Evaluation and improvement of prehospital trauma triage

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Evaluation and improvement of prehospital trauma triage

Evaluatie en verbetering van pre-hospitale trauma triage

(met een samenvatting in het Nederlands)

Proefschrift

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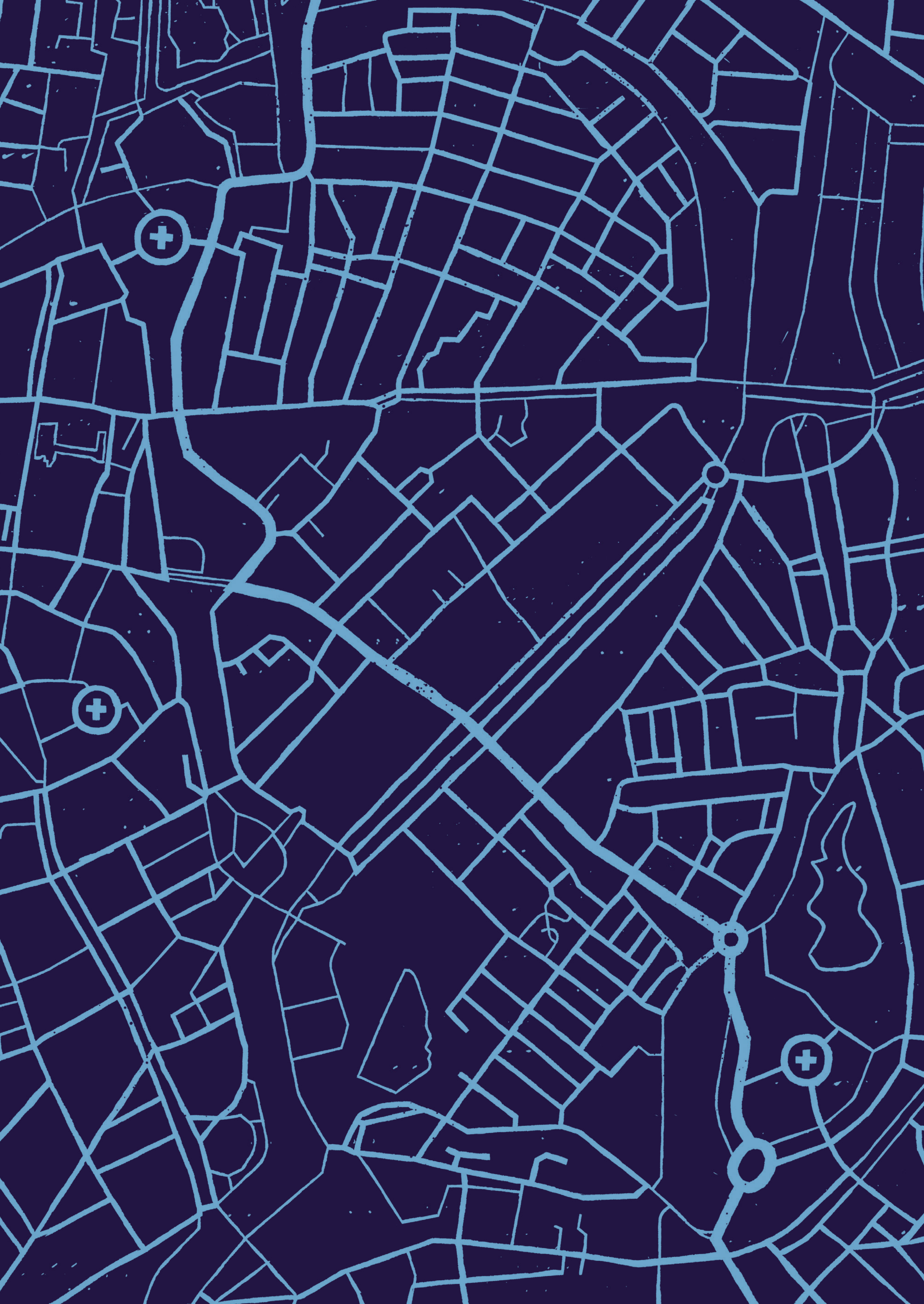
Contents



General introduction

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General introduction

Worldwide, every minute ten people die as a result of injury and even more are left with life-long disabilities. Establishing effective systems of injury control and trauma care is one of the biggest opportunities in public health to save millions of lives every year in all countries around the world. Yet, trauma and injuries have been neglected from the global health agenda for many years.[1]

Trauma systems: two types of trauma centers

Over the last decades, trauma systems have been developed and improved to provide optimal care for trauma patients and increase their chances of survival.[2, 3] Trauma systems are an organized effort within a geographical region to provide care for all trauma patients. In a trauma system, two types of trauma centers can be distinguished; higher-level and lower-level trauma centers. The higher-level trauma centers are capable to provide care for every aspect of injury and have all the necessary facilities to treat severely injured patients; such as round the clock neurosurgical care. While, lower-level trauma centers are, in their turn, designed to treat the patients without severe injuries.

