Field triage of victims of trauma

Efficacy of trauma team activation protocols

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To Janne, Tobias, Oliver and Markus

Any man’s death diminishes me, because I am involved in Mankind
John Donne (1572–1631)

Contents

Preface

I first encountered emergency medicine as a clearance diver in the Royal Norwegian Navy. My interest for trauma care was further refined as a Sea King rescue helicopter winch man in the Royal Norwegian Air Force. When I left the service after four years for medical school, pre-hospital critical care (PhCC) was my crystal clear career choice.

Providing critical care for trauma victims offers ample challenges for dedicated healthcare professionals. Emergency medical service (EMS) providers must execute time-critical emergency procedures with rapid decision-making in a hostile pre-hospital environment. If you add the intellectual challenge of doing PhCC research on top of the before mentioned tasks, you have an occupation it takes a lifetime to master.

EMS providers are privileged to assist patients in a critical period in their life, and I have had the opportunity to meet many dedicated colleagues during my years in the service. The most recent friendships were made while working as a Ph.D. student in the Norwegian Air Ambulance Foundation (SNLA). SNLA is Norway's largest non-profit organization, representing about 20% of the Norwegian population. Its roughly 800 000 members allow funding of EMS quality improvement initiatives. The SNLA research group evolved from six Ph.D. students (including myself!) and one senior researcher to become one of the largest emergency medicine research clusters in Northern Europe. Being a patient organisation for the critically ill, SNLA perseveringly believes that improvement in care comes through research. I am grateful for all support SNLA has provided, both socially and financially.

One cannot mention SNLA research without thinking of Professor Hans Morten Lossius. Hans Morten contacted me while I was still a medical student. His enthusiasm, loyalty and dedication to critical care sparked my interest in research and still motivate me to engage in projects. Now, 6 years later we still heatedly discuss matters of research and quality improvement (as well as football and craft beer). I am grateful for all his support and look forward to future projects and discussions. Dr. Torsten Eken has been a mentor during medical school and throughout this Ph.D. project. His analytical mind and knowledgeable feedback have taught me to improve my work and work hard. I am very grateful for his friendly and thoughtful advice. Professor Petter Andreas Steen shared his wealth of experience and helped me off to a

good start at the University of Oslo. His ability to structure manuscripts has been a great inspiration. It has also been a true privilege to participate in the social and academically rewarding environment created by my talented and dear SNLA research fellows. I am really excited about the future and have great expectations.

This thesis would never have been completed without the enormous support and kindness shown by my family and good friends. We have shared fun and frustrations throughout many years and I value your support enormously. My closest ally throughout adulthood has been my very dear wife. Janne Thon Rehn has a huge share in this project through her thoughtful advice and love (and patience) for all the boys in our family. My dearest sons, Tobias, Oliver and Markus have sometimes lent their father to projects involving those not so fortunate as themselves. I take their patience and understanding as a sign of solidarity to victims of trauma they have fortunately never seen.

List of papers

This thesis is based on the following papers, which will be referred to by Roman numerals in the text:

I: Rehn M, Eken T, Krüger AJ, Steen PA, Skaga NO, Lossius HM. Precision of field triage in patients brought to a trauma centre after introducing trauma team activation guidelines. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine, 2009. 17: 1.

II: Rehn M, Lossius HM, Tjosevik KE, Vetrhus M, Østebø O, Eken T. Efficacy of a two-tiered trauma team activation protocol in a Norwegian trauma centre. British Journal of Surgery, 2012. 99: 199-208.

III: Rehn M, Perel P, Blackhall K, Lossius HM. Prognostic models for the early care of trauma patients: a systematic review. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine, 2011. 19: 17.

IV: Lossius HM, Rehn M, Tjosevik KE, Eken T. Calculating trauma triage precision: effects of different definitions of major trauma. Submitted

Abbreviations

AAAM	Association for the Advancement of Automotive Medicine
ACS-COT	American College of Surgeons, Committee on Trauma
AIS	Abbreviated Injury Scale
ASA-PS	American Society of Anaesthesiologists Physical Status
CCI	Charlson Co–morbidity Index
ED	Emergency Department
EMCC	Emergency Medical Communication Centre
EMS	Emergency Medical Service
GCS	Glasgow Coma Scale
GPS	Global Positioning System
HEMS	Helicopter EMS
ICU	Intensive Care Unit
ISS	Injury Severity Score
MGAP	Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure
NISS	New Injury Severity Score
OUH – U	Oslo University Hospital – Ullevål†
PhCC	Pre-hospital critical care
PPV	Positive Predictive Value
Ps	Probability of Survival
RR	Respiratory Rate
SAR	Search and Rescue
SBP	Systolic Blood Pressure
SNLA	Norwegian Air Ambulance Foundation*
SUH	Stavanger University Hospital
TRISS	Trauma Score—Injury Severity Score
T-RTS	Triage-Revised Trauma Score
TTA	Trauma Team Activation
UUH	Ullevål University Hospital†

* Stiftelsen Norsk Luftambulanse (In Norwegian)

† Name change due to hospital reorganisation during the Ph.D. period: Ullevål University Hospital to Oslo University Hospital – Ullevål.

General introduction

Prerequisites for high quality trauma care are systems designed to get “the right patient to the right treatment at the right time”. Early identification of major trauma enables healthcare providers to “do the most for most” by providing timely emergency care and rapid transport to an appropriate health-care facility.

Triage is a widely applied term derived from the French verb trier, meaning to sort or to sift [1]. The credit for inventing triage has historically been attributed to Baron Dominique Jean Larrey, chief surgeon to Napoleon Bonaparte [2]. Interestingly, the technique was initially used to identify soldiers with minor injuries that could be returned to the acts of war [1]. Originally, the term was confined to prioritization of mass casualties in resource-constrained environments. Today, triage is routinely applied when EMS providers classify patients according to injury severity to match victim needs with available resources [3]. Accordingly, triage encompasses processes such as hospital destination decisions and trauma team activation (TTA). Further, an increasing number of hospitals utilize triage systems to give patients that bypass pre-hospital EMS a priority in crowded emergency departments. The process must identify and sort the small proportion of trauma victims in need for high resource specialized trauma care. Triage remains a core component in modern trauma systems as inaccurate assessment of injury severity has negative effects on quality of care, patient safety, and resource utilisation.

For purposes of this thesis, field triage pertains to algorithms designed for civilian routine decision-making on level of care and activated resources for trauma victims.

The overall goal of this thesis with its four component studies has been to improve trauma system efficacy through higher precision of field trauma triage. The first study evaluates triage guidelines efficacy at a large trauma centre (I). The second prospectively investigates if the efficacy can be improved by implementing a two-tiered trauma team activation protocol (II). As we acknowledge that healthcare providers rely on valid field friendly tools in their early evaluations, we also sought to systematically review and investigate the quality of existing models that estimate prognosis of patients in the early stages of care (III). The lack of a uniform definition of "major trauma" is a serious methodological issue. We therefore explored the possible influence of different definitions of major trauma on triage precision calculations (IV) by using data from study II.

Epidemiology of injuries

Globally, over five million people annually perish as a consequence of injuries, while innumerable others become permanently or temporarily disabled [4]. The global trauma burden represents an increasing health problem that causes incalculable suffering for individuals, families and societies [3]. More than 90% of injury deaths occur in low- and middle-income countries, where the scale of the healthcare system is insufficient to cope with the challenges [5]. Although the death toll is largest among the economically deprived, injury remains a leading cause of deaths among adults aged 15–59 years also in high income countries [4].

In Norway, injuries constitute a major public health problem with an annual paediatric injury mortality rate of 4,8 per 100 000 [6]. Road traffic injuries constitute a major cause of death among male youth (age 16–20 years) with an annual death rate of 33,8 per 100 000 compared to 10,0 per 100 000 females [7].

Trauma systems

The impact of trauma is optimally reduced by preventive measures to avoid their occurrence or minimize their severity. When this fails, harm from injury may be minimised through prompt initiation of specialized comprehensive care [3].

It is recommended that health care systems have a systematic and inclusive approach to trauma care [3, 8] with coordinated pre-hospital and acute care services in their catchement area to ensure the best use of available trauma care resources [9]. Trauma system have administrative components such as leadership, system development, legislation and finance and clinical components such as injury prevention, pre-hospital care, definitive care facilities and research [10]. Inclusive trauma systems define roles for all levels and types of health care facilities from the scene of injury to rehabilitation. Accordingly, such systems acknowledge the ability of all acute healthcare facilities, including local and central hospitals, to care for patients with more minor injuries [11] (cf. Figure 1). In contrast, exclusive trauma systems incorporate only specialized centres as trauma care providers.

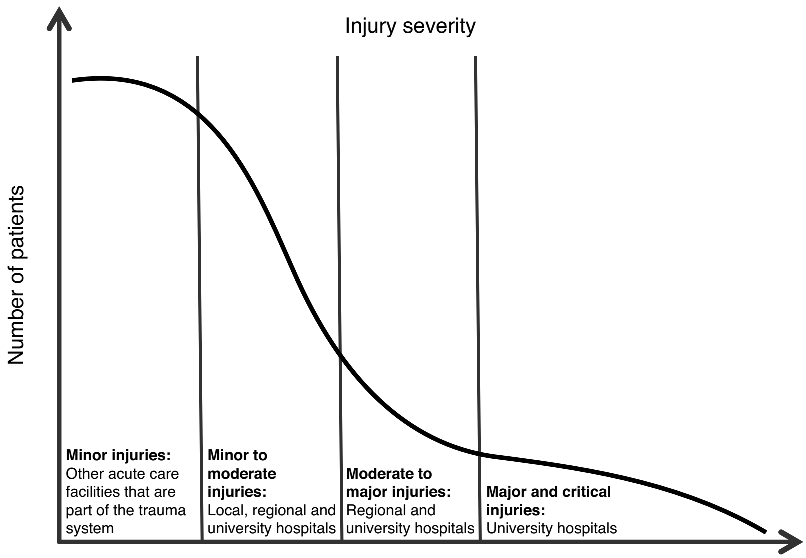


Figure 1 Inclusive trauma system. Adapted from U.S. Department of health and human services: Model trauma care system plan. Rockville; 1992. Modified to accomodate the Norwegian system.

For major trauma victims, regionalized trauma care with specialized trauma centres reduces in-hospital trauma mortality [12-15] and the trend increases with injury severity [16]. Accordingly, victims of major trauma may profit from bypassing local hospitals with direct transport to the regional trauma centre. However, if transportation time to the trauma centre is long, it may be beneficial to transport to a local hospital for stabilisation prior to inter-hospital transfer for definitive care [3].

Norway has a three-level system of local, central, and regional university hospitals. The catchment areas for local and central hospitals range from 13 000 to 400 000 patients. University hospitals serve as trauma referral centres and provide definitive care for populations ranging from 460 000 to 2 700 000 [8]. Although Norway encompasses an inclusive approach with approximately 50 hospitals offering trauma care, formal trauma systems remain unimplemented [8, 17].

Trauma research

High quality documentation on care processes and patient factors is the backbone of trauma research. Accordingly, the establishment of trauma registries has paralleled the development of trauma systems [18]. Trauma registries document data pertaining to predictive models, system characteristics and process mapping and add value beyond easily available administrative data [19-21]. These registries serve multiple purposes including epidemiology, quality improvement, clinical research and administrative and political decision-making [14, 22]. In Norway, as in many European countries, trauma registries are regional, university hospital based, and lack uniformity. This complicates inter-registry research collaboration and benchmarking with international standards [23]. In general, missing and heterogeneously defined pre-hospital and hospital data variables remain a significant barrier for trauma research [24-26]. Initiatives have been launched to counteract these deficiencies and recognised data set dictionaries are now available [21, 27, 28]. Although a consensus regarding the establishment of a national trauma database exists [8] a national Norwegian trauma registry remains unimplemented.

Pre-hospital critical care and the Norwegian EMS

Pre-hospital critical care (PhCC) aims to provide early clinical evaluation of the patient's chief complaints, provide appropriate time-dependent care on-scene and enroute to the most appropriate receiving health care facility [29]. PhCC is heterogeneously organised since factors such as public versus private healthcare, EMS provider competence, and pre-hospital physician involvement vary [25]. Further, geographical conditions, patient volume and injury characteristics contribute to regional variations.

In Norway, equal access to health services regardless of residency is a long-standing major political goal [30]. While this is not fully achievable due to scattered populations, time consuming transport and subarctic climatic conditions [25, 31] the extensive air ambulance service contributes to balancing the differences in access to critical care between rural and urban areas. Together the ground and air ambulances constitute a chain of survival for patients with acute, treatment-dependent conditions [8, 32]. Below is a description of the Norwegian EMS.

Emergency medical communication centres

Emergency medical communication centres (EMCCs) handle bystander calls and communicate with the EMS providers, making it the first-line trauma triage service. They are staffed by nurses and paramedics with a physician on-call to provide medical direction. They utilize the criteria-based "Norwegian Index of Medical Emergencies" to establish priority (green, yellow, red response) [33], and coordinate ambulance resources and in many areas also general practitioners (GP) on-call. EMCCs can be accessed by calling a nationwide, toll-free three-digit emergency number 1-1-3 [34] , and handle approximately 25 red responses (potentially or manifest life-threatening situations) annually per 1 000 inhabitants. A recent study concluded that the majority of these red responses involved patients suffering from non-life-threatening conditions [35]. The government indicated in 2000 that for red responses 90% of the urban and 90% of the rural population should be reached within 12 and 25 minutes respectively [36].

Ground and boat ambulance units

Ground and boat ambulances manned by emergency medical technicians or paramedics constitute the main pre-hospital EMS alternative throughout the country [37]. Several initiatives such as global positioning system (GPS) assisted fleet coordination systems and tele-medical solutions have been launched to improve quality and standardize the service [38].

General practitioners

GPs on-call provide emergency primary health care services to patients arriving at community-based casualty clinics. In addition, they make house calls and also to various degrees attend patients at the scene together with the ambulance services outside the larger cities. In many areas the EMCCs are instructed to alert all red responses simultaneously to ambulance units and the GP on-call [39]. Recent reports have found decreasing GP involvement in these responses [40, 41]. No formal competence in emergency medicine beyond medical school is required for GPs on-call and experience with emergency procedures remains low [42].

Air ambulance system

The national Norwegian air ambulance system was formed in 1988 and is today integrated in the national emergency medical preparedness programme [43]. The service is administered by "Luftambulansetjenesten ANS", a cooperation established by the four Regional Health Authorities in 2004 [44]. The service has full governmental funding and consists of 11 all-year day and night operational helicopter

EMS (HEMS) bases operating under both visual and instrumental flight rules. Additionally, seven fixed wing bases and seven search and rescue (SAR) helicopter bases [44] are included in the national air ambulance program. All helicopter units aim to provide rapid access to high quality advanced life support by including specially trained anaesthesiologists in the crew [25, 45-47]. The fixed wing bases have specially trained nurses with an anaesthesiologist as an optional resource. Demanding geographical and climatic conditions with seasonal darkness challenge regularity for air operations [31, 48-50]. On all HEMS and some SAR bases, the crew use rapid response cars as an alternative transportation resource [51].

Emergency departments

Trauma care comprises a multidisciplinary approach and interns, residents and consultants from the various specialties cover emergency departments (EDs) in Norway [31, 41, 43]. A majority of the hospitals have implemented specialised and dedicated trauma teams [17] and formal ED triage systems to identify and prioritize patients according to injury severity [52]. In 2005 50 hospitals provided trauma care in Norway, most with low admission rates. Almost 90% of these hospitals deliver immediate care via multidisciplinary trauma teams to optimize outcome (cf. Table 1 for suggested team composition) [17, 53]. The majority of these hospitals have predefined TTA criteria. A cross-sectional study revealed considerable variation in these criteria, including physiological cut-off values [54].

Field triage in regional trauma systems

A majority of trauma related deaths occur during the pre-hospital period or in the initial hours after injury [3]. In regional trauma systems, early identification of major trauma may enable EMS providers to rapidly transport victims to the appropriate level of care (e.g. a regional university hospital) and activate appropriate resources (e.g. the trauma team) prior to arrival. The time to "restoration of adequate flow and physiology" is recognised as crucial and pre-notification of hospital resources ensures rapid access to damage control resuscitation resources [28, 55-59].

The development of field triage protocols has paralleled the development of regional trauma centres and trauma teams. The American College of Surgeons, Committee on Trauma (ACS-COT) has pioneered this progress through periodical

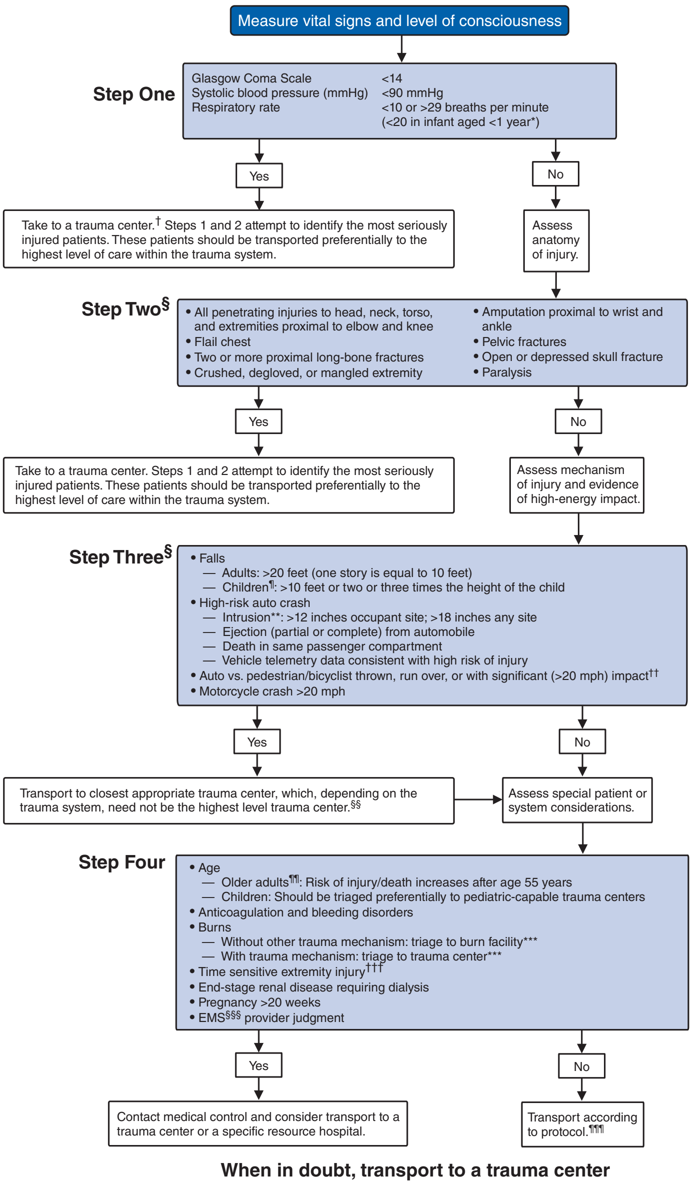
FULL trauma team (13 members)	**REDUCED trauma team** (4 members)
Team leader surgeon	Surgeon
Orthopaedic surgeon	Orthopaedic surgeon
Theatre nurse	2 ED nurses
3 ED nurses	
Anaesthesiologist	
Nurse anaesthetist	
Radiologist	
2 radiographers	
Laboratory technician	
Orderly	

Table 1 Suggested trauma team composition (FULL and REDUCED; Stavanger university hospital). ED, Emergency Department.

revisions of "Resources for optimal care of the injured patient" [10] and the "Field triage decision scheme" (cf. Figure 2) [60].

Mistriage

Pre-hospital recognition of major trauma remains a challenge due to occult injuries, the evolutionary nature of symptoms following major trauma, and the complexities of evaluating patients in the field in the early stages of care. If major trauma victims are treated at the local hospital rather than being stabilized and rapidly transported to a central or regional university hospital providing higher level of trauma care (undertriage), avoidable deaths may occur [3]. At hospital admission, delay to high resource resuscitation and expert evaluation provided by a trauma team can result in unfavourable outcome [53, 61]. At the same time trauma team attention to patients with minor injuries (overtriage) consumes scarce financial and human resources [62] and contributes to ED overcrowding with subsequent suboptimal care of other patients [63-65]. It also causes unnecessary local hospital bypass with increased transportation time causing reduced EMS coverage in the primary catchment area. During major incidents, overtriage leads to flooding of scarce medical resources with



SOURCE: Adapted from American College of Surgeons. Resources for the optimal care of the injured patient. Chicago, IL: American College of Surgeons; 2006. Footnotes have been added to enhance understanding of field triage by persons outside the acute injury care field.

