intubated pre hospital
Pre hospital adult systolic BP <90
Pre hospital GCS motor < 5
Pre hospital GCS < 10
Pre hospital pulse <50 or >130
Pre hospital resp rate <10 or >30

Retrospectie Application
Sensitivity = 67.16% (90 of 134)
Under-triage = 32.84%

Second proposed set
Flail chest
Intubated pre hospital
Pre hospital adult systolic BP <90
Pre hospital GCS motor < 5
Pre hospital GCS < 10
Pre hospital pulse < 50 or >120
Pre hospital resp rate <15 or >25

Retrospective Application
Sensitivity = 76.44% (133 of 174)
Under-triage = 23.56%

Final proposed set
Flail chest
Intubated pre hospital
Pre hospital adult systolic BP < 90
Pre hospital GCS motor < 5
Pre hospital GCS < 12
Pre hospital pulse <60 or >110
Pre hospital resp rate <15 or >25
Pre hospital O2 sats <92%

All patients directly admitted to UHS in 2013/14			
	ISS>15	ISS<=15	Total
Pre Alert	331	147	478
No Pre Alert	57	265	322
Total	388	412	

Sensitivity	85.31%
Under-triage	14.69%
Specificity	64.32%
PPV	69.25%
Over-triage	30.75%
NPV	82.30%

Figure 4 Tables depicting the retrospective application and performance of the revised set of criteria

The figure illustrates the numerous stages involved in refining the proposed TTA criteria. The first and the second proposed sets were initially applied retrospectively to a relatively small patient sample, it was clear that these sets were not sensitive enough, hence prompting further modifications to be made. All proposed sets of criteria were applied to TARN data for patients directly admitted to UHS in 2013/14.

Current set of TTA criteria in use	
Sensitivity	87.42%
Undertriage	12.58%
Specificity	42.63%
PPV	54.77%
Overtriage	45.23%
NPV	81.00%

Proposed revised set of TTA criteria	
Sensitivity	85.31%
Under-triage	14.69%
Specificity	64.32%
PPV	69.25%
Over-triage	30.75%
NPV	82.30%

Figure 5 Comparison of the performance of the current TTA criteria and the proposed set of criteria

The tables depict the performance of the two sets of TTA criteria when utilizing 'all patients admitted to UHS in 2013/14' as the patient sample in both instances.

CONCLUSION

The final proposed set of TTA criteria was retrospectively applied to patients directly admitted to UHS in 2013/14 (n=800). The revised criteria would have yielded a sensitivity of 85.31% and an over-triage rate of 30.75% had it been in use. The performance of the revised set of TTA criteria was then compared to the current criteria in use, as shown in Figure 5. The simplified TTA criteria significantly reduced the rate of over-triage from 45.23% to 30.75%. Although the rate of under-triage increased from 12.58% to 14.69%, the increase is not substantial and is likely over-shadowed by the benefits of such a significant reduction in the rate of over-triage. Unfortunately given the nature of trauma, there will always be some level of under-triage, however it is possible to minimise it. Utilising these findings, a simplified revised set of TTA criteria using predominantly physiological and anatomical criteria can act to safely reduce over-triage without a substantial increase in under-triage.

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