The performance of trauma team activation criteria at an Australian regional hospital

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ABSTRACT

Objective: It is common practice for hospitals to use a trauma team activation criteria (TTAC) to identify patients at risk of major trauma and to activate a multidisciplinary team to receive such patients on arrival to the ED. The aims of this study are to describe the frequency of individual criteria and the ability of one currently used system to predict major trauma, and to estimate the effect of simplified criteria on the prediction.
Design and setting: A retrospective observational study of the entire cohort of adult patients who a) received trauma team activation or b) were included in the trauma registry of Royal Darwin Hospital in 2015. From the original clinical record all components of the TTAC, and corresponding outcomes, were extracted for each case. The predictive effect of each criterion, adjusted for the presence of others, was assessed by logistic regression. The poorest predictors were sequentially "dropped" to develop a number of models of which the predictive value of the resulting hypothetical TTAC was calculated.
Main outcome measures: Major trauma (MT) was defined as a death in ED, immediate operative intervention or direct admission to ICU. Overtriage was defined as activation of the trauma team without major trauma. Undertriage was defined as major trauma without trauma team activation.
Results: 794 trauma presentations were reviewed, 428 of those presentations met TTAC. Major trauma was present in 135 (32%) of those with TTAC hence overtriage was 68%. Criteria based on mechanism of injury (MOI) were responsible for over half of the overtriage and were collectively present without other activation criteria in only 10 MTs (6%). Removal of the criteria with the worst predictive value decreased overtriage to 50% before a rise in undertriage to beyond 24%.
Conclusion: A number of criteria including those based on MOI decrease the accuracy of TTAC and lead to high rates of overtriage. Airway, respiratory and neurological compromise were the best predictors of MT. Any criteria simplification should be introduced in the context of a further audit of TTAC performance, as the estimates of the separate criteria in the current TTAC are not robust to bias or to undetected correlation.

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Introduction

It has become standard practice for hospitals accepting trauma patients to provide a dedicated multidisciplinary team to receive patients who are at high risk for serious complications of traumatic injury, with a defined skill mix, standard operating procedures and streamlined access to higher intensity investigation and interventions. Initial care by such a "Trauma Team" may improve outcomes

for patients who have suffered severe injuries [1,2]. In seeking to maximise the benefit of hospital behaviour at the population level, the benefit to severely injured trauma patients is balanced against the effect of removing resources from other areas [3,4]. This balance is unlikely to be the same in every trauma centre. For example, in a hospital with a higher proportion of severely injured patients who arrive in the early phase of trauma, plus both a low rate and a constant and low illness severity of patients presenting with non-traumatic illness, the prior probability of severe trauma that is considered by the person performing triage is high, and the impact of Trauma Team activations on service for other patients is low, easily predicted and easily mitigated.

An ideal list of Trauma Team Activation Criteria (TTAC) would always activate for patients who require trauma team care but only

rarely activate for patients that do not. The criteria should also be simple and rapid to apply.

Following consistent observations of better outcome if severely injured patients are transferred to a trauma centre directly, guidelines were developed to mandate which patients require immediate transfer [5,6]. Early systems using only physiological abnormalities [7,8] had low rates of false positives but had unacceptable rates of false negatives [9,10]. In mature trauma systems, the contribution of mechanism of injury (MOI) is not clear. There is evidence in favour [11,12], but more evidence suggesting that in the presence of normal physiology, MOI does not contribute strongly to accuracy of detection [13–17]. The American College of Surgeons (ACS) trauma guidelines suggest an initial TTAC using predominantly physiological criteria and less urgent assessment of patients meeting MOI criteria [18].

Royal Darwin Hospital (RDH) is a 360 bed hospital servicing a large geographical area containing some of the most remote and inaccessible communities in Australia with a population of about 180,000 [19]. There are 70,000 ED presentations and 1000 ICU admissions yearly. Severe trauma incidence is 3 times the national average [20].

RDH uses a two tiered approach to trauma presentations. The higher acuity patients, who meet any one of 45 separate MOI or physiological criteria are triaged as a Category 1 ("requires immediate review") and activate a multidisciplinary hospital wide trauma team that includes ED, Trauma Service, ICU and Anaesthetics staff (see Appendix 1 for the full list of criteria and trauma team members). The second tier activates a "within ED only" urgent response, triaged as a category 2 (to be seen within 10 min), also based on MOI and some physiological criteria. A dedicated Trauma Service coordinates ongoing care of trauma patients using a nurse led model with close consultant input, and maintains a register of all trauma patients admitted with an ISS > 9, or who are admitted following either tier of trauma notification or who are admitted to ICU.