* The upper limit of respiratory rate in infants is >29 breaths per minute to maintain a higher level of overtriage for infants
† Trauma centers are designated Level I–IV, with Level I representing the highest level of trauma care available.
§ Any injury noted in Steps 2 and 3 triggers a "yes" response.
¶ Age <15 years.
** Intrusion refers to interior compartment intrusion, as opposed to deformation which refers to exterior damage.
†† Includes pedestrians or bicyclists thrown or run over by a motor vehicle or those with estimated impact >20 mph with a motor vehicle.
§§ Local or regional protocols should be used to determine the most appropriate level of trauma center; appropriate center need not be Level I.
¶¶ Age >55 years.
*** Patients with both burns and concomitant trauma for whom the burn injury poses the greatest risk for morbidity and mortality should be transferred to a burn center. If the nonburn trauma presents a greater immediate risk, the patient may be stabilized in a trauma center and then transferred to a burn center.
††† Injuries such as an open fracture or fracture with neurovascular compromise.
§§§ Emergency medical services.
¶¶¶ Patients who do not meet any of the triage criteria in Steps 1–4 should be transported to the most appropriate medical facility as outlined in local EMS protocols.

Figure 2 Field triage decision scheme – United States of America. Adapted from Centers for Disease Control: Material in the public domain. No reprint permission necessary.

minor trauma victims not in need of specialized comprehensive care [66], potentially delaying treatment of those seriously injured with increased mortality [67].

Specificity and sensitivity are often negatively correlated making optimal field triage a balance between efficient resource utilisation and patient safety. ACS-COT therefore describes 5% undertriage as acceptable and associated with an overtriage rate of 25% – 50% [10], a benchmark which remains debated [68].

Triage protocols

A combined literature review and US national expert panel consensus resulted in the 2009 "Guidelines for Field Triage of Injured Patients" [69, 70] (cf. Figure 2). To improve triage efficacy, this report recommends a tiered response according to patients' risk for suffering from major trauma. Further, it presents a stepwise evaluation of trauma victims for physiological instability, obvious anatomical injury, mechanism of injury (MOI), and co-morbidity. A systematic literature review found several studies evaluating field triage criteria, but concluded that there is insufficient evidence to support existing algorithms [70]. Nevertheless, many of these criteria have been adopted in TTA protocols to avoid unnecessary delay to multispecialty resuscitation and evaluation provided by the trauma team.

Triage criteria; physiology

In general, criteria pertaining to "vital signs" are considered highly specific (i.e., when positive, the patient is a major trauma victim), but not very sensitive (i.e., if negative, the patient may still be a major trauma victim), particularly at an early stage. Therefore, vital signs can never be utilized as the only field triage criteria [69], but several prognostic models combining physiological predictors have been developed and included in triage protocols [71]. To overcome the mistriage that occurs when children are subject to adult physiological triage criteria, several triage systems adjust for paediatric physiology [72-74].

Triage criteria; anatomy

Criteria pertaining to anatomical injury focus on obvious injuries like penetrating proximal trauma and mangled extremities [75, 76]. Detection of more occult injuries compels a fully exposed patient, usually not feasible in the field, and requires considerable competence, thereby increasing the risk for low inter-operator reliability.

Lastly, anatomical criteria alone often fail to detect internal haemorrhage, a major threat to trauma victims, and cannot therefore be used as the only field triage criteria.

Triage criteria; mechanism of injury

Trauma victims not meeting physiologic or anatomic criteria may have severe, occult injuries [77]. MOI criteria are relatively easy to assess and may identify patients who have sustained major trauma before physiological decompensation occurs. MOI criteria have been widely studied and perform poorly when employed alone to detect major trauma [78]. It is notable that many of these studies evaluated MOI as the primary criteria, and did not analyze their predictive ability after identifying patients fulfilling the first two steps (physiology and anatomy).

Triage criteria; co-morbidity

Criteria that incorporate co-morbidity reflect that outcome also depends on the patient's physical status at the time of injury. Criteria pertaining to the added risks associated with the extremes of age, pregnancy, immunosuppression and coagulopathy have been suggested [69, 79]. Patients not fulfilling physiologic, anatomic or MOI criteria but who have co-morbid factors that increase their risk for negative outcome, might still require trauma centre care.

Triage criteria; miscellaneous

It seems difficult to design a criteria list that encompasses all potential trauma scenarios. Injuries are intricate and may be unsuitable for dichotomous checklists. Accordingly, gaps in the triage criteria directory should not prohibit transport of trauma victims to an appropriate hospital. As an example, the "Guidelines for Field Triage of Injured Patients" (cf. Figure 2) [69] utilize the dictum "when in doubt take to a trauma centre" to acknowledge the relevance of EMS personnel discretion.

Prognostic models

The before mentioned individual triage criteria have variably proven useful as predictors of patient's injury severity [69, 80, 81]. In this context, severity has been defined by the patient's prognosis. Prognosis can be defined as "the probable course and outcome of a health condition over time" [82]. To overcome the limitation of individual triage criteria characteristics, different predictors can be included in prognostic models [82]. Prognostic models in the context of trauma are also referred to as risk models, prediction models, prognostic scores, triage scores or risk scores. Some of these models are field friendly and may guide EMS providers in their early evaluations of patients, while other models are exclusively designed for research [19].

Anatomic injury models

A system for classification of injuries by character and severity is fundamental for trauma research. The Abbreviated Injury Scale (AIS) has for over three decades been the world's most recognised tool for anatomical injury scoring [83, 84]. It consists of injury diagnoses that are assigned a unique 6-digit numerical code and a severity score from 1 (minor) to 6 (maximum; unsurvivable), and requires radiology, surgery and autopsy data (when applicable). The AIS has been continuously updated and is now in the AIS 2005 Update 2008 version [85], however discrepancies in the codesets remains a challenge to data validity [86].

The Injury Severity Score (ISS) provides an overall score for patients with multiple injuries and has reigned as the standard for injury measurement for over three decades [83, 87]. The ISS is the sum of the squares of the highest AIS severity score in each of the three most severely injured ISS body regions. The score ranges from 1 to 75, and has been reported in ranges: 1-3 (minor injury), 4-8 (moderate injury), 9-15 (serious injury), 16-24 (severe injury) and 25-75 (critical injury) [88].

The ISS has some limitations [89]. It fails to account for multiple injuries to the same body region, limiting its validity especially in penetrating trauma [90]. A simple modification (new ISS; NISS) based on the three most severe injuries regardless of body region [91] has proven superior to ISS in predicting outcome following trauma [92, 93]. NISS will be equal to or greater than ISS for any given patient. NISS >15 is recommended as inclusion criterion in a consensus report on uniform reporting of data following trauma [21]. As ISS and NISS are based on complete AIS coding that necessitates a thorough diagnostic process, they are unsuitable for field triage [80].

Physiologic derangement models

Physiological models aim to depict time dependent physiological derangements after injury, reflecting the dynamic component of trauma. This is influenced by factors such as pre-hospital resuscitation, co-morbidity, climate and time spent pre-hospitally. Several models including field friendly physiological variables have been designed to estimate patient prognosis and guide EMS providers in their early evaluations.

Champion et al. developed the Revised Trauma Score (RTS) and the Triage-Revised Trauma Score (T-RTS) [94] as a revision of the Trauma Score [95]. The T-RTS is used in the clinical context for triage and clinical decision-making, whereas RTS is used by researchers and administrators for case mix control and benchmarking. The RTS predicts outcome based on logistic regression analysis of Major Trauma Outcome Study data. The original weighted RTS ranges from 0 to 7,84. The T-RTS divides systolic blood pressure (SBP) and respiratory rate (RR) into five integers that approximates the survival probabilities of the GCS intervals. The T-RTS has been the most widely used model for over two decades [96, 97] and ranges from 0 (worst prognosis) to 12 (best prognosis).

Co-morbidity models

Pre injury health status has proven to be an independent predictor of mortality after trauma [98]. A few co-morbidity models exist, among which the Charlson Co-morbidity Index (CCI) is probably most widely used [99, 100]. However, the CCI is unsuitable in the field and triage scores have accordingly represented co-morbidity with age [101]. The American Society of Anaesthesiologists Physical Status (ASA-PS) score [102] has been proposed as an alternate for scoring pre-injury health status in pre-hospital triage [103].

Performance analysis models

To isolate the relationship between outcome and intervention in research, one needs to adjust for the risk profile of the patients to remove sources of variation unrelated to the health care provided. Optimally, residual outcome differences should reflect quality of care. Statistical models that include anatomical injury, physiological derangement, co-morbidity, age and gender exists [104-106]. The Trauma Score—Injury Severity Score (TRISS) has been the standard tool for hospital benchmarking and mortality monitoring for over two decades despite several documented shortcomings [107-110]. TRISS is based on Major Trauma Outcome Study data on overall anatomical injury, physiological status upon hospital admission, age and mechanism of injury to calculate probability of survival (Ps) [87, 94, 107]. The TRISS is unsuitable for the clinical context as it includes data unavailable in the field [111].

Aims of the study

General aim of the thesis

Evaluate triage efficacy in TTA in selected trauma centres. Further, to identify, implement and evaluate initiatives to improve trauma system efficacy through higher precision of field trauma triage.

I. Efficacy of a one-tiered trauma team activation protocol

Previously, TTA at Ullevål University Hospital (UUH) was based on clinical judgement alone. We hypothesized that introducing formal TTA would reduce mistriage and aimed to describe pre-hospital triage efficacy by calculating precision of TTA for major trauma victims. Further, we wanted to analyze how factors such as age, gender, pre-hospital response type (with vs. without anaesthesiologist), vital signs and MOI influenced triage precision. We also wanted to describe frequency and overtriage estimates for different triage criteria and to investigate mortality among patients subject to undertriage.

II. Efficacy of a two-tiered trauma team activation protocol

A previous informal analysis had detected imprecise TTA at Stavanger University Hospital (SUH). We wanted to introduce a two-tiered TTA protocol and prospectively analyze its impact on triage precision and resource utilization. A full trauma team should attend patients suffering from obvious major injury, but a reduced trauma team may systematically evaluate patients with potential injuries. We hypothesized that lowering the threshold for access to multidisciplinary trauma team evaluation and resuscitation would reduce undertriage while avoiding increased resource consumption. Further, we wanted to analyze how factors such as age, gender, pre-hospital response type (with vs. without anaesthesiologist) and mechanism of injury influenced triage precision. We also wanted to describe frequency and overtriage estimates for different triage criteria and to investigate mortality among patients subject to undertriage.

III. Identification and quality appraisal of prognostic models for early care of trauma patients

We aimed to systematically review existing prognostic models aimed at improving early trauma care, to appraise their quality, and describe their characteristics and performance.

IV. The influence of various definitions of major trauma on triage precision calculation

In order to compare datasets, assess external validity and conduct multicentre trials, a universally accepted definition of major trauma may be necessary. We aimed to investigate how different definitions of major trauma influenced the calculation of triage precision in a Norwegian trauma cohort.

Methodological considerations

Study populations

The main data source for this thesis has been trauma registry records, and accordingly several methodological considerations need to be addressed [112]. The UUH and SUH trauma registries utilise identical registry software and variable catalogues, and have implemented rigorous protocols for data quality checks [113]. These similarities eliminates the information bias that occurs when comparing populations from registries with systematic differences in coding practices [19].

Both registries are manned by Association for the Advancement of Automotive Medicine (AAAM) certified AIS coders (registered nurse) with previous trauma care experience to ensure high quality data coding. The coders at UUH and SUH coded in 2010 data on 1 382 and 417 patients respectively. The coders screen the hospital administrative system to localize all patients with International Classification of Diseases (ICD) S- and T-codes and possibly relevant patients without ICD-codes. This list is manually searched for relevant patients (cf. Table 2 for trauma registry inclusion and exclusion criteria) to reduce the risk for selection bias that occurs when patients are erroneously not included in the registry (false negatives) [19].

Both registries are based at university hospitals with regional trauma care function. Major trauma victims admitted to other hospitals in the region are only included in the registries if they are transferred to the university hospital. Although secondary transfers remain a significant proportion of the trauma population they were excluded from our studies. They often require additional data collection, and introduce several methodological difficulties beyond the scope of this thesis [114-116]. The exclusion of patients admitted to local hospitals implies that not every member of the target population has an equal opportunity to be investigated [22]. To what extent this convenience sampling introduces selection bias in the calculation of undertriage rates remains unknown.

Ethical considerations

Everyday practice in critical care is characterized by time-critical conditions and patients with limited ability to provide informed consent. The patient's situational awareness may be influenced by compromised vital functions, pharmacological agents

Inclusion criteria	Exclusion criteria
Absolute criteria: • Activated trauma team • Penetrating injury to: ○ Head ○ Neck ○ Trunk ○ Extremities proximal to knee or elbow Relative criterion: • ISS ≥10 • NISS >15*	Patients not fulfilling the absolute criteria, or: • Isolated fracture with skin injury (AIS 1) in: ○ Upper extremity ○ Lower extremity ○ Floor of orbita • Chronic subdural haematoma • Drowning, inhalation injury, asphyxia related injury (hanging, strangulation) • Secondary admission to UUH/SUH >24 hours after injury

Table 2 Inclusion and exclusion criteria for the Oslo University Hospital (OUH) and Stavanger University Hospital (SUH) trauma registries. ISS, Injury Severity Score; NISS, New Injury Severity Score; AIS, Abbreviated Injury Scale; *after implementing The Utstein template for uniform reporting of data following major trauma

and emotional stress. Surrogate consent is difficult and perhaps unethical to collect when the next of kin might be absent or in emotional distress [117, 118].

Three publications in this thesis are therefore based on aggregated and anonymous data from the SUH and UUH trauma registries (I, II, IV). These registries primarily provide data for internal quality assurance processes according to The Health Personell Act. All relevant patients are automatically included (cf. Table 2 for trauma registry inclusion criteria) without the need for consent, but patients who defy inclusion may later withdraw their data from the registry (The Health Registry Act). Data from these registries can be utilised in trauma research without informed consent if governing bodies consider the data to be anonymous.

The Regional Committee for Medical and Health Research Ethics deemed these studies to be quality improvement initiatives not in need of formal approval. Further, the Norwegian Social Science Data Services (SUH studies; II, IV) and the Data Protection Official (UUH study; I) approved access to anonymous registry data.

Accordingly, the studies were exempted from the demand of informed consent due to anonymity of extracted data and the absence of any treatment study protocol. Further, to improve transparency of observational research [119] and ensure possible publication [120], the SUH two-tiered TTA study (II) was registered in ClinicalTrials.gov.

Open access to electronic journals provides the user with free access to peer-reviewed publications. The Norwegian authorities have expressed their support to open-access publication [121], and their goal is to make all government-funded research openly available [122]. All papers in this thesis were published open access, as we believe that professional advances in trauma care in high-income countries ought to be made freely available on a global scale as a matter of collegial solidarity [123]. Open access to updated science can contribute to improvements in the quality of trauma care, and thereby even out the difference in mortality rates between the rich and poor.

Epidemiological considerations

Study design

Studies based on trauma registry data are generally considered retrospective. Although trauma registries have a forward going data collection, the term prospective requires that the research questions are generated before the data is collected [22]. In the UUH study (I) the hypothesis was generated 7 years after data collection was initiated. It was therefore subject to retrospective bias and incomplete data collection, and restricted to variables already defined in the trauma registry. Some predefined data points (e.g. TTA criteria) lacked detail that limited analysis precision. The same study design limitations apply to study IV. The SUH study (II) was considered prospective, as the trauma registry data variable catalogue was modified to describe the system revision prior to implementation.

Measures of efficacy

We obtained survival status 30 days after injury from patient records and the Norwegian Population Registry [21, 124] in all registry studies (I, II, IV). Trauma is a multifactorial disease process, and outcomes are intricate and troublesome to measure and interpret [125]. Mortality is a feasible and unequivocal end point, but does not portray morbidity from injuries that carry little mortality. For the majority of trauma

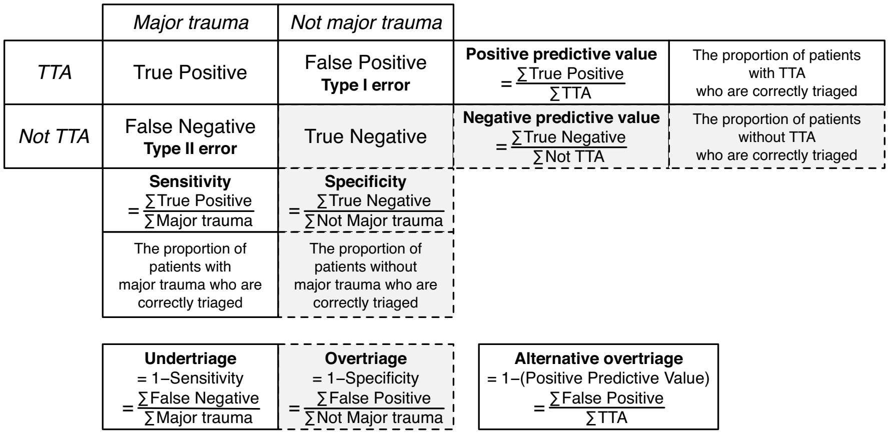


Figure 3 Injury severity and trauma team activation; definitions of triage precision. True negatives are unknown; calculations based on this value cannot be computed and are displayed in grey boxes.

victims, PhCC is the first intervention in a continuum of care that extends throughout the hospital phase into later rehabilitation. Therapeutic interventions delivered along the continuum of care can influence outcomes monitored at the end of the clinical course [111]. Accordingly, one need to identify the influence of pre-hospital interventions on patient outcome [126]. Consequently, to quantify the safety and effectiveness of triage guidelines, we collected patient-centred non-mortality proxy outcomes such as mistriage rates and time spent on overtriage to depict triage efficacy. These process measures allow improvements in triage guidelines that are missed by assessment of global outcomes (e.g. mortality). However, more research is needed into the relationship between measures of triage accuracy as indicators of trauma system efficacy in improving outcomes [125].

The evaluation of triage precision was based on the assumption that all major trauma victims benefit from assessment by a trauma team upon arrival to hospital (cf. Figure 3 for definitions). Undertriage was defined as the probability of not being examined by a trauma team despite being a major trauma victim. Overtriage was defined as the proportion of patients without major trauma among those who were triaged to a trauma team. In addition to direct comparison of overtriage rates before and after the SUH system revision (paper II), we compared skilled hours expenditure on overtriage per major trauma victim. The individual TTA criteria were analysed for usage and overtriage in both UUH and SUH studies (I and II).

In an attempt to better understand reasons for incorrect triage, we built logistic regression models with undertriage (I and II) and overtriage (only II) as outcome variables. In study II probability of survival was calculated using TRISS methodology [107]. W-statistic [127] (expressing excess survivors per 100 patients compared with TRISS model predictions) with 95% confidence interval was used to compare outcome from the two study periods [128]. Non-overlapping 95% confidence intervals were deemed as indicating significant differences in survival.

The present results must not be interpreted as cause-effect relationships [129] (e.g. new TTA criteria cause improved TTA accuracy), only as associations, as both (I, II) were uncontrolled before-after studies. Epidemiological techniques never eliminate all confounders.

Definition of major trauma

Injury severity is a continuum, and there is no universal consensus on what constitutes the threshold for major trauma. The definition of major trauma is fundamental as it provides the reference standard against which triage guidelines will be tested. In the US Major Trauma Outcome Study [107] ISS >15 was associated with a mortality risk of at least 10% and related to a distinct flex in the mortality curve. Although the use of anatomic injury models is debated, many triage studies dichotomize study populations into "major trauma" (ISS >15) and "not major trauma" patients (ISS ≤15) [69, 88]. Accordingly, these definitions have been used to construct related two–by–two tables to calculate triage precision (cf. Figure 3). Several studies combine anatomic injury scales such as the ISS/NISS, with variables depicting mortality, morbidity, mechanism of injury or resource consumption to define major trauma [128, 130, 131]. The rationale is an understanding of major trauma as more than anatomic injury with a subsequent risk of excluding important patient groups in triage precision calculations. Often such compound definitions take process-mapping variables into account, making the definitions more system specific thereby susceptible to reduced external validity and reproducibility.

In the UUH study (I) major trauma was defined as fulfilling at least one of the following: ISS>15, proximal penetrating injury, admitted intensive care unit (ICU) > 2 days, transferred intubated to another hospital within 2 days, and dead from trauma within 30 days. In the SUH study (II) NISS >15 defined major trauma adhering to the Utstein recommendation for uniform reporting of trauma data [21]. Study III describes various major trauma definitions applied in prognostic model studies. Study IV depicts how various major trauma definitions influenced triage precision calculations in a Norwegian trauma cohort.

Summary of papers

Paper I

This study aimed to describe TTA precision at a primary trauma centre (UUH) among paramedics and anaesthesiologists. It also analyzed how age, gender, category of pre-hospital care provider, vital signs, type of injury and triage criteria influenced triage precision.

In the year 2000, UUH introduced one-tiered TTA guidelines after an analysis revealed that the previous informal system for TTA generated unacceptable mistriage [128]. The 2001–07 trauma registry data were retrospective analysed after exclusion of inter-hospital transfers to UUH and patients transported by non-healthcare personnel, as they were not subject to UUH field triage guidelines. There was an overall overtriage of 55% and undertriage of 10%, indicating that triage precision had not improved after TTA guideline introduction. MOI was TTA criterion in 1 508 cases (34%), of which only 392 were severely injured (overtriage 74%). Falls, high age and admittance by paramedics were significantly associated with undertriage. Patients subject to undertriage had a significant ISS-adjusted Odds Ratio for 30-day mortality of 2.34 compared to those correctly triaged to TTA. Study I found that paramedic-manned pre-hospital services provided 66% overtriage and 17% undertriage, whereas anaesthesiologist-manned services provided 35% overtriage and 2% undertriage.

We concluded that the TTA guidelines did not improve triage precision, and that increased competence in patient evaluation and a user friendlier TTA protocol were needed. Further, we recommended that the hospital should consider implementing a two-tiered TTA protocol to increase triage efficacy.

Paper II

This study aimed to prospectively analyse how a two-tiered TTA protocol influences triage precision and resource utilization at a primary trauma centre (SUH).

Registry-based analysis of the informal one-tiered TTA practice at SUH revealed unacceptably high under- and overtriage rates. A two-tiered TTA protocol was therefore developed and studied as a prospective implementation study utilizing SUH trauma registry data. It was divided into 2 stages: a retrospective period of the informal one-tiered practice (January 1st, 2004 to December 31st, 2008), and a prospective period after implementing the two-tiered TTA protocol (July 1st, 2009 to December 31st, 2010). The implementation period itself (January 1st, 2009 to June 30th, 2009) was excluded from the analysis. A full trauma team should attend patients suffering from obvious major injury, but a reduced trauma team may systematically evaluate patients with potential injuries. For the same reason as in study I, inter-hospital transfers to SUH and patients transported by non-healthcare personnel were excluded.

The introduction of two-tiered TTA was associated with significantly reduced overall undertriage from 28.4% to 19.1% after system revision. Overall overtriage increased from 61.5% to 71.6%, but mean number of skilled hours spent per overtriaged patient was significantly reduced from 6.5 to 3.5 after the introduction of a reduced trauma team. Further, the number of skilled hours spent per major trauma victim was significantly reduced from 7.4 to 7.1. For the study period as a whole, increasing age and falls increased risk for undertriage and decreased risk for overtriage, while motor vehicle related accidents showed the opposite effects. Patients triaged by the EMCC to a prehospital response involving an anaesthesiologist had reduced risk for both undertriage and overtriage. For the total population of included patients, W statistic did not change significantly indicating no significant change in overall survival. Although we found a relative reduction in overall undertriage of 32.6% after system revision, the current undertriage rate of 19.1% remains unacceptable and continuous efforts to further improve triage precision are absolutely essential. Further, the death of one upgraded patient with NISS=50 indicates that the practice of upgrading a reduced team to a full team requires constant monitoring.

We concluded that converting from informal one-tiered TTA to formalized two-tiered TTA lowered the threshold for immediate access to high quality trauma care by reducing undertriage rates. Although the introduction of a reduced trauma team increased overtriage rate, the amount of work hours spent per major trauma victim was reduced. Educational efforts are needed to reduce the increasing undertriage of patients with increasing age and patients subject to falls.

Paper III

This study aimed to systematically review prognostic models for early care of adult trauma patients, investigate their quality and describe their characteristics.

Several prognostic trauma models have been developed to improve early clinical decision-making. The ideal prognostic model for trauma should be developed according to methodological guidelines, be clinically sensible, well calibrated, and with good discriminative ability. It should be cost-effective, externally validated and field-friendly, and provide useful information to EMS providers that improves triage decision-making and patient outcome.

Five studies deriving a total of five prognostic models, and nine studies that validated one or more of these models in independent populations were identified. Most models were developed in patient cohorts from the 1980s. The number of predictors included ranged from three to five; only systolic blood pressure was included in all models.

All prognostic models intended to change clinical practice, but none were tested in a randomised clinical trial. The variables and outcomes were valid, but only one model was derived in a low-income population, and this was the only model not validated in an independent sample [132]. Although prognostic models for trauma should be developed according to methodological guidelines, the quality appraisal revealed several areas of improvement for most models. We found methodological limitations pertaining to issues such as inadequate methods to develop the prognostic models, handling of continuous variables, dealing with missing data, impact and practicality analysis.

We concluded that the models generally performed well in predicting survival. However, there are many areas for improvement of methodological quality. We only identified nine validation studies, indicating a need for further evaluation of performance transportability.

Paper IV (submitted)

This study aimed to investigate how various definitions of major trauma influenced the calculation of under- and overtriage in a Norwegian trauma cohort.

Although the definition of major trauma provides the reference standard against which over- and undertriage rates will be calculated, it is inconsistent in the current literature.

We performed a retrospective analysis of SUH trauma registry data, and included patients admitted to SUH from January 1st, 2004 to December 31st, 2008. For the same reason as in study I and II, inter-hospital transfers to SUH and patients transported by non-healthcare personnel were excluded.

Two "traditional" definitions were developed based on anatomical injury severity scores (ISS >15 and NISS >15), one "extended" definition was based on outcome (30-day mortality) and mechanism of injury (proximal penetrating injury), one "extensive" definition was based on the "extended" definition and on ICU resource consumption (admitted to the ICU for >2 days and transferred intubated out of the hospital in ≤2 days), and an additional four definitions were based on combinations of the first four.

There were no significant differences in the perceived under- and overtriage rates between the two "traditional" definitions (NISS >15 and ISS >15). Adding "extended" and "extensive" to the "traditional" definitions also did not significantly alter perceived under- and overtriage. Defining major trauma only in terms of the MOI and mortality, with or without ICU resource consumption (the "extended" and "extensive" groups), drastically increased the perceived overtriage rates.

We concluded that expanding the definitions of major trauma using parameters other than anatomic injury was not useful for over- and undertriage calculations based on our data. We recommend a consensus-based definition of the term "major trauma".

General discussion and conclusions

Trauma system and triage models

A nationwide regionalised Norwegian trauma system has been called for [8]. Although a growing body of evidence on regional trauma system efficacy exists [12-14, 16], regional trauma systems as seen in the UK [133], remain unimplemented in Norway [31]. Nevertheless, the ongoing tendency of centralizing all healthcare resources makes field triage of trauma victims essential for optimal patient outcome, and a national standard has been called for [52]. Several Norwegian studies confirm the tendency of imprecise field triage of trauma victims (cf. Table 3). A major limitation to these studies is the lack of papers on triage efficacy at local hospitals. Although national guidelines for field triage have been designed elsewhere [69], no national Norwegian consensus on TTA protocol exists. Triage decisions are influenced by several factors, including local resource availability, transportation distances and medico-legal considerations, making it challenging to establish unanimous guidelines for field triage [134]. To correctly portray national status on triage accuracy, a Norwegian pan-trauma system analysis hopefully facilitated by a future national trauma registry needs to be conducted [52, 135]. Regardless of national trauma registry implementation, hospitals should consider initiatives to improve triage accuracy.

Tiered TTA systems as seen in SUH aim to provide a full trauma team to patients suffering from obvious major injury, while the reduced trauma team systematically evaluates patients with unclear injury panorama (cf. Table 1) (Paper II). The two-tiered TTA protocol was associated with reduced undertriage and increased overtriage, while trauma team resource consumption was reduced. In the light of this, UUH has also implemented a two-tiered TTA protocol [136].

A systematic literature review included in this thesis (Paper III) identified 5 prognostic models focussing on physiologic predictors (cf. Table 4). The review concluded that the Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure (MGAP) model [101] fulfilled most of the suggested methodological quality items and is recommendable for routine use. Whether MGAP is utilized in Norway remains uncertain, however we have implemented RTS in the SUH catchement area and have initiated a validation study.

Study, year	Pts.	Hospital, City	Main outcome	Under- vs. overtriage
Lossius et al. 2000	3 383	Ullevål UH, Oslo◊,†	1)	15% : 53%
Krüger et al. 2006	109	UNN, Tromsø◊,†	2)	50% : 58%
Uleberg et al. 2007	809	St.Olavs UH, Trondheim◊,†	3)	13% : 79%
Rehn et al. 2009	4 659	Ullevål UH, Oslo†	4)	10% : 55%
Dehli et al. 2011	441	UNN, Tromsø◊,†	2)	32% : 71%
Rehn et al. 2012	557	Stavanger UH‡	5)	19% : 72%
Lossius et al. 2012	1 255	Stavanger UH†	5)	28% : 62%

◊ Including patients subject to interhospital transfer
† One tiered TTA
‡ Two tiered TTA

Main outcome:
1) ISS>15; proximal penetrating injury; ICU LOS>2 days; in-hospital mortality
2) ISS>15
3) ISS>15; emergency surgery<24h after admission; need for ICU; hospital LOS>3 days; death (unspecified)
4) ISS>15; proximal penetrating injury; ICU LOS>2 days; transferred to another hospital intubated within 2 days; 30 day mortality
5) NISS>15

Table 3 Triage precision; Norwegian studies. UH: University Hospital; UNN: University Hospital of Northern Norway; ISS: Injury Severity Score; NISS: New ISS; Pts: Patients; ICU: Intensive Care Unit; LOS: Length of Stay; TTA: Trauma Team Activation.

In general, patients with unclear injury panorama are difficult to identify and physician involvement in the triage process has been associated with improved triage accuracy [137, 138]. This thesis includes two studies (I, II) that indicate that patients triaged to a pre-hospital response involving an anaesthesiologist had less chance of both undertriage and overtriage. However, in the Norwegian pre-hospital system, anaesthesiologist-manned units normally attend patients considered severely injured by either dispatch or paramedic-manned units already at the scene, whereas paramedics respond to a considerably less pre-selected patient population. The differences in patient case-mix may introduce spectrum and selection bias that makes direct comparison between the two EMS provider categories both unreasonable and counterproductive [139]. However, the findings emphasize that accurate dispatch of physician-manned PhCC units is of crucial importance and should be a matter of further investigation [140].

CRAMS		PHI		T-RTS		PSS		MGAP	
Circulation		SBP		SBP		SBP		SBP	
normal CR		>100	0	>89	4	>90	4	>120	5
and SBP >100	2	86–100	1	76–89	3	70–90	3	60–120	3
delayed CR		75–85	2	50–75	2	50–69	2	<60	0
or SBP 85–100	1	0–74	5	1–49	1	<50	1		
no CR or SBP <85	0			no pulse	0	no pulse	0	MOI	
		Pulse						Blunt	4
Respiration		≥120	3	Respiration (RR)		Respiration (RR)			
normal	2	51–119	0	10–29	4	10–24	4	Age	
abnormal	1	<50	5	>29	3	25–35	3	>60	5
absent	0			6–9	2	>35	2		
		Respiration		1–5	1	1–9	1	Consciousness	
Abdomen/thorax		normal	0	0	0	0	0	GCS	*)
nontender	2	laboured / shallow	3						
tender	1	RR <10 / needs intubation	5	GCS		Consciousness			
rigid/flail chest	0			13–15	4	normal	4		
Motor		Consciousness		9–12	3	confused	3		
normal	2	normal	0	6–8	2	responds to sound	2		
response to pain	1	confused	3	4–5	1	responds to pain	1		
no response	0	no intelligible words	5	3	0	no response	0		
Speech									
normal	2								
confused	1								
no intelligible words	0								
Score range:	0–10		0–20		0–12		0–12		3–29

Table 4 Presentation of prognostic models included in the review. CRAMS: Circulation, Respiration, Abdomen, Motor, Speech; PHI: Pre-Hospital Index; T-RTS: Triage-Revised Trauma Score; PSS: Physiologic Severity Score; MGAP: Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure; CR: Capillary Refill; SBP: Systolic Blood Pressure; GCS: Glasgow Coma Scale; MOI: Mechanism of Injury; RR: Respiratory Rate; *) GCS value

Trauma research and future concepts

EMS providers attend patients suffering from both injuries and non-traumatic time critical conditions. Accordingly, future field triage guidelines should address both medical and surgical patients to provide integrated triage solutions. Further, ED triage systems should be an intuitive continuation of field triage guidelines to provide a comprehensive triage solution. Additionally, a national standard for major incident triage has been called for [141] and concepts have been launched as candidates [142, 143]. In a future possible national trauma system, major incident concepts should be a simplification of established routines, and guidelines must consider including concepts for major incidents [144].

Different trauma systems accommodate pre-hospital information differently and have various guidelines for online/offline medical direction. Accordingly, it remains a controversy whether the decision to perform TTA should be made in the field or in the hospital setting according to information radioed by EMS personnel. In the light of the upcoming reorganisation of the Norwegian emergency communication system, future studies on EMCCs and field trauma triage are called for.

Although the role for randomised study design in PhCC is debated [145], high quality studies should be conducted with a control group to strengthen the evidence on triage efficacy [52, 146]. Further, outcomes of trauma care are a function of patient characteristics, quality of care and chance [147]. Studies on PhCC are primarily focused on examining outcomes pertaining to survival and impaired physiology (death and disease) [148]. Accordingly, these studies fail to investigate outcomes addressing important issues such as limit disability, alleviate discomfort, satisfaction, and cost-effectiveness (disability, discomfort, dissatisfaction, destitution) [149]. E.g. the UUH and SUH trauma registries lack detail on the post-hospital care phase for survivors [19]. To better portray the burden of trauma and the impact of trauma care, future studies should expand their outcomes to other than survival [125, 150].

Conclusions

Our findings confirm that field triage remains a challenge to EMS providers, but that a two-tiered triage system increased efficacy at SUH. To further increase triage precision, EMS providers need access to field friendly models that estimate patient prognosis and guide their early evaluations. Although several prognostic models exist, there are many areas for methodological improvement. To compare datasets and conduct multicentre trials, a universally accepted definition of major trauma may be necessary. This thesis indicates that trauma system efficacy may be improved through higher precision of field triage of victims of trauma.

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Precision of field triage in patients brought to a trauma centre after introducing trauma team activation guidelines

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Abstract

Background: Field triage is important for regional trauma systems providing high sensitivity to avoid that severely injured are deprived access to trauma team resuscitation (undertriage), yet high specificity to avoid resource over-utilization (overtriage). Previous informal trauma team activation (TTA) at Ulleval University Hospital (UUH) caused imprecise triage. We have analyzed triage precision after introduction of TTA guidelines.

Methods: Retrospective analysis of 7 years (2001–07) of prospectively collected trauma registry data for all patients with TTA or severe injury, defined as at least one of the following: Injury Severity Score (ISS) > 15, proximal penetrating injury, admitted ICU > 2 days, transferred intubated to another hospital within 2 days, dead from trauma within 30 days. Interhospital transfers to UUH and patients admitted by non-healthcare personnel were excluded. Overtriage is the fraction of TTA where patients are not severely injured (1-positive predictive value); undertriage is the fraction of severely injured admitted without TTA (1-sensitivity).

Results: Of the 4 659 patients included in the study, 2 221 (48%) were severely injured. TTA occurred 4 440 times, only 2 002 of which for severely injured (overtriage 55%). Overall undertriage was 10%. Mechanism of injury was TTA criterion in 1 508 cases (34%), of which only 392 were severely injured (overtriage 74%). Paramedic-manned prehospital services provided 66% overtriage and 17% undertriage, anaesthetist-manned services 35% overtriage and 2% undertriage. Falls, high age and admittance by paramedics were significantly associated with undertriage. A Triage-Revised Trauma Score (RTS) < 12 in the emergency department reduced the risk for undertriage compared to RTS = 12 (normal value). Field RTS was documented by anaesthetists in 64% of the patients compared to 33% among paramedics.

Patients subject to undertriage had an ISS-adjusted Odds Ratio for 30-day mortality of 2.34 (95% CI 1.6–3.4, p < 0.001) compared to those correctly triaged to TTA.

Conclusion: Triage precision had not improved after TTA guideline introduction. Anaesthetists perform precise trauma triage, whereas paramedics have potential for improvement. Skewed mission profiles makes comparison of differences in triage precision difficult, but criteria or the use of them may contribute. Massive undertriage among paramedics is of grave concern as patients exposed to undertriage had increased risk of dying.

Background

Regional trauma care with designated trauma centres improve outcome for trauma patients [1-6]. Essential for these systems is field triage that identifies trauma victims with injury severity that justifies access to the documented benefits of trauma team resuscitation [7]. Some mistriage is unavoidable, given the evolutionary nature of symptoms following major trauma and that field triage is often performed in the early stages of care. Although physician input is known to increase triage precision [8,9], triage is often performed independently by paramedics with limited training in patient evaluation and structured triage decision-making. Imprecise field triage results in overtriage (trauma team activation (TTA) for the minimally injured patient) and undertriage (severely injured patient admitted without TTA). Priority has been to minimize undertriage, as it may result in adverse patient outcome due to denial of the potential benefits of immediate expert assessment and resuscitation provided by the trauma team. Although overtriage does not directly reduce patient safety, it results in overutilization of limited financial and human resources [10-12] and can cause reduced local emergency medical service (EMS) coverage [13]. As with any test, the cost of improved specificity will be reduced sensitivity. American College of Surgeons, Committee on Trauma (ACS-COT) [14] therefore describes 5% undertriage as acceptable and associated with an overtriage rate of 25% – 50%.

A wide range of trauma triage criteria have been proposed [2,5,15-17], but there is no consensus on the ultimate set of variables due to local variations in patient severity mix and trauma care organization. Still, many systems have partly adopted criteria proposed by ACS-COT [14], which focus on physiologic, anatomic and mechanistic parameters in addition to comorbidity. Although some of these criteria have been validated as predictors of severe injury [18-23] the majority remains without scientific evidence.

Ulleval University Hospital (UUH) is the largest trauma hospital in Norway and the trauma referral centre for half of the Norwegian population. Previously, UUH lacked a trauma triage protocol, and TTA was based on clinical judgment alone. In the year 2000, an analysis [9] found that the informal TTA system was imprecise with an undertriage of 11% and overtriage of 58% for primary admitted patients. Further, field triage was significantly more correct for patients admitted by anaesthetist-manned units than by paramedic-manned ambulances. This revealed an opportunity for improvement that catalysed the introduction of trauma triage guidelines (Fig. 1).

The continuous process of performance improvement as proposed by ACS-COT [14] refers to a cycle of monitoring, finding, fixing, and monitoring again. In order to close the loop, we wanted to describe triage precision among paramedics and anaesthetists after the introduction of the UUH TTA protocol. We also wanted to analyse how age, gender, category of prehospital care provider, vital signs, type of injury and triage criteria influenced triage precision.

Methods

Clinical background

UUH is the major trauma hospital for 550 000 and referral trauma hospital for 2.5 million people. The trauma team is one-tiered, with activation procedures partly based on guidelines published by ACS-COT (Fig. 1) [14]. Prehospital EMS units do not activate the trauma team directly, but report their findings to the ambulance dispatch centre. This information is immediately passed on to the nurse coordinator in the emergency department (ED) who activates the trauma team when at least one of four TTA criteria categories is fulfilled (Fig. 1). When in doubt, the nurse coordinator confers with the trauma team leader before TTA. Prehospital emergency care is provided by ordinary ambulance units staffed with paramedics and by anaesthetist-manned ground and air ambulances.

Patients

We performed a retrospective analysis of prospectively collected data from the UUH trauma registry. The UUH trauma registrar utilizes a search engine to localize all patients with International Classification of Diseases (ICD) S- and T-codes from the hospital administrative system. This list is manually searched for relevant patients (see Fig. 2 for trauma registry inclusion and exclusion criteria). The study was exempted from the demand of informed consent due to anonymity of extracted data and the absence of any treatment study protocol, and the Regional Committee for Research Ethics and the Data Protection Official deemed approval as not necessary.