Our aim was to evaluate the performance of each criteria that comprise RDH's, 1st tier, TTAC in identifying Major Trauma (MT) in the unique cohort of patients whom we serve. Our hypothesis given the current available evidence is that some criteria, particularly those based on MOI, could be removed from the TTAC with the greatest reduction in false positive activations with minimal effect on the number of MTs not receiving trauma team activation.

Methods

Major Trauma has been defined as trauma presentations that received any of the following disposition criteria; direct ICU admission, direct transfer to the Operating theatre (OT) for procedures considered potentially life or limb saving, or who suffer mortality within the ED. This approach of utilising direct disposition from ED to define major trauma is consistent with multiple previous studies assessing TTAC [1,17,21–23] and in this cohort uses data sources of high quality. This study received ethics approval from NT Department of Health/Menzies School of Health Research ethics committee (approval HREC 2016–2734).

The sampling frame was the entire cohort of adult patients who a) received trauma team activation or b) were included in the trauma registry of Royal Darwin Hospital in 2015. From the original clinical record all components of the TTAC, and corresponding outcomes, were extracted for each case. Any registry entries that were unclear on which TTAC were met underwent an electronic chart review that included triage comments, surgical admission note or ICU/hospital discharge summary.

Presentations in which patients clearly met criteria for a trauma team activation but were not included in the trauma registry,

commonly because the patients did not require hospital admission, were found by interrogating the hospitals patient tracking software for a record of all ED presentations triaged as a category 1 over the trial period. Presentations that were duplicated in the trauma registry were removed and the enduring presentations were electronically reviewed to eliminate patients less than 15 years of age and non-trauma emergencies. The remaining presentations underwent a paper and electronic chart review to extract the necessary information.

One author (MC) reviewed every case to determine which, if any, TTAC were fulfilled for each presentation regardless of if a trauma team activation occurred at presentation. The presentations that were transferred direct to OT were reviewed by authors, MC and LC, to determine if the need was indeed for potentially life or limb saving surgery. ISS was calculated by Trauma Service Nurse Consultants using the Abbreviated Injury Scale (AIS) 2005 revision, 2008 updates [24].

The association odds ratio of each criterion with the outcome of MT was calculated. Where the criterion was not present in any patient, or MT was not present in any patient with the criterion, no association was possible and they were not considered further.

Various measures may be used to test the performance of a Trauma System. The concept of "Overtriage" has been defined as the proportion of patients that met TTAC but did not suffer MT. This views the TTAC as a clinical test, so that Overtriage equates to the false positive proportion (1-positive predictive value (PPV), where PPV is the probability of MT conditional on trauma team activation). This is a commonly agreed upon approach [15,18,25,26]. "Undertriage" is equivalent to false negatives (1-sensitivity) and has been defined as the fraction of patients who suffer major trauma and did not fulfil TTAC. These patients have been considered at increased risk of adverse outcomes [25–29].

The predictive effect of each criterion, adjusted for the presence of others, was assessed by logistic regression. Individual criteria were sequentially "dropped" (treated as never observed) starting from those represented in zero patients, progressing through those present in fewer than 5 patients and then those with the lowest predictive value. The predictive value of the resulting hypothetical TTAC was calculated and all criteria were retained which were contained in the first model in the chained series with a significant drop in likelihood ratio compared to the non-selective model. In addition, the initial model and the model rejecting non-contributory criteria were reparameterised by "collapsing" similar criteria into a priori defined groups. Pearson's correlation of each criterion with each other in this cohort was calculated.

Results

During the study period there were 690 trauma registry patients aged 15 or over. In addition there were 94 trauma team activations not included in the trauma registry (Fig. 1). The mean age of patients was 39.6 years. 428 (55%) of presentations met TTAC of whom 293 did not suffer MT, an overtriage risk of 68%. 164 (21%) presentations suffered MT; two patients died in ED, 135 were admitted direct to ICU of whom 6 died, 27 required urgent OT of whom 8 died. The odds ratio of MT if meeting TTAC was 5.20 (p < 0.0001 chi squared test) in this cohort of 784 patients.

There were 29 patients with MT who did not meet TTAC, an undertriage risk of 18%, none of whom died. The median ISS of undertriaged patients was 10 while in "appropriate triage" the median ISS was 17 (p = 0.0056, Mann-Whitney U test). Of the 29 MTs not meeting TTAC, 15 patients met criteria for a second tier activation. Four patients died of the 356 who had not met TTAC compared to 19 of the 428 who had met TTAC, an odds ratio of 4.09 (p = 0.004).
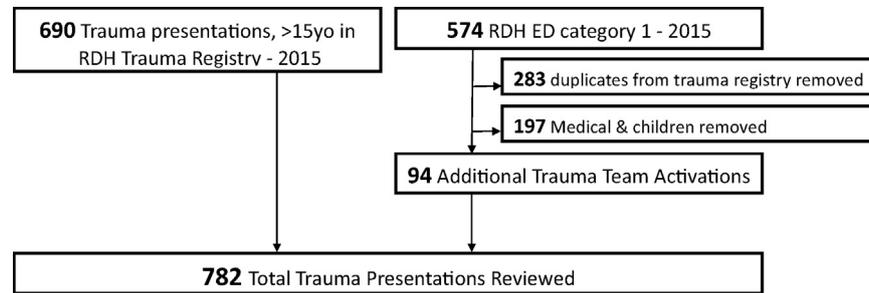
Fig. 1. Study cohort and data source.

Table 1 shows the number of activations and the associated MTs for each TTAC. No criterion was significantly associated with any other by pairwise analysis. Criteria that activated 5 or less trauma team activations have been removed. Subjective criteria based on clinical judgment including "respiratory distress", "severe injury to two or more regions", and "severe facial injury" were removed from further analysis due to likely significant differences between the interpretation amongst triage nurses and the reviewing authors. There were only seven trauma team activations in which the subjective criteria or the rare activators were the only criteria met, three of which were MTs.

Notable criteria removed due to rare activation are "prolonged capillary refill" or "cyanosis". These criteria are not included in trauma registry data intake and unless documented by triage nurse this was not included in our data collection, as such there were likely to be more patients presenting with these findings then has been recorded.

The Pre-hospital Criteria coupled with "HR > 120" and ">2 Long bone fractures" have the lowest associations with MT. When those presentations that meet Pre-hospital Criteria without meeting any of the Clinical Criteria are examined separately (Table 2) the extent of overtriage from these criteria can be appreciated. 57% of the overtriages seen at RDH can be attributed to these criteria yet only independently contribute 6% (10/164) of MT identification.

Criteria with similar mechanism, similar injury profiles and similar physiological system abnormalities were grouped together to simplify the current criteria for logistic regression (Appendix 2). Fig. 2 demonstrates the collapsed criteria associations with MT and associated adjusted odds ratios from logistic regression. Of note circulation criteria (HR > 120 or SBP < 90) were not significant independent predictors. One of "GCS < 14", "pelvic instability" or "airway compromise" was present in all but two hypotensive patients.

Criteria with the poorest predictive ability for MT under multivariable analysis were sequentially removed and the number of appropriate, under and over triages estimated. Through this process a number of models with proposed altered TTAC were created, their performance in predicting major trauma is compared with the current TTAC in Table 3. Removal of the common "Pre-hospital Criteria" or removal of the "Non-significant Criteria" from logistic regression result in large decreases in the number of overtriages and subsequent overtriage rate. As more criteria are removed however the number of undertriages increase. An altered criteria resembling the "ACS COT" minimum suggested criteria comprising of "GCS < 14", airway or respiratory compromise, gunshot wound or "SBP < 90", quarters the total number of overtriages but the undertriage rate doubles to 35%. In this cohort all three altered criteria show a significant improvement in accuracy when compared to the current TTAC. There were no in hospital deaths in any of the extra patients undertriaged by the altered TTAC. The median ISS of the undertriaged patients from all 3 of the altered TTAC were significantly lower than the median ISS of the appropriately triaged.

Table 1
Association of individual criteria with major trauma.