We included patients admitted to UUH during the period from 1st of January 2001 to 31st of December 2007, included in UUH trauma registry, and assigned one or more AIS codes (AIS 98; Abbreviated Injury Scale, 1990 Revision, Update 98) with an activated trauma team and/ or severe injury. Patients were classified as severely injured if they fulfilled one of the following criteria: Injury Severity Score [24] (ISS) > 15; penetrating trauma to the head, neck, trunk, or extremities proximal to elbow or knee irrespective of ISS; need of intensive care for more than two days; transferred to another hospital intubated within two days; dead from trauma within 30 days. Interhospital transfers to UUH and patients transported by non-health-care personnel were excluded, as they were not subject to UUH field triage guidelines.

30 days mortality was determined by information from the Norwegian Population Registry and hospital records

Anatomic Category
Stab or gunshot wound to head, neck, torso or body proximal to elbow or knee.
Obvious massive haemorrhage.
Obvious massive blunt injury.
Dislocated injury to the pelvis.
Two large fractures.
Flail chest.
Burns > 15% body surface and/or inhalation damage.
Children, elderly and patients suffering from chronic diseases tolerate less and shall have a lower threshold for TTA.
Physiologic category
Disturbed respiration: Dyspnoea, tachypnoea or bradypnoea.
Hypotension.
Significantly reduced consciousness.
Trauma team is activated when a stable patient turns unstable.
Mechanism of Injury category
Co passenger dead.
Trapped in wreck.
Considerable deformation of vehicle compartment.
Ejected from vehicle.
Pedestrian thrown up on vehicle or through the air.
Child hit by vehicle > 30 km/h.
Fall from > 5 meter.
If time from accident to assessment is long and the patient seems unaffected, trauma team shall not be activated, but team leader shall be informed of acute injury.
Multiple patients
> 2 injured patients admitted simultaneously
UUH: Ulleval University Hospital; TTA: Trauma Team Activation

Figure 1
Ulleval University Hospital trauma team activation (TTA) criteria.

Absolute Criteria:

- Activated trauma team
- Penetrating injury to:
  - Head
  - Neck
  - Trunk
  - Extremities proximal to knee or elbow

Relative criterion:

- ISS ≥ 10

Excluded are patients with:

- Isolated fracture and skin injury (AIS 1) in:
  - Upper extremity
  - Lower extremity
  - Floor of orbita
- Chronic subdural haematoma
- Drowning, inhalation injury, asphyxia related injury (hanging, strangulation)
- Secondary admission to UUH > 24 hours after injury

ISS: Injury Severity Score; AIS: Abbreviated Injury Scale

Figure 2
Inclusion and exclusion criteria for the UUH trauma registry.

[25]. Repatriated foreign citizens with inaccessible information on 30 days survival status were coded as survivors [26].

In patients who were prehospitally intubated and in general anaesthesia on hospital arrival, respiratory rate and Glasgow Coma Scale [27] (GCS) were scored according to values documented by the prehospital services immediately before intubation. In the absence of this information, we estimated the Triage – Revised Trauma Score (RTS) [28] category (0–4) of the variables respiratory rate and GCS score from the patient record, always utilizing the least pathological value when in doubt. In cases with complete lack of information, normal values were used as default [29].

Statistical analysis

We assumed severely injured patients to potentially benefit from trauma team presence upon admission, and our evaluation of diagnostic precision of triage was based on this assumption. Various parameters can describe trauma triage precision. We defined ""Sensitivity" as the fraction of severely injured patients that were met by a trauma team (Table 1). "Undertriage" was defined as the contrary event, i.e. 1-sensitivity, interpreted as the probability of not being met by a trauma team despite being severely injured. To calculate specificity and thereby the classical definition of overtriage (1-specificity) [30], the number of patients with minor injuries admitted without TTA must be identified. As UUH each year receives a large number

Table 1: Injury severity and trauma team activation (TTA)

	Severely injured	Not severely injured	Total
TTA	(a)	(b)	(a + b)
No TTA	(c)	(d)	(c + d)
Total	(a + c)	(b + d)	(n)

Sensitivity = a/(a + c); Specificity = d/(b + d)
Positive predictive value (PPV) = a/(a + b)
Undertriage = 1 - Sensitivity = c/(a + c); Overtriage = 1 - PPV = b/(a + b)

of primary admitted injured patients, the classical definition is of limited value. This sizeable and not easily definable group of patients is seldom considered for TTA, and would strongly bias the calculation of overtriage based on specificity. Optimal utilization of hospital resources requires a triage protocol that excludes minimally injured patients from TTA. Thus, "overtriage" was defined as the complement of the positive predictive value (1-PPV), where PPV represents the probability of a patient being severely injured when the trauma team is activated (Table 1) [9,31]. The null hypothesis that the TTA protocol did not improve triage precision was adopted. All data were analyzed using Statistical Package for the Social Sciences, v. 16.0 (SPSS, Inc., Chicago, IL). Data distributions are reported by medians and interquartile ranges (IQR). Non-parametric data were analysed with the Mann-Whitney test. For categorical data, the chi-square test was used and results are reported as odds ratios (OR) with 95% confidence interval (95% CI). We specifically wanted to study undertriage among severely injured patients, therefore undertriage was used as the dependent variable in the univariate and multivariate analyses. We used logistic regression to estimate the adjusted effects of each significant variable from the univariate analysis [31]. Variables were age, handled as a three level categorical variable (< 55, 55–70, > 70 years), whereas fall (yes, no), prehospital care provider (paramedic, anaesthetist), RTS (12, < 12) and gender were handled as dichotomous variables. ISS was handled as numerical value. Statistical significance was assumed for $p < 0.05$.

Results

Descriptive

During the study period, 4 885 patients were entered in the UUH trauma registry, of which 4 659 fulfilled our study inclusion criteria. Of the included patients, 4 208 (90%) had suffered blunt and 451 (10%) penetrating injuries as the dominant type of injury. Forty-two patients (1%) suffered both penetrating and blunt injury. Median age of included patients was 32 years (IQR 21 – 47), and median ISS was 9 (IQR 4 – 21).

Clinical details of severely injured patients

Of the 4 659 patients, 2 221 (48%) fulfilled our criteria for being severely injured. A majority of these, 1 662 (75%), were men. Median ISS was 21 (IQR 14 – 29), with women having significantly higher ISS than men (median ISS 22 vs. 21, p = 0. 002). Median age was 36 years (IQR 23 – 53), with a significant difference in median age between the genders (women median 40 vs. men 34, $p < 0.001$).

Precision in field triage

Among the 4 659 patients included, we recorded 4 440 (95%) activations of the trauma team. It was not activated for 219 of the 2 221 severely injured patients; an undertriage of 10%. The team was activated for minor injuries 2 438 times; an overtriage of 55%. Patients admitted by anaesthetist-manned units had 2% undertriage (among 1 059 severely injured patients, 25 received no TTA) and 35% overtriage (1 598 TTA where 564 were for minor injuries). Patients brought in by paramedics were subject to 17% undertriage (among 1 162 severely injured patients, 194 received no TTA) and 66% overtriage (2 842 TTA where 1 874 were for minor injuries) (Table 2). Among the 1 508 patients with TTA due to the mechanism of injury (MOI) criterion, 392 (26%) were severely injured (Table 3). The MOI criterion was used for 1 052 (37%) patients admitted by paramedics, compared to 456 (29%) of those admitted by anaesthetists (Table 4).

Factors associated with undertriage

Among the 2 221 severely injured patients, age was significantly associated with undertriage, with an adjusted odds ratio (OR) of 2.19 for those between 55 – 70 years of age (CI 1.45 – 3.31; $p < 0.001$) compared to those younger than 55 years. For those older than 70 years, adjusted OR for being undertriaged was 5.41 (CI 3.60 – 8.13; $p < 0.001$).

Gender per se was also associated with undertriage, with an OR of 1.91 (CI 1.43 – 2.56; $p < 0.001$) for women compared to men. This difference lost its significance when we adjusted for age, giving an OR of 1.25 for women (CI 0.89 – 1.77; p = 0.202), as females were strongly represented among those over 55 years of age. Admittance by paramedics was also significantly associated with undertriage with an adjusted OR of 5.84 (CI 3.73 – 9.13; $p < 0.001$) compared to admittance by anaesthetists. Further, fall was associated with undertriage, with an adjusted OR of 4.89 (CI 3.51 – 6.83; $p < 0.001$). Finally, a Triage – RTS < 12 in

Table 2: Field triage precision by category of prehospital care before and after introduction of TTA protocol

	Without TTA protocol (1996)		With TTA protocol (2001 – 2007)	
	Overtriage	Undertriage	Overtriage	Undertriage
All patients	58%	11%	55%	10%
Anaesthetist admitted	44%	6%	35%	2%
Paramedic admitted	67%	17%	66%	17%

Table 3: Association and number of patients by category of prehospital care provider, TTA criteria, undertriage and correct triage

	Total	Severely injured	Dead within 30 days	Proximal penetrating injury	ICU > 2 days or transferred intubated	ISS > 15
Admission:						
Anaesthetist	1 623 (35%)	1 059 (65%)	185 (11%)	80 (5%)	756 (47%)	902 (56%)
Paramedic	3 036 (65%)	1 162 (38%)	173 (6%)	372 (12%)	476 (16%)	739 (24%)
Total	4 659 (100%)	2 221 (48%)	358 (8%)	452 (10%)	1 232 (26%)	1 641 (35%)
Patients with TTA	4 440 (95%)	2 002 (45%)	316 (7%)	426 (10%)	1 154 (26%)	1 467 (33%)
TTA criteria:						
Anatomic	1 192 (27%)	702 (59%)	107 (9%)	235 (20%)	361 (30%)	452 (38%)
Physiologic	76 (2%)	42 (55%)	9 (12%)	12 (16%)	20 (26%)	28 (37%)
MOI	1 508 (34%)	392 (26%)	33 (2%)	4 (0%)	245 (16%)	324 (22%)
Multiple patients	8 (0%)	3 (38%)	0 (0%)	1 (13%)	1 (13%)	2 (25%)
Several	760 (17%)	504 (66%)	127 (17%)	62 (8%)	351 (46%)	430 (57%)
Unknown	896 (20%)	359 (40%)	40 (5%)	112 (13%)	176 (20%)	231 (26%)
Undertriage	219	219 (100%)	42 (19%)	26 (12%)	78 (36%)	174 (80%)
Correct triage	2 002	2 002 (100%)	316 (16%)	426 (21%)	1 154 (58%)	1 467 (73%)

ICU: Intensive Care Unit; ISS: Injury Severity Score; MOI: Mechanism of Injury

the ED reduced the risk for undertriage with an adjusted OR of 0.42 (CI 0.30 – 0.60; $p < 0.001$) compared to RTS = 12 (normal value). Field RTS was documented by anaesthetists in 64% of the patients compared to 33% among paramedics ($p < 0.001$). Factors associated with undertriage are outlined in Table 5.

The consequence of undertriage

Patients subject to undertriage had significantly higher mortality risk compared to those correctly triaged, with an OR adjusted for ISS of 2.34 (CI 1.59 – 3.43; $p < 0.001$) (Table 6).

Discussion

Patients brought to UUH by anaesthetists had a satisfactory triage precision, with an undertriage of 2% and overtriage of 35%, whereas patients brought in by paramedics were subject to unacceptable mistriage, with an undertriage of 17% and overtriage of 66% (Table 2).

Although patients admitted by paramedics were associated with less injury severity compared to those admitted by anaesthetists (median ISS 5 vs. 17, $p < 0.001$) due to overtriage, they were subject to a significantly higher risk for undertriage (Table 5). These results indicate that both patients and the trauma system could profit from integrating the highest level of medical competence accessible into the triage process. However, comparison of these patient groups must be made with caution, as skewed mission profiles might contribute to the observed differences.

The overall trauma triage system performance at UUH was outside the recommendations stated in the ACS-COT guidelines [14], with an undertriage of 10% and overtriage of 55% (Table 2). However, comparison of triage

Table 4: Usage and performance of TTA criteria by category of prehospital care provider

	Paramedic			Anaesthetist		
TTA criteria	Total	Correct triage	Overtriage	Total	Correct triage	Overtriage
Anatomic	717 (25%)	372 (52%)	345 (48%)	475 (30%)	330 (70%)	145 (30%)
Physiologic	65 (2%)	33 (51%)	32 (49%)	11 (0%)	9 (82%)	2 (18%)
MOI	1 052 (37%)	163 (15%)	889 (85%)	456 (29%)	229 (50%)	227 (50%)
Multiple patients	6 (0%)	2 (33%)	4 (67%)	2 (0%)	1 (50%)	1 (50%)
Several criteria	354 (13%)	182 (51%)	172 (49%)	406 (25%)	322 (79%)	84 (21%)
No documented criteria	648 (23%)	216 (33%)	432 (67%)	248 (16%)	143 (58%)	105 (42%)
Total	2 842	968 (34%)	1 874 (66%)	1 598	1 034 (65%)	564 (35%)

MOI: Mechanism of Injury

Table 5: Triage outcome split by factors associated with undertriage among 2221 severely injured patients. Unadjusted and adjusted (for gender, age, category of prehospital care, ED-RTS and fall), estimates of odds ratio for undertriage with 95% CI and p values

	Correct triage (n = 2 002)	Undertriage (n = 219)	OR (95% CI)	Adjusted OR (95% CI)
Gender:				
Men	1 525 (76%)	137 (63%)	1.00	1.00
Women	477 (24%)	82 (37%)	1.91 (1.43 – 2.56)*	1.25 (0.89 – 1.77)†
Age:				
<55 years	1 595 (80%)	99 (45%)	1.00	1.00
55–70 years	261 (13%)	46 (21%)	2.84 (1.96 – 4.13)*	2.19 (1.45 – 3,31)*
>70 years	146 (7%)	74 (34%)	8.17 (5.78 – 11.54)*	5.41 (3.60 – 8.13)*
Admitted by:				
Anaesthetist	1 034 (52%)	25 (11%)	1.00	1.00
Paramedic	968 (48%)	194 (89%)	8.29 (5.42 – 12.69)*	5.84 (3.73 – 9.13)*
ED-RTS:				
12	1 035 (52%)	156 (71%)	1.00	1.00
<12	967 (48%)	63 (29%)	0.43 (0.32 – 0.59)*	0.42 (0.30 – 0.60)*
Fall:				
No	1 632 (82%)	81 (37%)	1.00	1.00
Yes	370 (18%)	138 (63%)	7.52 (5.59 – 10.11)*	4.89 (3.51 – 6.83)*

CI: Confidence Interval; OR: Odds Ratio; *: $p < 0.001$; †: $p = 0.202$;
ED-RTS: Revised Trauma Score in the Emergency Department

rates must be made with care, as different definitions of what constitutes a suitable patient for TTA – frequently referred to as a "severely injured" patient – are applied. Injury severity is a continuum and the cut off has traditionally been arbitrary. Nevertheless, the definition is fundamental, as it determines the threshold for inclusion to the care given by an activated trauma team, and provides the retrospective standard against which the triage guidelines will be tested. The US Major Trauma Outcome Study [32] found that ISS > 15 was related to a mortality risk of at least 10%, and despite some well-documented limitations [33,34], this cut off has been widely applied to define severe injury. We addressed these limitations by including proximal penetrating injury, need for ICU care and death from trauma within 30 days [25]. To achieve comparability with a previous analysis [9], the need for urgent ED procedure or operative intervention [35,36] (e.g. damage control laparotomy) was excluded from our definition, highlighting that consensus among researchers regarding a common definition of "severely injured" is needed. The current study is a retrospective review of trauma registry data and as such has several limitations. It is subject to retrospective bias and incomplete data collection, and it is restricted to variables already defined in the trauma registry. Some of the predefined data points (e.g. TTA criteria) lack detail and thus limit analysis precision. Further, the seven years delay between guideline introduction and the study of its efficacy may be considered too long.

Patients admitted by ordinary ambulances were more frequently triaged to TTA due to MOI (Table 4). MOI criteria were generally unable to predict severe injury regardless of personnel category involved in the triage process (Table 3). MOI was introduced as criterion after retrospective studies [37-39] revealed that some blunt trauma scenarios

Table 6: 30 day mortality by category of triage. Unadjusted and adjusted for ISS

		Dead within 30 days				
	Total	Number of patients	OR (95% CI)	p-value	Adjusted OR (95% CI)	Adjusted p-value
Correct triage	2 002	316 (16%)	1.00		1.00	
Undertriage	219	42 (19%)	1.27 (0.89 – 1,81)	p = 0.23	2.34 (1.59 – 3.43)	P < 0.001

OR: Odds Ratio; CI: Confidence Intervals; ISS: Injury Severity Score were associated with significant victim injury, which might remain occult throughout the prehospital period. Although it was recognized that this criterion would yield over-utilization of trauma centre resources, a certain amount of overtriage was deemed necessary to avoid preventable trauma deaths [14]. Car safety design and the utilization of safety restraints has markedly improved since many of these studies were published, and other papers now confirm the association between MOI as single criterion for TTA and overtriage [13,40-43].

Our results are consistent with prior studies that show that physiological and anatomical trauma triage criteria are predictive of the need for TTA [13,18,19,21,23] (Table 3). In general, anaesthetists put more emphasis on vital signs, as evidenced by prehospital RTS [28] being documented for 64% of the patients compared to 33% among paramedics ($p < 0.001$). Unsurprisingly triage – RTS < 12 in the ED reduced the risk for undertriage (Table 5). The presence of abnormal vital signs after involvement in trauma may suggest significant haemorrhage and the need for evaluation by the trauma team. However, the absence of abnormal vital signs or obvious anatomic injury does not rule out severe injury. We believe that "physiologic derangement" and "anatomic injury" categories should be mandatory criteria for full TTA at UUH, whereas MOI and "comorbidity" should be downgraded to only activate a trauma team consisting of fewer members. In an attempt to deal with the burden of overtriage generated by excessive use of the MOI criterion several trauma centers have introduced tiered triage systems, and published their positive experiences with them [11,16,44-46].

Patients subject to undertriage had significantly higher mortality risk compared to those correctly triaged, when adjusted for injury severity (Table 6). Phillips and coworkers [47] described falls as the main aetiology behind severe injury among elderly (hip fractures were excluded form the study), and that triage criteria according to ACS-COT recommendations failed to identify these trauma victims. We found both falls and increasing age to be significantly associated with undertriage, but there was no significant difference between genders when adjusted for age (Table 5). Problems in the initial evaluation of the traumatized geriatric patient may contribute to an increased risk of undertriage. Misleadingly "normal" initial vital signs despite severe injury due to medication and an inability to launch normal physiologic responses have been suggested as contributing factors [22]. Elderly trauma patients have particularly high mortality, even with fairly minor or moderately severe injuries. Undertriage in this group probably contributes to an even higher mortality. Demetriades et al. [22] have suggested that age over 70 years alone should be a criterion for TTA. In a later paper, Demetriades and coworkers [48] found that activated trauma team and early intensive monitoring, evaluation, and resuscitation of geriatric trauma patients improved survival.

The present study was conceived to highlight the supposed advantages of a trauma triage protocol, but increased precision could only be demonstrated among anaesthetists (Table 2). Although the introduced guidelines were based on fairly well documented material [18-22], triage precision among paramedics did not improve and therefore camouflaged any possible benefit on total system precision. Further, we found examples of breeched guidelines such as EMS providers activating the trauma team from the field instead of via the trauma coordinator. Such failure of guideline adherence may also contribute to this unexpected lack of increased triage precision. These results indicate that paramedics need further training in evaluating trauma victims. We also call for improved routines in communicating patient data from EMS units to the nurse coordinator in the ED, with vital signs, obvious anatomic injury, injury mechanism and comorbidity to be ordinal reported. Further, nurse coordinators would benefit from additional training in triage decision-making.