Criteria	Trauma team activations	Associated major traumas (proportion)	Univariate OR
Pre-hospital Criteria			
MVC ejection	40	17 (0.43)	3.0[*]
MVC entrapment	25	11 (0.44)	3.1[*]
MVC fatality at scene	16	6 (0.38)	2.3
Pedestrian vs car > 30 km/h	32	12 (0.38)	2.4[*]
Fall > 3 m	26	7 (0.27)	1.4
Central crush injury	9	3 (0.33)	2.3
Central penetrating injury	75	8 (0.11)	0.4
>3 Simultaneous patients	70	14 (0.20)	0.9
Clinical Criteria			
Airway compromise	29	26 (0.90)	38.9[*]
Intubation attempted/required	50	50 (1.0)	
Heart rate > 120 bpm	77	27 (0.35)	2.3[*]
SBP < 90 mmHg	37	24 (0.65)	8.0[*]
>2 Long bone fractures	17	6 (0.35)	2.1
Pelvic instability	11	9 (0.82)	18[*]
Respiratory rate > 30	43	25 (0.58)	6.0[*]
Oxygen saturation < 90%	29	24 (0.83)	21.2[*]
Flail chest	7	7 (1.0)	
GCS < 14	123	79 (0.64)	12.2[*]
Agitated post head injury	21	15 (0.71)	10.3[*]
Seizure post head injury	11	5 (0.45)	3.2[*]
Neurological deficit	7	4 (0.57)	5.2[*]

Univariate odds ratio (OR) refers to the odds of patients with a criterion for the outcome of "Major Trauma" compared to the odds for those without the criterion. [*]Statistically significant 95% confidence interval. MVC - motor vehicle crash, SBP - systolic blood pressure, GCS - Glasgow coma scale.

Table 2
Association of Pre-hospital Criteria with overtriage when no Clinical Criteria are met.

Criteria	Trauma team activations	Associated major traumas	Proportion of overtriage
MVC ejection	24	3	0.07
MVC entrapment	7	0	0.02
MVC fatality at scene	9	1	0.03
Pedestrian vs car > 30 km/h	15	0	0.05
Fall > 3 m	17	0	0.06
Central crush injury	4	0	0.01
Central penetrating injury	52	5	0.16
>3 simultaneous patients	51	2	0.17
Total	167	10	0.57

Twelve activations were MVCs with ">3 simultaneous patients" and one Major Trauma was both a "MVC ejection" and ">3 simultaneous patients".
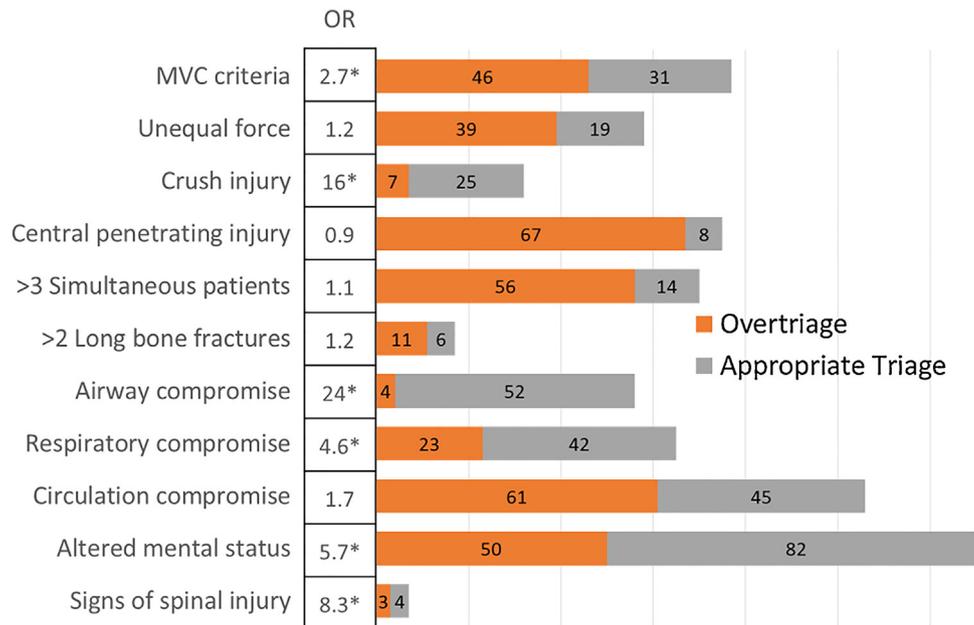

Fig. 2. Collapsed criteria association with major trauma.
The adjusted odds ratio (OR) for each collapsed criteria for the outcome of "major trauma". * - statistically significant 95% confidence interval.
Each bar represents the total number of trauma team activations divided into sections indicating the number with and without the presence of major trauma.

Table 3
Comparison of the performance of the Current TTAC with Altered TTAC.

	Current TTAC	Pre-Hospital Criteria Removed	Non-significant Criteria Removed	ACS COT Criteria
Trauma team activations	428	261	246	179
Major traumas missed	29	39	40	58
Activated without MT	293	136	122	73
Overtriage %	69	52	50	41
Undertriage %	18	24	24	35
ISS of the undertriaged	10	10	10	12
Accuracy	0.59	0.78	0.80	0.83

TTAC – Trauma Team Activation Criteria, Non-significant – collapsed criteria that did not achieve a significant multivariable odds ratio for the independent prediction of major trauma, ACS COT Criteria – minimum criteria for trauma team activation suggested by American College of Surgeons Committee on Trauma. ISS reported is the median.
Accuracy of criteria has been calculated using (true positive + true negative)/total cases.

Discussion

The activation of a trauma team provides a multidisciplinary team to expedite definitive treatment or perform urgent procedures on the arrival of an injured patient. The accuracy of the criteria used to activate that team is critical as it determines the commitment of a limited hospital wide resource as well as helping to ensure the efficient initial management of those severely injured patients. This study has evaluated the performance of a TTAC in predicting which patients will require initial trauma team care at an Australian regional hospital.

The system in use at RDH, in which any one finding among 45 separate criteria may activate a trauma team, is found elsewhere but is prone to activation by operator-dependent criteria, momentary findings, selection bias due to cherry picking of observations and inability to be "tuned". Tuning of a predictive system refers to the ability

to place more weight on certain criteria without rejecting others, perhaps in response to changing epidemiology or improved outcome detection altering the predictive value of given criteria.

Our assumptions in predicting behaviour of a future TTAC system using modification of the current criteria are as follows: firstly, that there is no correlation between individual criteria. Perhaps surprisingly, this is largely the case in the current cohort. Secondly, that there is no confounding of the predictive effect of a given highly performing criterion and an apparently poorly performing criterion which is a candidate for removal. Thirdly, that triage behaviour will remain unaltered after a significant change to the TTAC system. There is some evidence of complex confounding in the current cohort, particularly between hypotension and other indicators of severe injury such as "GCS < 14", "pelvic instability" and "airway compromise".

With these assumptions, the criteria "Pedestrian/cyclist vs car >30 km/h" and "falls from height greater than 3 m" add little predictive value, as seen elsewhere [28,30,31]. These criteria were the worst performers and could be moved from the current TTAC to achieve a modest reduction in overtriage without any effect on undertriage.

In previous studies Motor vehicle Crash (MVC) mechanisms contribute a significant degree of overtriage, in particular "MVC ejection" and "MVC Entrapment" criterion that are used in RDH's current TTAC [13,31,32]. Similarly in this study greater than 10% of the total overtriage can be attributed to these criteria. When these criteria are collapsed together however they are an independent predictor of MT, although numbers are small.

The "Multiple simultaneous patients" criterion is not commonly used in Australian institutions [33], this study is the first to examine its performance in predicting MT. This criterion was responsible for a large proportion of overtriage and would likely perform similarly in different settings given that it is not linked to any form of mechanism or physiological factor. The benefits of this criterion on ED patient flow has not been examined.

"Central penetrating injury" was a common presentation in this study. This high incidence is in contrast to other studies from Australian institutions [4,29], a result that may be partly explained by the higher rates of domestic violence seen in the Northern Territory [34]. Only 11% of central penetrating injuries were related to major trauma and this contributed a significant proportion of the total overtriage. Gunshot wound was uncommon (1/85). The low incidence of major trauma related to penetrating injuries contrasts with studies from institutions that see a higher rate of gun related injuries [15], central gunshot wounds are consistently an independent predictor of major trauma [17,35]. Kohn et al. found a similar rate of 15% major trauma when examining centrally located penetrating injuries caused by stabbing alone [17]. We propose revising the penetrating injury criteria to "Gunshot Wound" to improve TTAC accuracy, this finding may be generalizable to other institutions.

Systolic blood pressure of less than 90 mmHg is a significant, consistent, powerful independent predictor of MT [14,15,17] but was not in this study. Hypotension was strongly correlated with other criteria (GCS < 14, airway compromise and pelvic instability) and became non-significant when combined in any model with these collinear predictors. This instability of estimate with collinearity is exacerbated by treatment selection bias, whereby patients with impaired consciousness or airway compromise are far more likely to be intubated and hence defined as MT. A more important reason for the lack of influence of hypotension is the lack of risk-proportionate weighting among the TTAC, where any positive finding among the 45 criteria activates a trauma team.

Institutions that include MOI criteria to activate trauma teams report rates of undertriage [36] and overtriage similar to those found in this study [16,36]. Systems without MOI criteria cite higher undertriage rates of 26–35% and lower overtriage rates of 27–49% [4,17,22,23,37].