Conclusion

Evaluating vital signs and anatomic injury require competence, and anaesthetists performed field triage with higher precision than paramedics, who displayed an unacceptably high mistriage rate. We therefore failed to reject the null hypothesis about any benefit brought about by introducing a trauma triage protocol. The discrepancy between personnel categories amplifies the need for a user-friendlier triage protocol and increased competence in trauma patient evaluation among paramedics. Although MOI with its low prediction accuracy was extensively used as TTA criterion, this alone could not explain all the imprecision. The "physiologic" and "anatomic" criteria performed well. Our findings should be an incitement to design a two-tiered trauma triage protocol, and thereafter change provider behaviour through a well-documented implementation strategy.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MR and HML conceived the study. MR, TE, AJK, NOS and HML designed the study. MR and AJK performed the data analysis. NOS and TE designed and developed the UUH trauma registry. MR drafted the manuscript. All authors interpreted data and critically revised the manuscript. All authors have read and approved the final manuscript

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II

Original article

Efficacy of a two-tiered trauma team activation protocol in a Norwegian trauma centre

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Background: **A registry-based analysis revealed imprecise informal one-tiered trauma team activation (TTA) in a primary trauma centre. A two-tiered TTA protocol was introduced and analysed to examine its impact on triage precision and resource utilization.**

Methods: **Interhospital transfers and patients admitted by non-healthcare personnel were excluded. Undertriage was defined as the fraction of major trauma victims (New Injury Severity Score over 15) admitted without TTA. Overtriage was the fraction of TTA without major trauma.**

Results: **Of 1812 patients, 768 had major trauma. Overall undertriage was reduced from 28·4 to 19·1 per cent (*P* < 0·001) after system revision. Overall overtriage increased from 61·5 to 71·6 per cent, whereas the mean number of skilled hours spent per overtriaged patient was reduced from 6·5 to 3·5 (*P* < 0·001) and the number of skilled hours spent per major trauma victim was reduced from 7·4 to 7·1 (*P* < 0·001). Increasing age increased risk for undertriage and decreased risk for overtriage. Falls increased risk for undertriage and decreased risk for overtriage, whereas motor vehicle-related accidents showed the opposite effects. Patients triaged to a prehospital response involving an anaesthetist had less chance of both undertriage and overtriage.**

Conclusion: **A two-tiered TTA protocol was associated with reduced undertriage and increased overtriage, while trauma team resource consumption was reduced. Registration number: NCT00876564 (http://www.clinicaltrials.gov).**

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Introduction

Early recognition of major trauma enables emergency medical services (EMS) to accurately triage and transport injured patients to an appropriate hospital. Field triage, however, remains a challenge due to occult injuries, the unpredictable evolution of symptoms and complexities of evaluating patients in difficult circumstances. A combined literature review and US national expert panel consensus resulted in 'Guidelines for Field Triage of Injured Patients'[1,2]. This presented a stepwise evaluation of trauma victims for physiological instability, obvious anatomical injury, mechanism of injury and co-morbidity. The report recommended that tiered trauma care should be provided according to the probability of having sustained major trauma.

Norway is sparsely populated with weather-dependent and time-consuming patient transport. Some 50 Norwegian hospitals receive patients with major injuries, most with low admission rates[3]. In an attempt to optimize patient outcome[4], immediate resuscitation is increasingly being delivered via multidisciplinary one-tiered trauma teams. However, several studies indicate a trend for imprecise activation of such teams[5–8].

If patients with major injuries are deprived access to the possible benefits of immediate resuscitation and expert evaluation provided by a trauma team (undertriage), avoidable deaths may occur[9]. Conversely, if the trauma team attends patients with minor injuries (overtriage), scarce financial and human resources are consumed. To improve triage efficacy, a two-tiered trauma team activation (TTA) response has been recommended[1]. A full trauma team should attend patients suffering from obvious major injury, but a reduced trauma team may systematically evaluate patients where the extent of injury is unclear. A growing body of evidence suggests that a tiered response is safe and cost-effective[10–21]. The American College of Surgeons considers 5 per cent undertriage associated with 25–50 per cent overtriage as acceptable[22]. An unpublished registry-based analysis of the informal one-tiered TTA practice at Stavanger University Hospital (SUH) revealed unacceptably high undertriage and overtriage rates. For this reason, a two-tiered TTA protocol was developed and implemented at this trauma centre according to international recommendations[1]. The impact of this system revision on medical resource utilization and triage precision was evaluated using trauma registry data.

Table 1 Inclusion and exclusion criteria for the Stavanger University Hospital trauma registry

Inclusion criteria	Exclusion criteria
Absolute criteria	Patients not fulfilling the absolute criteria
Activated trauma team	*or*
Penetrating injury to	Isolated fracture with skin injury (AIS 1) in
Head	Upper extremity
Neck	Lower extremity
Trunk	Floor of orbita
Extremities proximal to knee or elbow	Chronic subdural haematoma
Relative criteria	Drowning, inhalation injury, asphyxia-related injury (hanging, strangulation)
ISS $\geq$ 10	Secondary admission to SUH > 24 h after injury
NISS > 15*	

*After implementing the Utstein template for uniform reporting of data following major trauma. AIS, Abbreviated Injury Scale; ISS, Injury Severity Score; NISS, New Injury Severity Score; SUH, Stavanger University Hospital.

Methods

SUH is a 630-bed primary trauma centre for a mixed rural/urban population of approximately 330 000 inhabitants and the trauma referral centre for an additional 120 000 people living in Rogaland county in southwestern Norway. The hospital admits each year approximately 140 adult and paediatric patients with a New Injury Severity Score[23] (NISS) greater than 15[24,25]. A hospital-based trauma registry has been fully operational since 2004. An Association for the Advancement of Automotive Medicine-certified Abbreviated Injury Scale (AIS) coder (a registered nurse) manually searches the hospital administrative data system for relevant patients (*Table 1*) and annually codes data on approximately 360 patients.

Prehospital emergency care in the SUH catchment area is provided by on-call general practitioners, vehicle ambulance units staffed by paramedics and emergency medical technicians, and anaesthetist-manned rapid response cars and helicopters[26]. Until February 2009, the hospital practised informal activation of a one-tiered 13-personnel multidisciplinary trauma team.

The Rogaland Trauma System Study Group was established by SUH in 2008 in cooperation with the Norwegian Air Ambulance Foundation research department. The group comprised clinical representatives from the emergency department, dispatch, surgery, anaesthesiology, and ground and air ambulance units in addition to researchers. They developed guidelines on field triage and TTA based on available evidence[1,5] and multidisciplinary consensus on optimal local practice. EMS providers were empowered to assign patients into two tiers of TTA according to field triage criteria (*Table 2*). Activation of the full multidisciplinary trauma team was based on physiological or anatomical criteria. The purpose of the full team was to provide immediate resuscitation and rapid evaluation, and initiation of definitive care. A reduced team was initiated in patients not meeting the criteria for the full team but when there was either one mechanism of injury or one co-morbidity criterion present (*Table 3*). The purpose of the reduced team was rapidly to assess physiologically stable patients for occult injuries. When two or more mechanisms of injury or co-morbidity criteria were fulfilled the full team was activated. The reduced team was capable of rapid upgrading to a full team if potentially severe injures were detected. Both full and reduced teams were led by the same surgeon with a minimum of 2 years of experience in surgery and certified as an Advanced Trauma Life Support provider. The remaining team members had no formal competence requirements. Additional surgical subspecialty resources were available at the team leader's discretion.

The trauma registry was upgraded to prospectively collect data necessary to compare practice after introduction of the two-tiered guidelines. The guidelines were launched on 3 February 2009 under the direction of the Rogaland Trauma System Study Group. Throughout the implementation period, instructors addressed specific aspects of the system revision during educational outreach visits. Information posters and periodical newsletters were used to increase understanding and awareness of the system revision.

Table 2 Triage criteria for tiered trauma team activation (full and reduced)

Full trauma team	Reduced trauma team
1. Physiology 1·1 RTS ≤ 11 1·2 GCS < 14 1·3 Respiratory rate < 9/min 1·4 Respiratory rate > 25/min 1·5 Sp_{O_2} < 90% 1·6 Intubated/attempted intubation 1·7 Obvious massive haemorrhage 1·8 Systolic blood pressure < 90 mmHg	5. Co-morbidity 5·1 Age > 60 years 5·2 Age < 6 years 5·3 Severe co-morbidity (e.g. COPD, congestive heart failure) 5·4 Pregnancy 5·5 Increased risk of haemorrhage (anticoagulant drugs, coagulopathy)
2. Anatomy 2·1 Facial injury with risk for airway obstruction 2·2 Flail chest 2·3 Suspected pneumothorax 2·4 Stab or gunshot wound proximal to knee or elbow 2·5 Suspected pelvic fracture 2·6 Crushed, mangled or amputated extremity 2·7 Two or more long bone fractures 2·8 Open fracture with ongoing haemorrhage 2·9 Open skull fracture or impression fracture 2·10 Suspected spinal cord injury 2·11 Burn injury (≥ grade II) > 15% total body surface area	6. Mechanism of injury 6·1 Co-passenger killed 6·2 Entrapped person 6·3 Person ejected from vehicle/motorcycle 6·4 Pedestrian, cyclist run down at > 30 km/h or thrown up in the air 6·5 Collision speed > 50 km/h 6·6 Deformed vehicle compartment 6·7 Airbag set off 6·8 Vehicle roll-over 6·9 Fall > 5 m (adults) 6·10 Fall > 3 m (children) 7. Interhospital transfer 7·1 Interhospital transfer and < 24 h since time of injury Note: If two or more criteria under list 5 or 6 are fulfilled, activate full trauma team
3. Several patients 3·1 Accident with several severely injured (suspected or confirmed)	
4. Upgrade to full trauma team 4·1 When two or more criteria for reduced trauma team (list 5 or 6) are fulfilled 4·2 When reduced trauma team finds a perceived stable patient to be unstable	

RTS, Revised Trauma Score; GCS, Glasgow Coma Scale; COPD, chronic obstructive pulmonary disease; Sp_{O_2}, oxygen saturation measured by pulse oximetry.

Table 3 Trauma team composition (full and reduced)

Full trauma team (13 members)	Reduced trauma team (4 members)
Team leader surgeon*	Team leader surgeon*
Orthopaedic surgeon†	Orthopaedic surgeon†
Theatre nurse	2 ED nurses
3 ED nurses	
Anaesthetist†	
Nurse anaesthetist	
Radiologist†	
2 radiographers	
Laboratory technician	
Orderly	

*Minimum of 2 years' experience with surgery and certified Advanced Trauma Life Support provider. †No formal competence requirements. ED, emergency department.

Table 4 Injury severity and trauma team activation

	Major trauma	Not major trauma	Total
TTA	a	b	$a + b$
No TTA	c	d	$c + d$
Total	$a + c$	$b + d$	n

Sensitivity $= a/(a + c)$; specificity $= d/(b + d)$; positive predictive value (PPV) $= a/(a + b)$; undertriage $= 1 -$ sensitivity $= c/(a + c)$; overtriage $= 1 -$ PPV $= b/(a + b)$. TTA, trauma team activation.

The trial was designed as a prospective interventional study utilizing SUH trauma registry data and was divided into an analysis of the 'before' period, which consisted of patients subject to the informal one-tiered practice (1 January 2004 to 31 December 2008), and an analysis of the 'after' period, which consisted of patients subject to the two-tiered TTA protocol (1 July 2009 to 31 December 2010). The implementation period (1 January 2009 to 30 June 2009) was excluded from the analysis.

Consecutive patients admitted to SUH during the study period who were registered in the SUH trauma registry and assigned one or more AIS codes were included if they had major trauma (NISS over 15) and/or had been triaged to meet the trauma team (*Table 4*, groups *a*, *b* and *c*). The AIS 1998 catalogue was used for all patients[27]. Interhospital transfers to SUH and patients admitted by non-healthcare personnel were excluded. Survival status 30 days after injury[28] was obtained from patient records and the Norwegian Population Registry. The Standards for Quality Improvement Reporting (SQUIRE)[29], Standards for Reporting of Diagnostic Accuracy (STARD) statement[30] and Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were used[31].

The Regional Committee for Medical and Health Research Ethics deemed the system revision to be a quality improvement initiative not in need of formal approval (2009/228-CAG). The Norwegian Social Science

Data Services approved access to aggregate anonymous data on relevant patients in the hospital-based trauma registry (20 840 KS/LR). The study was registered in clinicaltrials.gov (NCT00876564).

Statistical analysis

Patients were classified as major trauma victims if they had an NISS above 15[28]. The evaluation of triage precision was based on the assumption that all patients with major injury benefit from assessment by a trauma team upon arrival at hospital. Sensitivity was defined as the probability for major trauma victims to be assessed by a full and/or reduced trauma team. Undertriage was defined as the contrary event (1 – sensitivity), the probability of not being examined by a trauma team (full and/or reduced) despite having a major injury. To calculate specificity and thereby the conventional definition of overtriage (1 – specificity)[32], the number of patients with minor injuries admitted without an activated trauma team (true negatives; group *d* in *Table 4*) must be identified. As SUH annually treats a large number of patients (approximately 3400 subjects) with only minor injuries, the classical definition is of limited usefulness. This substantial and not easily definable group of patients is rarely considered in need of assessment by a trauma team, and would strongly bias a computation of overtriage based on specificity. Overtriage was therefore defined as the complement of the positive predictive value, 1 − PPV, where PPV represents the probability of a patient suffering from major trauma when the trauma team is activated (*Table 4*)[33]. This is equivalent to the proportion of patients without major trauma among those who were triaged to a trauma team.

In addition to direct comparison of overtriage rates ‘before’ and ‘after’ system revision, skilled hours’ expenditure on overtriage per major trauma victim was measured. For each member of the trauma team, 30 min per unnecessary activation was allocated (full trauma team, 13 members = 6·5 skilled hours; reduced trauma team, 4 members = 2 skilled hours; *Table 3*).

Probability of survival was calculated using the Trauma Score – Injury Severity Score (TRISS) methodology[34] with 1995 coefficients[35]. The *W* statistic[36] (expressing excess survivors per 100 patients compared with TRISS model predictions) with 95 per cent confidence interval (c.i.) was used to compare outcomes from the two study periods[33]. Non-overlapping 95 per cent c.i. were considered to indicate significant differences in survival.

Categorical variables were compared with Fisher’s exact test, whereas continuous variables were analysed using the Mann–Whitney *U* test. Assumed predictors of overtriage and undertriage were tested in a multiple logistic regression analysis. All data were analysed using STATA/SE™ version 10.1 (StataCorp LP, College Station, Texas, USA) and StatView version 5.0.1 (SAS Institute, Cary, North Carolina, USA). Statistical significance was assumed for $P < 0{\cdot}050$.

Results

During the study period (1 January 2004 to 31 December 2010), 2327 patients were entered in the SUH trauma registry. Some 364 injured patients who were transferred to SUH from other hospitals, admitted by non-healthcare personnel or admitted during the new TTA criteria implementation period (1 January 2009 to 30 June 2009) were excluded. A further 151 patients who had neither sustained major trauma nor been triaged to a trauma team (true-negatives) were also excluded. In total, 1812 patients met the inclusion criteria and were enrolled in the study. There was a missing probability of survival for seven patients and lack of documentation of TTA criteria in 123, but otherwise data were complete.

Table 5 shows population characteristics of included patients in the ‘before’ and ‘after’ study periods. Distribution of age and sex, proportion of accidents involving motor vehicles and the proportion of penetrating *versus* blunt injuries did not change significantly between the two study periods.

In the ‘after’ period, there was a significant increase in the proportion of traumas due to falls. The proportion of patients who met an anaesthetist before hospital decreased significantly and a higher proportion of the included patients had been triaged to receive a full or reduced trauma team. Median NISS score, proportion of patients with major trauma and number of deaths in ‘after’ patients were significantly lower.

Triage categories of included patients are shown in *Table 6*. Among the 1255 patients included in the ‘before’ study period, 1089 (86·8 per cent) were triaged to a trauma team. In the ‘after’ study period, 522 of 557 patients (93·7 per cent) were triaged to a team, 232 to the full team and 290 to the reduced team.

Undertriage and overtriage

In the ‘before’ period, 166 of the 585 patients with major trauma (28·4 per cent) were not triaged to a trauma team, and this fell to 35 of 183 (19·1 per cent) in the ‘after’ period ($P < 0{\cdot}001$). There was a 41·2 per cent relative reduction in undertriage rate in responses without anaesthetists, whereas the decrease in the low rate of

Table 5 Patients included in the 'before' and 'after' study periods

	Before	After	*P*†
Included patients (TTA and/or major trauma)	1255	557	
Age (years)*	31 (19–51)	34 (20–53)	0·280
Sex ratio (F : M)	354 : 901	155 : 402	0·910
Falls	273 (21·8)	164 (29·4)	0·001
Motor vehicle-related accidents	498 (39·7)	204 (36·6)	0·230
Dominant injury (penetrating : blunt)	58 : 1197 (4·8 : 95·2)	22 : 535 (3·9 : 96·1)	0·620
NISS*	12 (5–26)	8 (3–18)	< 0·001
Major trauma	585 (46·6)	183 (32·9)	< 0·001
Prehospital anaesthetist (yes : no)	737 : 518 (58·7 : 41·3)	271 : 286 (48·7 : 51·3)	< 0·001
TTA	1089 (86·8)	522 (93·7)	< 0·001
Deaths (unadjusted)	78 (6·2)	16 (2·9)	0·003

Values in parentheses are percentages unless otherwise stated; *values are median (interquartile range). TTA, trauma team activation; NISS, New Injury Severity Score; major trauma, NISS > 15. †Fisher's exact test for categorical variables; Mann–Whitney *U* test for continuous variables.

Table 6 Triage categories and prehospital response types

	Before		After			
	TTA	Not TTA	TTA			Not TTA
	Total (MT : not MT)	Total (MT)	Total (MT : not MT)	Full team (MT : not MT)	Reduced team (MT : not MT)	Total (MT)
All	419 : 670	166	148 : 374	108 : 124	40 : 250	35
Prehospital anaesthetist	338 : 364	35	99 : 165	80 : 73	19 : 92	7
No prehospital anaesthetist	81 : 306	131	49 : 209	28 : 51	21 : 158	28

TTA, trauma team activation; MT, major trauma (New Injury Severity Score > 15).

Table 7 Changes in triage categories by prehospital response types

		Before (%)	After (%)	Absolute change (%)	Relative change (%)	*P**
Undertriage	All	28·4	19·1	−9·3	−32·6	< 0·001
	Prehospital anaesthetist	9·4	6·6	−2·8	−29·6	0·155
	No prehospital anaesthetist	61·8	36·4	−25·4	−41·2	< 0·001
Overtriage, total	All	61·5	71·6	10·1	16·5	< 0·001
	Prehospital anaesthetist	51·9	62·5	10·6	20·5	0·001
	No prehospital anaesthetist	79·1	81·0	1·9	2·5	< 0·001
Overtriage, full team	All		53·4			
	Prehospital anaesthetist		47·7			
	No prehospital anaesthetist		64·6			
Overtriage, reduced team	All		86·2			
	Prehospital anaesthetist		82·9			
	No prehospital anaesthetist		88·3			

*Fisher's exact test.

undertriage performed by prehospital anaesthetists was not significant.

The proportion of patients triaged to a trauma team who had not suffered major trauma increased from 670 of 1089 (61·5 per cent) in the 'before' study period to 374 of 522 (71·6 per cent) in the 'after' period ($P <$ 0·001). The increase was most pronounced in prehospital responses with an anaesthetist, although responses without anaesthetists still had the highest rate (*Table* 7).

The proportion of patients who had not suffered major trauma was particularly high in patients assigned to receive reduced teams (250 of 290, 86·2 per cent) compared with 124 of 232 (53·4 per cent) in patients triaged to receive full teams ($P <$ 0·001) (*Table* 7).

The mean number of skilled hours spent per overtriaged patient was reduced from 6·5 to 3·5 ($P < 0.001$), whereas the number of skilled hours spent per major trauma victim was reduced from 7·4 to 7·1 ($P < 0.001$).

After initially finding an association between age and mistriage (*Fig. 1*), age was included as an independent variable in the logistic regression models, along with sex, fall, motor vehicle-related accident, prehospital response type (with *versus* without anaesthetist) and study period ('after' *versus* 'before'). Results are shown in *Table 8*.