The benefits of minimising undertriage have been previously examined. Activating a trauma team decreases time to definitive diagnosis and treatment [23,29,38–40]. A mortality benefit has also been suggested in moderate to severely injured patients when using TRISS analysis [1,2]. Although the ideal level of undertriage would be 0% [25] an accepted level using the false negative approach for defining undertriage has not been agreed upon. Conversely the impact of high rates of overtriage on patient care in the rest of the hospital has not been thoroughly examined although an acceptable overtriage rate of 25–50% has been proposed [4,18,41].

An "acceptable overtriage rate" at RDH may be achieved by removing a number of underperforming criteria suggested by the current cohort. If our assumptions are justified, to achieve an overtriage of less than 50% there would be a rise in the undertriage rate within limits seen in other Australian institutions to between 24% and 35%. In actual patient numbers, removal of the Pre-hospital Criteria, for example, would lead to the avoidance of 15 overtriages for every one additional undertriage seen.

As discussed previously by Kohn et al. [17] whether this is an acceptable change for a hospital depends on the relative cost of each additional missed activation versus the cost of the equivalent saved false positive activations. The cost of each undertriage would be a combination of the risk of increased morbidity suffered by the undertriaged patients coupled with the known detrimental effects on patient flow in the ED. The ability of the ED staff to initially manage the MT and minimise this risk may depend on time of day, ED staffing levels and seniority of staff. The results of this study do suggest that major traumas that are undertriaged tend to be less injured then those appropriately triaged when using current or altered TTAC and therefore may be at decreased risk of morbidity [42].

Limitations

The population that RDH serves has some unique characteristics in comparison to the majority of similarly sized hospitals in Australia. A significant proportion of the population live in remote communities that have limited access to health care and are inaccessible by road for many months of the year. The difficult access can often lead to prolonged transit times for the severely injured. Due to these differences the ability to generalise these results to urban centres and even other regional centres may be limited.

It has been shown that rates of injury and death are increased in relation to remoteness and other access difficulty [20,43]. The remoteness of location of injury and transit time between injury and arrival to hospital has not been examined in this study and may subject our results to bias. The most likely effect for physiological criteria would be to bias the estimates of predictive value for any physiological criterion towards no effect if physiology improved with treatment during transport in those who would remain severely injured and meet major trauma definitions, and have no effect in those in whom physiological parameters worsened as they deteriorated. In the presence of a bias toward the null hypothesis of no informational value, the TTAC system would appear less predictive, with an apparent increase in undertriage. In an effort to minimise this misclassification bias we have used any pre-hospital observations as well as ED arrival observations to calculate TTAC.

The retrospective nature of this analysis means our data is reliant on the quality of documentation and data collection. Models including highly subjective criteria such as "severe injury to 2 or more body areas" performed equivalently to models in which such criteria were excluded. A priori it seems that these

criteria may be removed, with due caution to the possible effect of that change in removing the clinical intuition of the person performing triage, and hence a recognition that further audit would be required.

The choice of study population has a strong influence on the interpretation of results. We included all those who, after screening for trauma using clinical intuition appropriately applied by a trained nurse, were felt to have suffered a traumatic injury sufficient to apply and activate the trauma team, or who evidently required higher level intervention from within ED or during their hospital stay. Patients who had neither MT nor activation of a trauma team do not contribute to the overtriage or undertriage calculations however these patients do contribute to the accuracy measurement. This group would contain many patients who never appear in this study and therefore the accuracy result reported is a significant underestimate of the true accuracy of the TTAC. As such the value of this accuracy figure is to compare between the current and altered TTAC within this study only and not for comparisons of accuracy with other centres or other studies.

By using the same data set to identify independent predictors and then test the performance of those altered criteria is a form of circular analysis and therefore may inflate the apparent performance of altered criteria. A study applying these findings to a separate cohort of patients would reduce this potential bias.

Conclusion

This study has demonstrated that physiological criteria that indicate the airway, respiratory or neurological system is compromised are the best predictors of MT. As hypothesized Pre-hospital Criteria that activate trauma teams based on mechanism of injury have been found to contribute a high proportion of overtriage. We predict that these criteria may be removed from the TTAC, improving the accuracy, with only a small increase in the rate of undertriage. There is a small amount of evidence that the assumptions underlying our recommendations are violated, particularly in the unstable estimates of the contribution of hypotension to outcome prediction due to collinearity. The impact of any change in the TTAC system should therefore be audited prospectively.

Conflict of interest

There are no declared conflict of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2018.09.050.

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