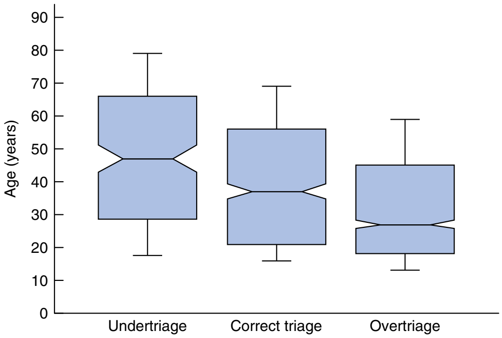

Fig. 1 Relationship between patient age and triage category. Box plots depict medians and interquartile ranges; whiskers represent 10th and 90th percentiles. Note non-overlapping 95 per cent confidence intervals for medians (notches)

Table 8 Odds ratios for undertriage and overtriage in the logistic regression model

	Odds ratio	*P*
Undertriage*		
Age (per decade)	1·28 (1·18, 1·39)	< 0·001
Sex (F *versus* M)	1·26 (0·86, 1·87)	0·241
Fall (yes *versus* no)	2·46 (1·71, 3·55)	< 0·001
Motor vehicle-related accident (yes *versus* no)	0·09 (0·04, 0·18)	< 0·001
Prehospital anaesthetist (yes *versus* no)	0·16 (0·11, 0·24)	< 0·001
Period (after *versus* before)	0·26 (0·17, 0·40)	< 0·001
Overtriage*		
Age (per decade)	0·79 (0·75, 0·83)	< 0·001
Sex (F *versus* M)	1·38 (1·10, 1·74)	0·006
Fall (yes *versus* no)	0·67 (0·52, 0·87)	0·003
Motor vehicle-related accident (yes *versus* no)	2·07 (1·64, 2·62)	< 0·001
Prehospital anaesthetist (yes *versus* no)	0·55 (0·45, 0·68)	< 0·001
Period (after *versus* before)	1·97 (1·57, 2·46)	< 0·001

Values in parentheses are 95 per cent confidence intervals. *Overall model R^2 for undertriage 0·101; for overtriage 0·291.

Table 9 Trauma team activation criteria in the 'after' period: frequency and overtriage

	n	Overtriage
Full team		
Physiology		
RTS ≤ 11	18	4 (22)
GCS < 14	37	18 (49)
Respiratory rate < 9/min	0	0 (0)
Respiratory rate > 25/min	5	4 (80)
Spo_2 < 90%	0	0 (0)
Intubated/attempted intubation	14	4 (29)
Obvious massive haemorrhage	1	1 (100)
Systolic blood pressure < 90 mmHg	0	0 (0)
Physiology total	75	31 (41)
Anatomy		
Facial injury with risk for airway obstruction	7	4 (57)
Flail chest	2	1 (50)
Suspected pneumothorax	21	9 (43)
Stab or gunshot wound proximal to knee or elbow	10	7 (70)
Suspected pelvic fracture	10	7 (70)
Crushed, mangled or amputated extremity	2	1 (50)
Two or more long bone fractures	4	1 (25)
Open fracture with ongoing haemorrhage	0	0 (0)
Open skull fracture or impression fracture	2	1 (50)
Suspected spinal cord injury	14	11 (79)
Burn injury > 15% total body surface area	2	2 (100)
Anatomy total	74	44 (59)
Other		
Several severely injured (suspected or confirmed)	14	8 (57)
Two or more criteria for reduced trauma team are fulfilled	8	6 (75)
Reduced team finds perceived stable patient unstable	5	1 (20)
Other total	27	15 (56)
Undocumented criteria	53	33 (62)
Full team total	229	123 (53·7)
Reduced team		
Co-morbidity		
Age > 60 years	9	7 (78)
Age < 6 years	7	6 (86)
Severe co-morbidity	8	4 (50)
Pregnancy	0	0 (0)
Increased risk for haemorrhage	4	2 (50)
Co-morbidity total	28	19 (68)
Mechanism of injury		
Co-passenger dead	1	1 (100)
Entrapped person	4	3 (75)
Ejected from vehicle/motorcycle	27	23 (85)
Pedestrian, cyclist run down at > 30 km/h or thrown in the air	33	28 (85)
Collision speed > 50 km/h	61	61 (100)
Deformed vehicle compartment	8	8 (100)
Airbag set off	14	14 (100)
Vehicle roll-over	8	8 (100)
Fall > 5 m (adults)	27	17 (63)
Fall > 3 m (children)	5	5 (100)
Mechanism of injury total	188	168 (89·4)
Undocumented criteria	70	55 (79)
Reduced team total	286	242 (84·6)

Values in parentheses are percentages. RTS, Revised Trauma Score; GCS, Glasgow Coma Scale. Spo_2, oxygen saturation measured by pulse oximetry.

All but one variable showed consistent and significant effects on triage. Increasing age clearly increased risk for undertriage and decreased risk for overtriage. For mechanisms of injury, falls showed increased risk for undertriage and decreased risk for overtriage, whereas motor vehicle-related accidents showed the opposite effects. Patients triaged by the emergency medical communication centre to a prehospital response involving an anaesthetist had reduced risk for both undertriage and overtriage. In the 'after' study period, risk for undertriage was reduced whereas risk for overtriage was increased. In this multiple logistic regression model, sex showed inconsistent effects on triage, possibly owing to a correlation between female sex, advanced age and trauma due to falls.

Analysis of individual TTA criteria in the 'after' study period for usage and overtriage showed that for reduced teams mechanism of injury criteria were associated with 89·4 per cent overtriage and co-morbidity criteria with 68 per cent overtriage (*Table 9*). Criteria were undocumented for 70 (24·5 per cent) of 286 reduced teams (79 per cent overtriage). For full teams, criteria pertaining to physiology were associated with 41 per cent overtriage, and criteria depicting anatomical injury with 59 per cent overtriage. Criteria were undocumented for 53 (23·1 per cent) of 229 full teams (62 per cent overtriage). Upgraded TTA due to the patient being unstable was applied to five patients of whom one had suffered minor injuries only (20 per cent overtriage). Four patients had falls and one was involved in a motor vehicle accident.

Mortality

No deaths were registered in patients triaged to reduced teams. Median time from activation of reduced team to full team upgrade for the five affected patients was 11 (range 0–21) min. Median NISS was 17 (range 6–50), and one upgraded patient died. There were 12 deaths among undertriaged patients, eight (4·8 per cent) in the 'before' and four (11 per cent) in the 'after' study period ($P = 0{\cdot}229$). The median age of patients who died was 80 (range 66–90) years and median NISS 46 (range 27–59). All had falls. For the total population of included patients, the W statistic (excess survivors per 100 patients compared with TRISS model predictions) did not change significantly: 2·123 (95 per cent c.i. 1·070 to 3·177) 'before' *versus* 2·510 (1·127 to 3·892) 'after'.

Discussion

The present study found that the introduction of a formalized TTA protocol with a two-tiered response was associated with reduced undertriage and increased overtriage. Trauma team resource consumption was significantly reduced. For the study period as a whole, increasing age and falls increased risk for undertriage and decreased risk for overtriage, whereas motor vehicle-related accidents showed the opposite effects.

Triage precision before implementation of the TTA protocol was poor. Informal activation of trauma teams did not correctly identify victims of major trauma. A relative reduction in overall undertriage of 32·6 per cent followed system revision. The current undertriage rate of 19·1 per cent is still considered unacceptable and continued efforts to further improve triage precision are essential. The death of one upgraded patient with an NISS of 50 emphasizes that the practice of upgrading a reduced team to a full team requires constant monitoring. There was a highly significant 41·2 per cent relative reduction in undertriage in prehospital responses without an anaesthestist but only a non-significant trend towards less undertriage when an anaesthetist was present. When studied in the logistic regression model, prehospital responses involving an anaesthetist had a higher overall triage precision with reduced risk for undertriage as well as overtriage. In the Norwegian prehospital system, anaesthetist-manned units normally attend patients considered severely injured by either dispatch or paramedic-manned units already at the scene, whereas paramedics respond to a considerably less preselected patient population. Direct comparison between the two EMS provider categories was therefore considered both unreasonable and counterproductive.

This undertriage rate in responses without an anaesthestist remains high, but is also seen in other organized trauma systems[5,10,12]. Initiatives such as increasing the number of employees with a certificate of competence in prehospital care have been launched to improve quality of care, but further studies on the reasons for undertriage are called for[37]. Triage precision should also be addressed in responses with an anaesthetist, although an undertriage rate of 5–10 per cent is considered acceptable[22].

All 12 patients who died in the undertriaged group were over 66 years old and had falls. The logistic regression model showed that increasing age and falls were both found to increase risk for undertriage and decrease risk for overtriage. Velmahos *et al.*[38] have previously found that unintoxicated patients over 55 years of age with low-level falls had a high likelihood of significant injuries. Others have recommended that age over 69 years should be a criterion for TTA[39] or a need for enhanced focus on apparently low-impact injuries in this population[5].

It was expected that a reduction in undertriage would be accompanied by increased overtriage. Although TTA is beneficial for trauma victims, it may lead to suboptimal care for other patients[40]. The two-tier TTA system was designed to reduce excess resource consumption due to overtriage. Skilled hours spent on overtriage per major trauma victim, reflecting the exploitation of manpower on minor trauma cases, were reduced from 7·4 to 7·1 after implementation of this system. This is of particular interest given the current focus on improvement of quality and cost reduction in healthcare.

Much emphasis has been put on mechanism of injury as a criterion for TTA[1], as it can contribute to the effectiveness of the triage tool in the absence of changes in vital signs or obvious anatomical injury[41]. Consequently, the findings that motor vehicle-related accidents were associated with both reduced risk for undertriage and increased risk for overtriage were expected. It was alarming, however, to find that falls carried an odds ratio for undertriage of 2·46. Educational efforts are obviously needed to reduce undertriage in this patient group.

The present study has a number of limitations. The 'before' study period involved a review of trauma registry data restricted to variables already defined in the trauma registry. Missing documentation of TTA criteria remained a challenge throughout the study period. A short 18-month 'after' period compared with a 60-month long 'before' period increases the risk for type II errors. The study is also susceptible to the Hawthorne effect[42]. The simultaneous introduction of revised TTA criteria and the two-tiered response also complicated the evaluation of the study outcome. Even though major trauma defines the threshold against which triage protocols are tested, several conflicting definitions exist[43]. An NISS of over 15 was used to define major trauma and adhere to the inclusion criteria recommended by the Utstein template for uniform reporting of trauma data[28]. This implies that undertriaged patients were those included in this group who were not met by a full or reduced trauma team. In contrast, Curtis *et al.*[44] considered all patients with an ISS of more than 15 assessed by a trauma standby (similar to the SUH reduced team) to be undertriaged. The different definitions highlight the difficulties of comparing data. The way in which definitions of major trauma influence calculations of triage precision merit investigation.

Implementation of system revisions can be a challenging enterprise with over 250 barriers identified in the literature[45]. To improve implementation of the new TTA criteria a teaching programme was developed addressing specific aspects of system revision. The programme was included in hospital and prehospital educational outreach visits arranged by trained instructors, a periodical newsletter was published and information posters were designed to remind staff of the new system for tiered TTA. To reduce the impact of failures related to lack of experience with the protocol, all patients from the 6-month implementation phase were excluded. However, examples of misapplication of the triage protocol were found throughout the entire 'after' period and act as reminders that implementation is a continuous process.

Converting from an informal one-tiered TTA to a formalized two-tiered TTA lowered the threshold for immediate access to high-quality trauma care by reducing undertriage rates. Although the introduction of a reduced trauma team increased the overtriage rate, the number of work hours spent per major trauma victim was reduced.

Collaborators

The members of the Rogaland Trauma System Study Collaborating Group were Espen Fevang, Kjetil Søreide, Eldar Søreide, Johannes Lokøy, Pieter Oord, Carina Lavransdatter Fossåen, Pål Stokkeland and Kristian Strand.

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REVIEW Open Access

Prognostic models for the early care of trauma patients: a systematic review

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Abstract

Background: Early identification of major trauma may contribute to timely emergency care and rapid transport to an appropriate health-care facility. Several prognostic trauma models have been developed to improve early clinical decision-making.

Methods: We systematically reviewed models for the early care of trauma patients that included 2 or more predictors obtained from the evaluation of an adult trauma victim, investigated their quality and described their characteristics.

Results: We screened 4 939 records for eligibility and included 5 studies that derivate 5 prognostic models and 9 studies that validate one or more of these models in external populations. All prognostic models intended to change clinical practice, but none were tested in a randomised clinical trial. The variables and outcomes were valid, but only one model was derived in a low-income population. Systolic blood pressure and level of consciousness were applied as predictors in all models.

Conclusions: The general impression is that the models perform well in predicting survival. However, there are many areas for improvement, including model development, handling of missing data, analysis of continuous measures, impact and practicality analysis.

Background

Trauma is a major global contributor to premature death and disability. The burden of injuries is especially notable in low and middle-income countries and is expected to rise during the coming decades [1,2]. Harm from major trauma may be minimized through early access to pre-hospital [2] and in-hospital trauma care [3]. A majority of trauma related deaths occur during the pre-hospital period or in the initial hours after injury. Emergency medical service (EMS) providers must therefore rapidly assess trauma severity in order to identify patients that require prompt referral to an appropriate hospital [2,3] and to ensure that necessary diagnostic and therapeutic interventions are initiated upon admission. However, early recognition of major trauma remains a challenge due to occult injuries, unpredictable evolution of symptoms, and the complexities of evaluating patients in the early hours after injury.

If patients only suffering minor injuries bypass the local clinic (overtriage; false-positives), the regional hospital will be overwhelmed and create a strain on scarce financial and human resources. However, if major trauma victims are treated at the local clinic rather than being stabilized and rapidly transported to a facility providing higher level of trauma care (undertriage; false-negatives), avoidable deaths may occur. Sensitivity and specificity are often negatively correlated making optimal prognostic model performance a balance between patient safety and optimal resource utilisation. American College of Surgeons-Committee on Trauma (ACS-COT) therefore describes 5% undertriage as acceptable and associated with an overtriage rate of 25% - 50% [4].

At hospital admission, delay to high resource resuscitation can result in unfavourable outcome [5,6]. Traditionally, these early decisions have been informed by the patient's injury severity. In this context, severity has been defined by the patient's risk or prognosis. Although commonly used interchangeably, risk and prognosis differ in their meaning. Prognosis can be defined as "*the probable course and outcome of a health condition over*

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time" [7]. Risk is sometimes used as a synonym of probability, but it can also used as a synonym for hazard [8]. We believe the term prognosis is more appropriate in this context and will use this term throughout this manuscript.

Assessment of injury severity traditionally includes clinical findings pertaining to physiological derangement, obvious anatomical injury, mechanism of injury, and pre-injury health status. These individual variables have been useful to predict a patient's prognosis in trauma (i.e. predictors), but have showed limitations when used as isolated parameters [9].

To overcome the limitation of individual characteristics, different predictors can be combined into scores or models to estimate patient's prognosis and guide EMS providers in their early evaluations of these patients. Prognostic models in the context of trauma are also referred to as risk models, prognostic scores, triage scores or risk scores. The abundances of prognostic models in the trauma setting indicate not only the need for early objective quantification of prognosis, but also the difficulties of addressing all requirements to be valid, precise and practical.

The ideal prognostic model for trauma should be developed following methodological guidelines, it should be clinically sensible, well calibrated and with good discriminative ability [10,11]. Further, it is cost-effective, externally validated, field-friendly and it provides useful information to EMS providers that improve triage decision-making and patient outcome [12-15]. We aim to conduct a systematic review that identifies existing prognostic models aimed at improving early trauma care, appraise their quality and describe their characteristics and performance in order to inform clinical practice and future research.

Methods

Study eligibility criteria

We included studies reporting prognostic trauma models that were developed to improve clinical decision-making in the field and upon immediate arrival to hospital.

We defined "prognostic model" as a tool for clinicians that includes 2 or more predictors obtained from the history and physical examination of a suspected trauma victim (Glasgow Coma Scale (GCS) [16] was considered to be a single predictor). Because we were interested in the models that could be used early in the assessment of trauma patients, we only included models with predictors collected in the field or in the emergency department up to 12 hours from injury. Further, we did not include models that required complex information such as para-clinical diagnostic tests (e.g. blood sampling) or models for organ specific injuries. Studies that investigated more than one predictor but did not combine them in a model (e.g. field triage decision schemes) were also excluded. We included studies that aimed to derivate prognostic models (derivation studies) or validate them (validation studies).

We included only prognostic models developed for adult patients defined, for the purpose of this review as over 15 years of age or if the patients were described by the authors as adults. This is due to differences between paediatric and adult physiology. Studies that aimed to derivate a prognostic model pertaining to adult trauma patients, but failed to report population age were included.

Models pertaining to burns, drowning, strangulation, isolated proximal femur fractures, isolated traumatic brain injury, pregnancy or medical conditions were excluded. We only included studies within the last 20 years. Studies conducted prior to 1989 were excluded because patient management and diagnostic techniques have changed considerably since then. Studies published in the inclusion period that validated prognostic models developed in the period 1982-89 were included and the original derivation study was assessed. Studies not written in English were excluded. The review was conducted according to PRISMA guidelines [17]. Being a systematic literature review, this study did not need approval from The Regional Committee for Research Ethics.

Study identification, selection and data extraction

A systematic literature search of MEDLINE to identify relevant studies was conducted (KB) (see additional file 1 for search strategy). All studies were collated in an Endnote bibliographic database (© 2007 Thomson Reuters). Two reviewers (MR & PP) independently examined titles, abstracts and keywords for eligibility. The full texts of all potentially relevant studies were obtained and two reviewers (MR & PP) assessed each study using pre-defined inclusion criteria (see additional file 2 for excluded full text studies with reasons). The bibliographies of all included studies were inspected for further relevant studies. Two reviewers (MR & PP) used a customized Excel spreadsheet (© 2007 Microsoft Corporation) to record extracted information from the selected studies in order to examine study characteristics and to appraise methodological quality.

Study characteristics

From all included studies, we collected descriptive data on study population and economic region (high income, middle income and low income countries). We also depicted study objective (derivation or validation study) as well as predictors. Finally, we described relevant study outcomes (mortality, morbidity or process outcomes), anatomic injury and measures of accuracy.

Quality appraisal of prognostic models

Assessment of methodological quality was facilitated through the application of a 17-item long quality appraisal list (see additional file 3). The list focussed on two areas:

a) Internal validity (to what extent is systematic error (bias) minimized).

b) External validity (to what extent can the prognostic model correctly be applied to other populations).

The internal validity and some items from the external validity (items 1 to 14) were only assessed in the original study that derived the prognostic model (derivation studies).

Depending on study design, some quality items are more relevant than others. It therefore proved difficult to determine the weight that each item should contribute to the overall score. We avoided the use of a quality assessment score; as such scores are debated [18,19]. Instead we described key components of methodological quality separately.

Performance of prognostic models externally validated

We collected performance data and focused on sensitivity/specificity, receiver operating characteristic (ROC) or area under ROC curve (AUC), when several measures of accuracy were portrayed. We focused on survival when several outcome measures were reported.

Results

Literature search

We identified 4 880 records from the MEDLINE search (see additional file 1 for the MEDLINE search strategy) and added additional 59 records identified through reference lists of selected studies identified in the initial search. We screened a total of 4 939 records of which 143 were assessed in full text for eligibility.

We included 5 studies [20-24] that derived 5 prognostic models and 9 studies [25-33] that validated one or more of these models in external populations.

Among the 129 full text studies excluded with reason, 7 validation studies were found ineligible as they included children (see additional file 2). Figure 1 shows a PRISMA diagram [17] to depict the flow of information through the different phases of the systematic review.

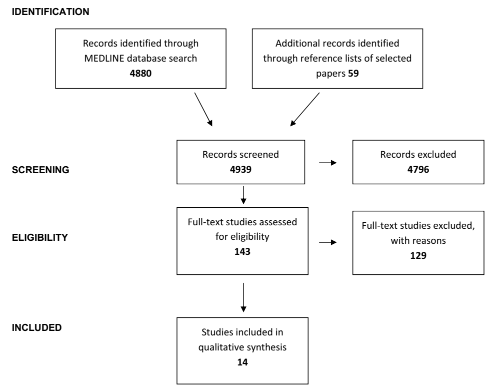

Figure 1 Information flow through the different phases of the systematic review.

Characteristics and performance of the prognostic models

Table 1 depicts the prognostic models with their corresponding predictors and scoring systems. Systolic blood pressure and level of consciousness were considered predictors in all models.

Circulation, Respiration, Abdomen, Motor, Speech (CRAMS)

The CRAMS was derived on 500 North American patients by Gormican in 1982 [20]. The derivation study included consecutive paramedic runs involving trauma and collected predictors both in the pre-hospital and early in-hospital phase. The CRAMS utilise predictors pertaining to capillary refill, systolic blood pressure (SBP), respiration, tenderness of the abdomen or thorax, motor response and ability to speech. The model predicts outcomes pertaining to need for emergency general- or neurosurgery and emergency department (ED) mortality.

Pre Hospital Index (PHI)

The PHI was derived on 313 North American patients by Koehler et al. in 1986 [21]. They included consecutive trauma patients to identify relevant model predictors easily obtained in the pre-hospital phase. Numerical weight assignments were performed on the same 313 patients. The PHI includes variables pertaining to SBP, heart rate, respiration and level of consciousness to predict the need for emergency general- or neurosurgery and 72 hours post injury mortality.

Triage Revised Trauma Score (T-RTS)

Champion et al. developed the Revised Trauma Score (RTS) and the Triage-Revised Trauma Score (T-RTS) in 1989 [22] as a revision of the Trauma Score [34]. The T-RTS is used in the clinical context for triage and clinical decision-making, whereas the RTS is used by researchers and administrators for case mix control and benchmarking.

The RTS was developed using the MTOS database (over 26 000 subjects), but the exact number of patients included in the development is unclear. The RTS uses the weight given by the logistic regression analysis and provides an outcome prediction. The weighted RTS ranges from 0 to 7,84 and is not considered to be a prognostic model for the early care of trauma patients in this review.

The T-RTS was derived on admission physiology data on 2 166 North American consecutive trauma patients included in a trauma centre database. Champion et al.

Table 1 Presentation of prognostic models included in the review

CRAMS		PHI		T-RTS		PSS		MGAP	
Circulation		**SBP**		**SBP**		**SBP**		**SBP**	
normal CR and SBP > 100	2	>100	0	>89	4	>90	4	>120	5
delayed CR or SBP 85-100	1	86-100	1	76-89	3	70-90	3	60-120	3
no CR or SBP < 85	0	75-85	2	50-75	2	50-69	2	<60	0
Respiration		0-74	5	1-49	1	<50	1	**MOI**	
normal	2	**Pulse**		no pulse	0	no pulse	0	Blunt	4
abnormal	1	≥120	3	**Respiration (RR)**		**Respiration (RR)**		**Age**	
absent	0	51-119	0	10-29	4	10-24	4	>60	5
Abdomen/thorax		<50	5	>29	3	25-35	3	**Consciousness**	
nontender	2	**Respiration**		6-9	2	>35	2	GCS	*)
tender	1	normal	0	1-5	1	1-9	1		
rigid/flail chest	0	labored/shallow	3	0	0	0	0		
Motor		RR < 10/needs intubation	5	**GCS**		**Consciousness**			
normal	2	**Consciousness**		13-15	4	normal	4		
resonse to pain	1	normal	0	9-12	3	confused	3		
no response	0	confused	3	6-8	2	responds to sound	2		
Speech		no intelligible words	5	4-5	1	respons to pain	1		
normal	2			3	0	no response	0		
confused	1								
no intelligible words	0								
Score range									
0-10		0-20		0-12		0-12		3-29	

Note: CRAMS = Circulation, Respiration, Abdomen, Motor, Speech; PHI = Pre-Hospital Index; T-RTS = Triage-Revised Trauma Score; PSS = Physiologic Severity Score; MGAP = Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure; CR = Capillary Refill; SBP = Systolic Blood Pressure; GCS = Glasgow Consciousness Scale; MOI = Mechanism of Injury; RR = Respiratory Rate; *) GCS value.

divided SBP and respiratory rate (RR) into integers that approximated the intervals chosen for GCS. The T-RTS varies from 0-12 and predicts Injury Severity Score [35] (ISS) > 15 and survival at end of acute care/hospital discharge. The T-RTS is simple to use and is included as a prognostic model in this review.

Physiologic Severity Score (PSS)

The PSS by Husum et al. was derived in 2003 on 717 patients injured in North Iraq and Northwest Cambodia [23] as a simplification of the T-RTS [22]. They collected pre-hospital data on consecutive trauma patients and included predictors pertaining to SBP, RR and level of consciousness. The model predicts survival during pre-hospital evacuation and hospital stay as well as ISS > 14.

Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure (MGAP)

The MGAP was derived on 1 360 French patients by Sartorius et al. in 2010 [24]. They included pre-hospitally collected data on consecutive trauma patients to identify relevant model predictors. The MGAP utilise SBP, mechanism of injury, age and GCS to predict 30-day mortality.

All the prognostic models utilized different times of survival as the primary endpoint. Two studies [20,21] included the need for emergency general or neurosurgery, whereas ISS was evaluated as an outcome in two studies [22,23].

Table 2 describes performance in the derivation and validation samples. There was clinically significant heterogeneity in the performance of the same prognostic model in different validation studies. Additional file 4 depicts characteristics of investigated outcomes.

Quality of prognostic models

Figure 2 shows the methodological quality items for each included prognostic model.

All derivation studies for the 5 prognostic models discussed the rationale to include the predictors and provided clear definitions. All outcomes seemed valid, but none were clear in their handling of missing data. Examination of interactions and handling of continuous variables were often unclear. None of the studies reported exploration of more complex relationships for continuous variables (e.g. fraction polynomial or spline functions). The only model that was developed using an appropriate multivariable approach was the MGAP. The CRAMS study neither described the process of predictor identification nor the numerical weight assignments. The PSS and the T-RTS aimed to simplify existing models and modified predictors previously presented. The PHI and

Table 2 Performance of prognostic models

Model Derivation study (No. pts; Country)	Study (No.pts; Country)	Main outcome	Performance
CRAMS	**Gormican-82**∞ (500 pts; USA)	Survival or emergency surgery	CRAMS < 9: Sens = 92%; Spec = NA
	Baxt-89 (2 434 pts; USA)	Survival	ROC-curves presented, AUC = NA
	Emerman-92 (1 027 pts; USA)*	Survival	CRAMS < 9: Sens = 100%; Spec = 83%
PHI	**Koehler-86 ∞ (**465 pts; USA)	Survival or emergency surgery	PHI > 3 = Sens = NA; Spec = NA
	Koehler-86 (388 pts; USA)	Survival or emergency surgery	PHI > 3: Sens = 94,4%; Spec = 94,6%
	Baxt-89 (2 434 pts; USA)	Survival	ROC-curves presented, AUC = NA
	Emerman-92 (1 027 pts; USA)	Survival	PHI > 3: Sens = 100%; Spec = 88%
	Plant-95 (621 pts; Canada)	Survival	PHI > 3: Sens = 98%; Spec = 54%
	Bond-97 (3147 pts; Canada)	ISS > 15	PHI > 3: Sens = 41%; Spec = 98%
	Tamim-02 (1 291 pts; Canada)	Survival or emergency surgery or ICU admittance	AUC = 0,66
T-RTS	**Champion-89 ∞ (**2 166 pts; USA)	ISS > 15	T-RTS < 12: Sens = 59%; Spec = 82%
	Baxt-89 (2 434 pts; USA)	Survival	ROC-curves presented, AUC = NA
	Emerman-92 (1 027 pts; USA)	Survival	T-RTS < 12: Sens = 100%; Spec = 88%
	Roorda-96 (398 pts; The Netherlands)	Survival or emergency surgery or ICU admittance	T-RTS < 12: Sens = 76%; Spec = 94%
	Al-Salamah-04 (795 pts; Canada)	Survival	AUC = 0,83
	Ahmad-04 (30 pts; Pakistan)	Survival	Mortality = T-RTS 6-7 = 60%, T-RTS 8-10 = 12,5%, T-RTS 11-12 = 8,3%
	Moore-06 (22 388 pts; Canada)	Survival	AUC = 0,84
	Sartorius-10 (1 003 pts; France)	Survival	AUC = 0,88
PSS	**Husum-03**∞(717 pts; Iraq and Cambodia)	Survival	AUC = 0,93
MGAP	**Sartorius-10**∞(1 360 pts; France)	Survival	AUC = 0.90
	Sartorius-10 (1 003 pts; France)	Survival	AUC = 0,91

∞) Derivation sample; *) Modified CRAMS scale; pts = patients; ROC = Receiver Operating Characteristic; AUC = Area under receiver operating characteristic curve; NA = Not Available; Sens = Sensitvity; Spec = Specificity; CRAMS = Circulation, Respiration, Abdomen, Motor, Speech; PHI = Pre-Hospital Index; T-RTS = Triage-Revised Trauma Score; ISS = Injury Severity Score; PSS = Physiologic Severity Score; MGAP = Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure.

MGAP models clearly portrayed the internal validation process. However, it remains unclear how the CRAMS, T-RTS and PSS were internally validated.

The CRAMS was externally validated in 2 studies [25,26], the PHI in 6 studies [21,25,26,31-33], the T-RTS in 7 studies [24-30]. The PSS remains unvalidated in an external population, whereas external validation of the MGAP was reported in the derivation study. None of the models clearly explain how to estimate prognosis for individual patients.

In all the original articles (derivation studies) the authors implied that the prognostic models would be useful to change clinical practice, but the clinical credibility of the model remained unevaluated, and none of the models were tested in a randomised clinical trial.

Discussion

This systematic review located 5 prognostic models for the early care of trauma patients. The majority of models were developed in cohorts of trauma patients from the 80's. All except one of the models were developed in populations from high-income countries. The number of predictors included in the models ranged from three to five, and SBP was the only predictor included in all models. GCS has proven to predict the need for trauma centre admittance [36], but have been criticized for

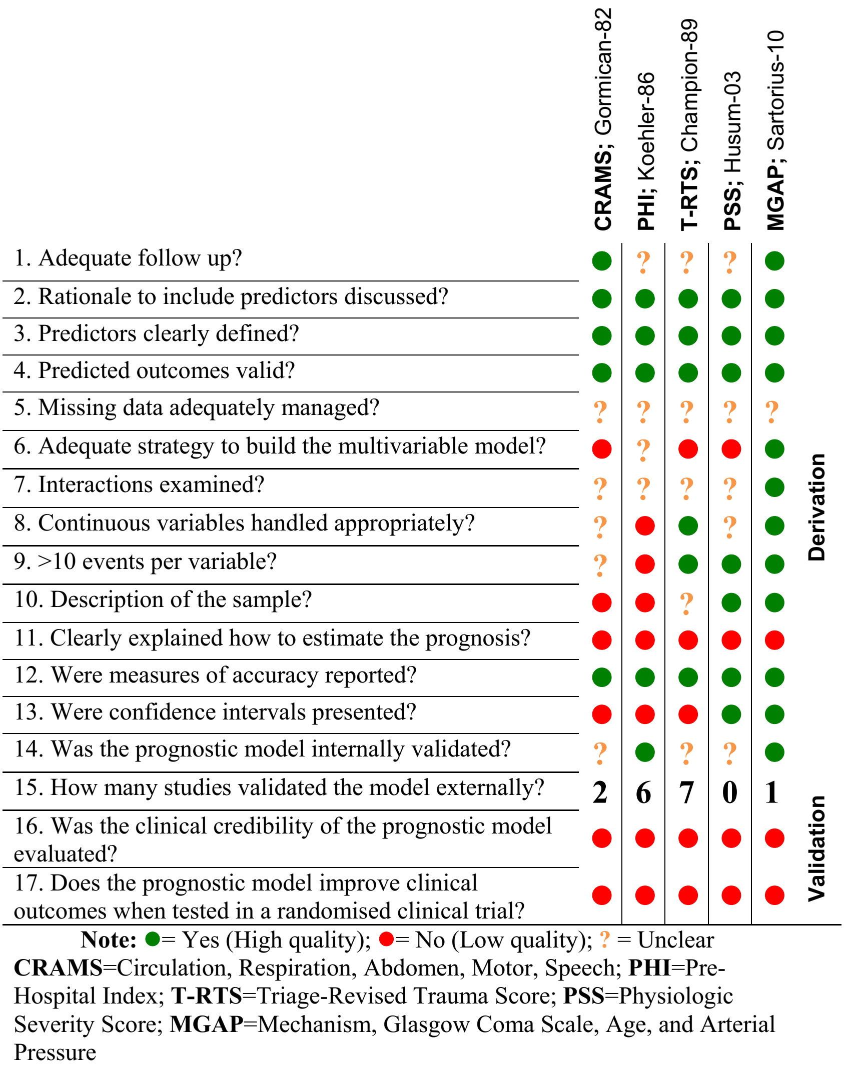

Figure 2 Quality assessment of prognostic models: Review authors' judgments about each methodological quality item.

being difficult to score correctly [37,38]. Reflecting this, variously defined predictors depicting consciousness were included in all models. All the prognostic models evaluated survival as an outcome, although the timing was defined differently for all the models. Further, we revealed heterogeneity in outcomes other than survival highlighting the consensus among researchers regarding a common definition of "major trauma" is needed (see additional file 4; Characteristics of investigated outcomes").

All the models, except PSS, were validated in external populations. The T-RTS was the most frequently validated (7 studies). The performance of the prognostic models showed a large variation between different validation studies (see table 2), although the majority of studies were conducted on populations from USA and

Canada. The reason for these differences can be related to methodological issues, such as different variable definitions or alternatively it could be related to the difficulty of transporting prognostic model to different settings. Factors that may affect the transportability of prognostic factors could be related with injury characteristics (e.g. penetrating injuries), patient's characteristics (e.g. age), or medical services characteristics (e.g. pre-hospital transportation distances or level of EMS personnel competence).

Importantly, although 80% of trauma deaths occur in low and middle-income countries where many of these characteristics are likely to be different from developed countries, we did not find any model that was developed and validated for this setting [1]. Trauma care providers in low and middle-income countries should have access to prognostic models derived in cohorts including patients from these populations.

Although prognostic models for trauma should be developed following methodological guidelines, the quality appraisal revealed several areas of improvement for most models. We found methodological limitations pertaining to issues such as inadequate methods to develop the prognostic models, handling of continuous variables and dealing with missing data. The MGAP was the one that fulfilled most of the recommended methodological quality items.

For a prognostic model to be used it should be well accepted by EMS providers. However, none of the studies evaluated the "acceptability" and "practicality" of the prognostic model. For a model to be effective it should improve patients' outcomes when tested in a randomised clinical trial, nevertheless the impact was not evaluated for any of the models. All models successfully discussed the rationale to include the predictors and included clearly defined predictors and valid outcomes.

We acknowledge that his systematic review has limitations. Some relevant studies may not have been located during our database search. Our literature review was only conducted in MEDLINE, although several other databases exist. The search strategy used in MEDLINE performed with high sensitivity (4 939 records retrieved) and low specificity (14 included studies). We identified three of the included studies through alternative sources (bibliographies); however, all 14 studies are included in MEDLINE. Closer examination of the included studies indicated inconsistent indexing of articles on prognostic scoring in adult trauma on MEDLINE. In the future, more homogenous reporting of studies pertaining to prognostic trauma models may reduce these limitations. Further, our exclusion of non-English language has contributed to the risk of missing relevant studies. However, we identified all the models included in a recently published triage guideline [39].

We only identified 9 validation studies indicating a need for further evaluation of performance transportability. In order to be able to evaluate the validity of future prognostic models we recommend to report the items included in our quality appraisal list (see additional file 3) as well as other relevant standards for reporting [40,41].

Our review should be incentives to further evolve the accuracy of prognostic models for the early care of trauma patients.

Conclusions

This systematic review located and appraised the quality of five prognostic models for the early care of trauma patients. The prognostic models reported various outcomes pertaining to major trauma, but all models evaluated survival as an outcome. The general impression is that all models predict survival adequately. The MGAP fulfilled most of the suggested methodological quality items and is recommendable for routine use. However, there are many areas for improvement, including model development, analysis of continuous measures, handling of missing data, practicality and impact analysis.

Additional material

Additional file 1: Literature search strategy. Electronic bibliographical databases and search strategies

Additional file 2: Excluded studies. List of full text studies excluded, with reason

Additional file 3: Quality assessment items list. Items used to appraise quality of included prognostic model derivation studies

Additional file 4: Characteristics of investigated outcomes. Table of outcomes pertaining to mortality, morbidity, process, anatomic injury and definition of "major trauma"

List of abbreviations used

ACS-COT: American College of Surgeons-Committee on Trauma; AUC: Area Under ROC Curve; CRAMS: Circulation, Respiration, Abdomen, Motor, Speech; ED: Emergency Department; EMS: Emergency Medical Service; GCS: Glasgow Coma Scale; ISS: Injury Severity Score; MGAP: Mechanism, GCS, Age, and Arterial Pressure; PHI: Pre-Hospital Index; PSS: Physiologic Severity Score; ROC: Receiver Operating Characteristics; RR: Respiratory Rate; SBP: Systolic Blood Pressure; TS: Trauma Score; T-RTS: Triage-Revised Trauma Score.

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Authors' contributions

MR, PP and HML developed the protocol. MR and PP conducted the systematic review. KB conducted the literature search. MR and PP conducted the data extraction. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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IV

Calculating trauma triage precision: effects of different definitions of major trauma

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Abstract

Triage is the process of classifying patients according to injury severity and determining the priority for further treatment. Although the term “major trauma” represents the reference against which over- and undertriage rates are calculated, its definition is inconsistent in the current literature. This study aimed to investigate the effects of different definitions of major trauma on the calculation of perceived over- and undertriage rates in a Norwegian trauma cohort.

We performed a retrospective analysis of patients included in the trauma registry of a primary, referral trauma centre. Two “traditional” definitions were developed based on anatomical injury severity scores (ISS >15 and NISS >15), one “extended” definition was based on outcome (30-day mortality) and mechanism of injury (proximal penetrating injury), one ”extensive” definition was based on the “extended” definition and on ICU resource consumption (admitted to the ICU for >2 days and transferred intubated out of the hospital in ≤2 days), and an additional four definitions were based on combinations of the first four.

There were no significant differences in the perceived under- and overtriage rates between the two “traditional” definitions (NISS >15 and ISS >15). Adding “extended” and “extensive” to the “traditional” definitions also did not significantly alter perceived under- and overtriage. Defining major trauma only in terms of the mechanism of injury and mortality, with or without ICU resource consumption (the “extended” and “extensive” groups), drastically increased the perceived overtriage rates.

We conclude that expanding the definitions of major trauma using parameters other than anatomic injury was not useful for over- and undertriage calculations based on our data. We recommend a consensus-based definition of the term “major trauma”.

Background

Early appreciation of major trauma enables emergency medical service (EMS) providers to match the available resources to each victim's needs. Triage is the process of classifying patients according to injury severity and determining the priority for further treatment [1, 2]. Field triage has become increasingly important, as regionalised trauma care with dedicated trauma teams has been shown to improve patient outcome [3-5]. Nevertheless, some mistriage is unavoidable, as field triage is performed close to the time of injury, with limited diagnostic resources in a multifarious pre-hospital environment. If major trauma victims are undertriaged and therefore denied access to high-resource resuscitation, avoidable negative outcomes may ensue [1, 6]. Conversely, overtriage may cause minor trauma victims to be unnecessarily transferred to dedicated trauma care facilities, thereby consuming scarce financial and human resources. Overtriage thus decreases the available resources for other patients with greater needs [7, 8].

The rates of over- and undertriage are considered to be trauma system quality indicators [2]. Although these data are debated, the American College of Surgeons - Committee on Trauma (ACS-COT) states that an undertriage rate of 5–10% is unavoidable, and most systems are associated with an overtriage rate of 30–50% [2] [9].

The definition of major trauma provides the reference standard against which the over- and undertriage rates are calculated [10]. There is a 40-year tradition of grading the severity of individual injuries using the Abbreviated Injury Scale (AIS), and based on this scale, the Injury Severity Score (ISS) can be calculated as the sum of the squares of the highest AIS codes in each of the three most severely injured ISS body regions [11, 12]. The US Major Trauma Outcome Study (MTOS) found that an ISS >15 was associated with a mortality risk of at least 10% and was related to a distinct increase in mortality [13]. Following this study, many subsequent triage studies dichotomised study populations into "major trauma" patients, who were defined as having an ISS >15, and "minor and moderate trauma" patients (ISS ≤15), and they presented two-by-two tables describing the diagnostic accuracy of triage algorithms [14, 10]. Several limitations of the ISS have been highlighted [15, 16], providing a basis for the New Injury Severity Score (NISS) [17]. The NISS is a simple modification of the ISS and is calculated from the three most severe injuries regardless of body region. The NISS has been considered to be more predictive of survival, especially in patients suffering from multiple head injuries or penetrating trauma [17-20]. Although the ISS is still the dominant scale in papers published on triage precision, an NISS >15 is recommended as an inclusion criterion in the Utstein template for uniform reporting of data following major trauma [21].

Mortality and morbidity are the principal outcomes after trauma, and their relevance remains undisputed [22, 23]. To define major trauma, several studies have therefore combined anatomic injury scales, such as the ISS or NISS, with variables associated with mortality, morbidity, type of injury, or resource consumption [24-26]. The rationale is an understanding of major trauma as more complex than anatomic injury alone. The compound definitions in these studies often include process-mapping variables, making the definitions more system-specific and thereby reducing the external validity and reproducibility.

Butcher et al. reported, in their review on the definitions of “polytrauma”, that there was no consensus on the term [27]. This lack of consensus was corroborated by a recent systematic review of pre-hospital prognostic trauma models [28], in which the authors also questioned the external validity of published studies on triage precision and emphasised the challenges inherent in the comparison of triage systems.

To compare data sets, assess external validity and facilitate multicentre trials, the impact of different definitions of major trauma on quality assessments should be clarified. The aim of the present study was to investigate how various definitions of major trauma influence the calculation of under- and overtriage in a trauma cohort.

Methods

Study population

Stavanger University Hospital (SUH) is a 630-bed hospital and is the primary trauma centre for a mixed rural/urban population of approximately 330,000 inhabitants. It is also the trauma referral centre for all 440,000 people living in Rogaland County in southwestern Norway. SUH admits approximately 140 adult and paediatric patients annually with NISS scores >15 and treats approximately 3,400 patients per year with minor injuries [26]. During the study period, the hospital practised the informal activation of a one-tiered, 13-personnel, large, multidisciplinary trauma team. Pre-hospital emergency care in the catchment area was provided by on call general practitioners, ground ambulance units staffed with paramedics, and anaesthesiologist-staffed rapid response cars and helicopters.

Study design

Since 2004, a hospital-based trauma registry has been fully operational. An Association for the Advancement of Automotive Medicine certified AIS coder (a registered nurse) manually searches the hospital administrative data system for eligible patients and annually codes the data from approximately 360 individuals (see Table 1 for the trauma registry inclusion and exclusion criteria).

We performed a retrospective analysis of the SUH trauma registry data and included consecutive patients who were admitted to SUH between January 1, 2004, and December 31, 2008, and had been assigned one or more AIS codes (AIS 98; Abbreviated Injury Scale, 1990 Revision, Update 98). Inter-hospital transfers to SUH and patients transported by non-healthcare personnel were excluded, as they were not subject to SUH field triage practices. Survival status 30 days after injury was obtained from the Norwegian Population Registry and from patient records [21].

The Regional Committee for Medical and Health Research Ethics deemed their formal approval unnecessary (2009/228-CAG). The Norwegian Social Science Data Services approved our access to anonymous data from relevant patients in the trauma registry (20840 KS/LR).

Definitions of major trauma

We constructed two "traditional" definitions based on anatomic injury severity scores (ISS >15 and NISS >15, respectively), one "extended" definition based on outcome and mechanism of injury (dead at 30 days and/or proximal penetrating injury), and one "extensive" definition based on the "extended" definition and on resource consumption ("extended" and/or admitted to the intensive care unit [ICU] for >2 days and/or transferred intubated out of the hospital at ≤2 days). An additional four definitions were constructed from combinations of these definitions (Table 3). Perceived triage precision was calculated according to each of these eight separate definitions of major trauma.

Statistical analysis

The calculation of perceived triage precision was based on the assumption that all of the patients suffering from major trauma, according to the above definitions, should have access to the trauma team upon hospital admission. Undertriage rate was defined as the proportion of patients who were not triaged by a trauma team despite having a major trauma (c/(a+c) in Table 2), i.e., the complement of the sensitivity (1-sensitivity) [25]. Overtriage rate was defined as the proportion of patients without major trauma among those who were triaged by a trauma team (b/(a+b) in Table 2), i.e., the complement of the positive predictive value (1-PPV), where PPV denotes the probability that a patient suffers from a major trauma when the trauma team is activated. The 95% confidence intervals (95% CI) for over- and undertriage were calculated as $p \pm 1.96 \times \sqrt{\frac{p \times (1-p)}{n}}$, where p is the proportion of patients that had been over- or undertriaged and n is the total number of patients who were triaged by a trauma team or had experienced major trauma (a+b and a+c in Table 2). Significant differences were defined as non-overlapping 95% confidence intervals.

Results

Descriptive

During the study period, of the 1 481 patients who were coded in the SUH trauma registry, 1 384 fulfilled our eligibility criteria. Among these included patients, 1 314 (95%) suffered blunt injuries, and 69 (5%) suffered penetrating injuries. The median age was 31 years old (IQR 19–51), and 997 (72%) of the patients were male. The median ISS score was 10 (IQR 5–19), the median NISS score was 12 (IQR 5–24), and 80 patients died within 30 days (mortality 5.8%). Figure 1 shows the number of patients falling within the combinations of the various definitions and highlights the proportion of patients who were met by a trauma team. There was a significant increase in the percentage of patients who were defined as having sustained a major trauma when the NISS-based definitions were compared to their ISS-based counterparts ($p<0.01$ for all comparisons). Table 4 shows the proportions of the included patients having sustained a major trauma according to the various definitions, with the corresponding values for over- and undertriage (see also Figure 2).

Triage quality assessment

There were no significant differences between perceived under- and overtriage using NISS >15 or ISS >15, NISS "extended" or ISS "extended", or NISS "extensive" or ISS "extensive" as definitions of major trauma, except for the ISS Traditional definition (i.e., ISS >15), which had higher perceived overtriage than NISS "extended" and NISS "extensive" (Table 4 and Figure 2). The major trauma definitions without anatomic criteria, i.e., "extended" (based on type of injury and 30-day survival only) or "extensive" ("extended" combined with ICU LOS >2 days or transferred out intubated within 2 days), resulted in significantly lower perceived undertriage than the NISS-based definitions and significantly higher perceived overtriage than any other definition (Table 4 and Figure 2).

Discussion

The definition of major trauma is commonly based on anatomic injury alone, and both ISS >15 and NISS >15 are recommended cut-off values. Our study revealed no significant differences in the perceived under- and overtriage rates between NISS >15 or ISS >15 as the definitions for major trauma. This finding suggests that the outcomes of triage precision calculations may be comparable between trauma systems, regardless of the use of NISS >15 or ISS >15 as definitions. In contrast, the NISS will be equal to or greater than the ISS for any given patient, depending on the injuries sustained. Accordingly, utilising NISS >15 instead of ISS >15 will result in an increased number of included patients in most trauma populations (cf. Table 4 and Figure 1). In the present population, we found a 24% relative increase in the number of patients who were defined as having sustained a major trauma when NISS >15 was applied, compared to ISS >15 (from 470 to 585; see Table 4). This increase might be interpreted as improved sensitivity without loss of specificity, implying that NISS >15 is superior to ISS >15 as a definition of major trauma [18, 29]. However, this difference in sensitivity caused by the use of a different injury scale obviously makes the results less comparable. It has therefore been argued that a compound definition of major trauma is necessary [25]. Factors other than anatomic injury influence mortality, and the inclusion of the mechanism of injury and/or outcome variables, such as mortality, in the definition of major trauma seems relevant. The Utstein template recommends 30-day mortality, Glasgow Outcome Scale (GOS), discharge destination, and hospital length of stay (LOS) to be reported as outcome measurements after trauma [21]. In an attempt to capture the complexity of trauma, several studies have included such outcomes in their definitions of major trauma [6, 25, 30-32]. In our cohort, expanding the purely anatomic definition of major trauma by including proximal penetrating injury, 30-day mortality, and ICU LOS greater than 2 days did not significantly influence the perceived triage precision.

Defining major trauma only in terms of the mechanism of injury and resource consumption, without including anatomic injury scaling, drastically reduced the number of cases defined as major trauma. The proportions of perceived major trauma patients in the study population were reduced from 34.0% and 42.3% with ISS >15 and NISS >15, respectively, to 9.5% in the "extended" group and 22.6% in the "extensive" group (Table 4), thereby putting into serious doubt the usefulness of these definitions for triage precision calculations.

Precise and complete reporting of diagnostic accuracy studies, e.g., triage research, enables readers to assess the external validity of the study results and to evaluate the possible sources of bias. To improve reporting, a STARD (Standards for Reporting of Diagnostic Accuracy) checklist has been developed [33]. STARD specifically requires that the reference standards identify the target conditions. For studies evaluating trauma triage, "major trauma" should be precisely and consistently defined, and the rationale for using the particular definition should be provided. To improve research on triage precision, researchers should adapt the STARD checklist and establish a uniform definition of major trauma.

Limitations

The present study presents a fairly small amount of data from a single centre, and its findings are dependent on the SUH trauma population's characteristics, including a very low number of penetrating injuries. The findings may also be susceptible to bias caused by idiosyncrasies of the informal trauma triage system at SUH. Thus, applicability to other trauma populations could be limited. Furthermore, the retrospective nature of this study restricted the data to variables that were already defined and coded in the institutional trauma registry.

Conclusion

The definition of major trauma provides a reference standard when calculating the precision of trauma triage. However, the definitions are inconsistent in the current literature. In our cohort, although the proportion of patients who were defined as having sustained a major trauma increased when NISS-based definitions were substituted for ISS-based definitions, the outcomes of the triage precision calculations did not differ significantly between the two scales. Additionally, adding the mechanism of injury and outcome variables did not significantly influence the triage precision calculations. For the triage precision calculations, the STARD checklist should be implemented, and researchers should establish a consensus on a uniform definition of major trauma.

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Authors' contributions

HML and MR conceived and planned the study. TE designed and built the SUH trauma registry, KET included and coded all of the patients, KET and MR extracted the data, and TE performed the analyses. All of the authors participated in the drafting and completion of the manuscript.

Conflicts of interest

The authors declare that they have no conflicts of interests regarding this study.

Figure legends

Figure 1

Set diagram of definitions for major trauma (circles); overlapping areas represent patients covered by two or more definitions. The “extensive” definition used in our study consisted of both “extended” and “ICU severity”. The number of patients triaged to be received by a trauma team is provided together with the number of patients not met by a team.

Figure 2

Consequences of the various definitions of major trauma for perceived over- and undertriage. ISS-based definitions are shown as circles, NISS-based definitions are shown as squares, and diamonds represent definitions that are not based on anatomic criteria (cf. Tables 3 and 4). The symbols representing “extended” and “extensive” definitions are grey and black, respectively. The lines denote 95% confidence intervals.

Table 1. Inclusion and exclusion criteria for the Stavanger University Hospital (SUH) trauma registry

Inclusion Criteria	**Exclusion Criteria**

Absolute:
• Activated trauma team
• Penetrating injury to:
  ○ Head
  ○ Neck
  ○ Trunk
  ○ Extremities proximal to the knee or elbow
Relative:
• ISS ≥10
	Patients only fulfilling relative criteria are excluded if:
	• Isolated fracture and skin injury (AIS 1) in:
	  ○ Upper extremity
	  ○ Lower extremity
	  ○ Floor of the orbit
	• Chronic subdural haematoma
	• Drowning, inhalation injury, asphyxia-related injury (hanging, strangulation)
	• Secondary admission to SUH >24 hours after injury

ISS: Injury Severity Score; AIS: Abbreviated Injury Scale	

Table 2. Injury severity and trauma team activation (TTA)

	Major trauma	**Non-major trauma**	**Total**
TTA	a	b	a+b
No TTA	c	d	c+d
Total	a+c	b+d	n

Sensitivity=a/(a+c); Specificity=d/(b+d); Positive predictive value (PPV)=a/(a+b)

Undertriage=1-Sensitivity=c/(a+c); Overtriage=1-PPV=b/(a+b)

Table 3. Definitions of "major trauma" used in the study

ISS traditional	ISS >15
ISS extended	"ISS traditional" **and/or** "Dead 30 days after injury" **and/or** "Proximal penetrating injury"
ISS extensive	"ISS extended" **and/or** "ICU LOS >2 days" **and/or** "ICU LOS ≤2 days and transferred out intubated"
NISS traditional	NISS >15
NISS extended	"NISS traditional" **and/or** "Dead 30 days after injury" **and/or** "Proximal penetrating injury"
NISS extensive	"NISS extended" **and/or** "ICU LOS >2 days" **and/or** "ICU LOS ≤2 days and transferred out intubated"
Extended	"Dead 30 days after injury" **and/or** "Proximal penetrating injury"
Extensive	"Extended" **and/or** "ICU LOS >2 days" **and/or** "ICU LOS ≤2 days and transferred out intubated"

ISS=Injury Severity Score; NISS=New Injury Severity Score; ICU=intensive care unit; LOS=length of stay

Table 4. Number and proportions of included patients with major trauma according to the different definitions and perceived triage precision

Definition of major trauma	Number of major trauma patients (% of total population)	Perceived undertriage (%) with 95% CI	Perceived overtriage (%) with 95% CI
ISS Traditional	470 (34.0)	23.4 (19.6 – 27.2)	66.9 (64.1 – 69.7)
ISS Extended	515 (37.2)	22.9 (19.3 – 26.5)	63.5 (60.7 – 66.4)
ISS Extensive	539 (38.9)	23.6 (20.0 – 27.1)	62.2 (59.3 – 65.0)
NISS Traditional	585 (42.3)	28.4 (24.7 – 32.0)	61.5 (58.6 – 64.4)
NISS Extended	629 (45.4)	27.7 (24.2 – 31.2)	58.2 (55.3 – 61.1)
NISS Extensive	641 (46.3)	27.8 (24.3 – 31.2)	57.5 (54.5 – 60.4)
Extended	132 (9.5)	12.9 (7.2 – 18.6)	89.4 (87.6 – 91.3)
Extensive	313 (22.6)	15.3 (11.3 – 19.3)	75.7 (73.1 – 78.2)

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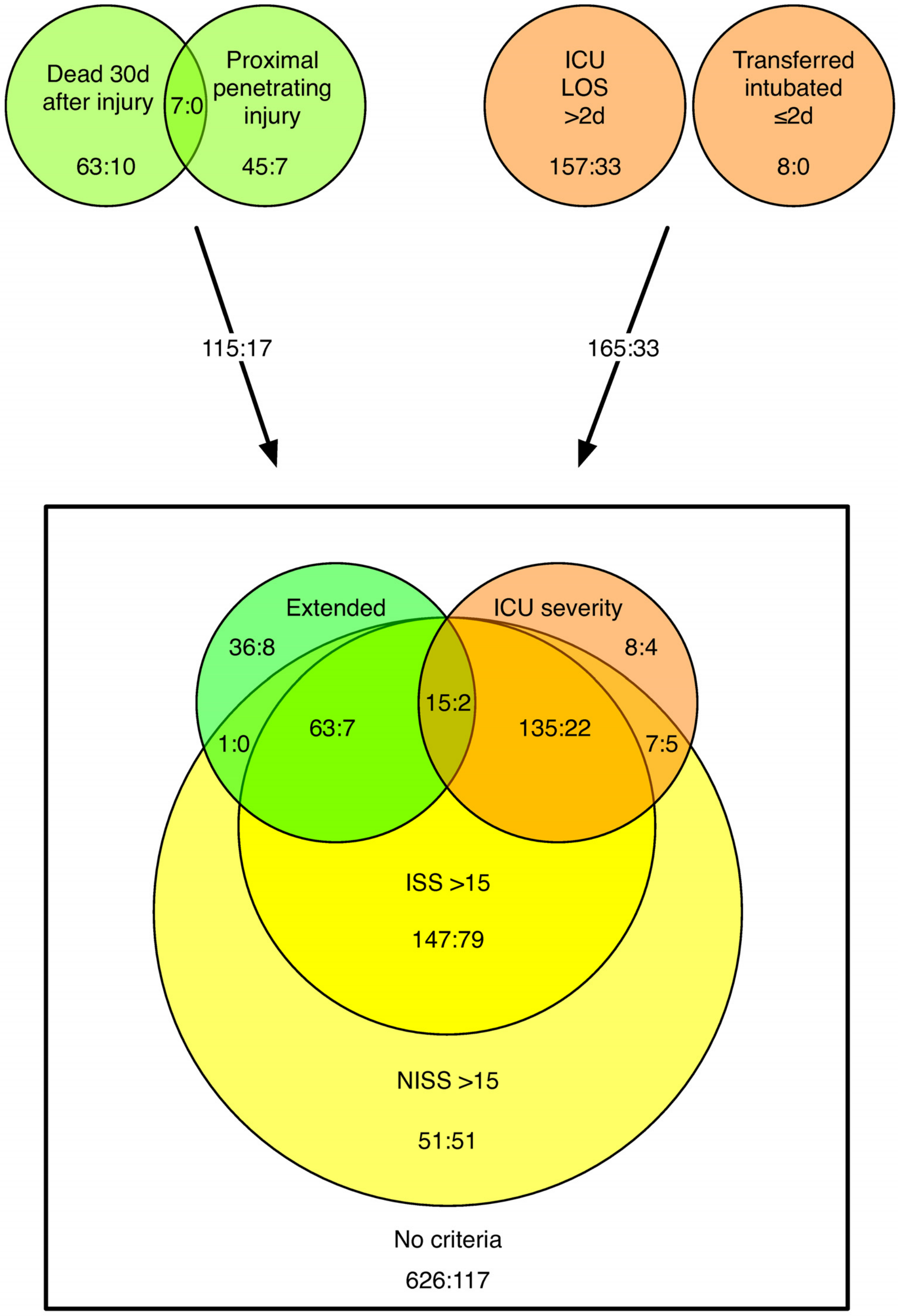
Figure 1



Total population 1384
Team : No team = 1089 : 295

Figure 1

Figure 2

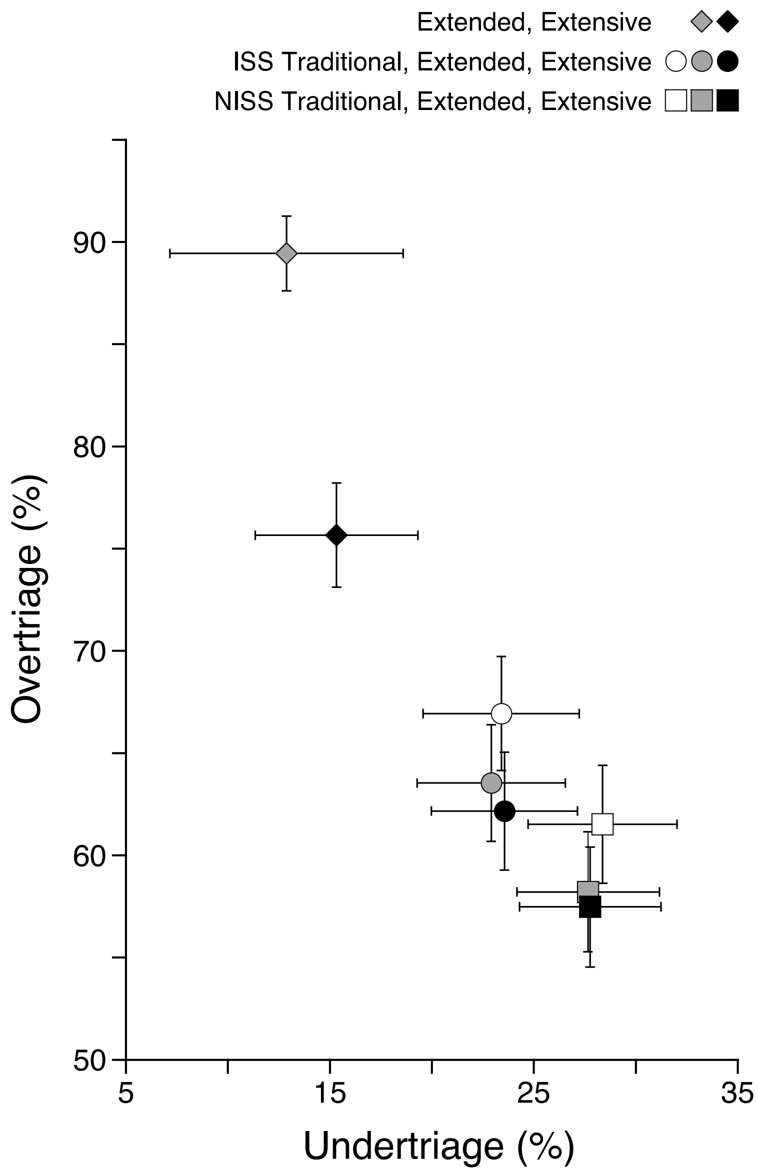


Figure 2