Transporting the patient to the appropriate level of care

Prehospital trauma triage by emergency medical services (EMS) providers is of fundamental importance in an effective trauma system. The EMS provider tries to determine the injury severity on-scene and decide what level trauma center is most appropriate.[4] Identifying severely injured patients is challenging; on-scene EMS providers must differentiate between patients, often in adverse situations, without advanced diagnostic tools.

Prehospital trauma triage protocols were developed to aid EMS providers in the identification of severely injured patients. In 1986, the American College of Surgeons Committee on Trauma (ACS-COT) established the first prehospital trauma triage protocol –which included the concept of bypassing the nearest hospital for a higher-level trauma center.[5, 6] This has proven to be pivotal in the development of prehospital trauma triage systems.

Worldwide, different triage protocols are used. Most include an assessment of vital signs, mechanism of injury, and injury type criteria.[7-9] However, the effectiveness of prehospital trauma triage is not solely determined by the quality of the protocol, but by many factors, such as: compliance to the protocol, geographical distance, and regional circumstances.

Optimizing prehospital trauma triage

Prehospital trauma triage quality is based on the transport of the right patient to the right trauma center. When severely injured patients are not transported to a higher-level trauma center, it is referred to as undertriage.[5, 7-9] On the other hand, overtriage refers to patients without severe injury, transported to a higher-level facility. In general, reduction of undertriage is key to decrease mortality and injury-related disabilities.[2, 3] Other consequences of undertriage include: delay in diagnosis and treatment, missed injuries, and decreased functional outcome. In order to lower undertriage, more patients –including the patients without severe injury– have to be transported to a higher-level trauma center, which inevitably increases overtriage. Overtriage also carries disadvantages, such as an unnecessary burden on higher-level trauma center resources and relatively high trauma care costs.[11, 12]

Injury severity can be determined according to the Injury Severity Scale (ISS).[10] The ISS is an anatomical scoring system that correlates with chance of hospitalization, injury-related disability, and mortality. The score ranges from 0 to 75, with a higher score indicating a more severe injury. A patient with an ISS > 15 is commonly considered a severely injured patient. The ISS is determined at the hospital and is based on all injuries of a patient.

Aims of the thesis

The first aim of this thesis was to evaluate the current effectiveness of prehospital trauma triage and its different aspects; trauma systems, triage protocols, and compliance to the triage protocol. The second aim was to develop a new method to improve the quality of prehospital trauma triage.

Outline of the thesis

To assess the quality of all aspects of prehospital trauma triage worldwide, four systematic reviews were done. As prehospital trauma triage protocols are the base of a trauma system, Chapter 2 evaluates the quality of the triage protocols used worldwide. Chapter 3, in its turn, provides an overview of the quality of trauma systems in different countries and highlights various aspects influencing the effectiveness of prehospital trauma triage. The accuracy of the triage protocol itself is fundamental in the prehospital triage process: it must be able to differentiate between patients in need of higher-level trauma care and those that do not. However, the EMS providers determine the destination facility for each individual patient. If the EMS providers do not comply with the triage protocol, even the perfect protocol will not lead to effective triage. Therefore, the compliance rates were analyzed in a systematic review in Chapter 4. Estimation of pediatric trauma injury severity and triaging these patients is very different from triaging adults. This problem led to the last systematic review in Chapter 5, all aspects of prehospital trauma triage of pediatric trauma patients were evaluated.

Multiple studies in the Netherlands were done to evaluate and improve prehospital trauma triage. In Chapter 6 the quality of prehospital trauma triage was assessed in one region of the Netherlands. In Chapter 7, the role of EMS provider judgment in the decision-making process of prehospital trauma triage was evaluated through a survey and an analysis of the compliance to the triage protocol in two regions of the Netherlands.

To improve triage rates, we used gained knowledge from previous chapters to create a prediction model for the identification of severely injured patients in Chapter 8. This prediction model can differentiate between severely injured patients and patients without severe injuries, with relatively simple measurements which can easily be performed by each EMS provider.
The two most common severely injured body parts are the head and thorax.[11-15] These injuries in particular are time sensitive and transportation to a facility with a higher-level of trauma care is of vital importance. However, patients with these injuries constitute to a large part of the undertriaged patients.[13, 15, 15-20] Therefore, in Chapter 9 and Chapter 10 the diagnostic value of EMS provider judgment in the identification of a head injury and thoracic injury, respectively, were evaluated.

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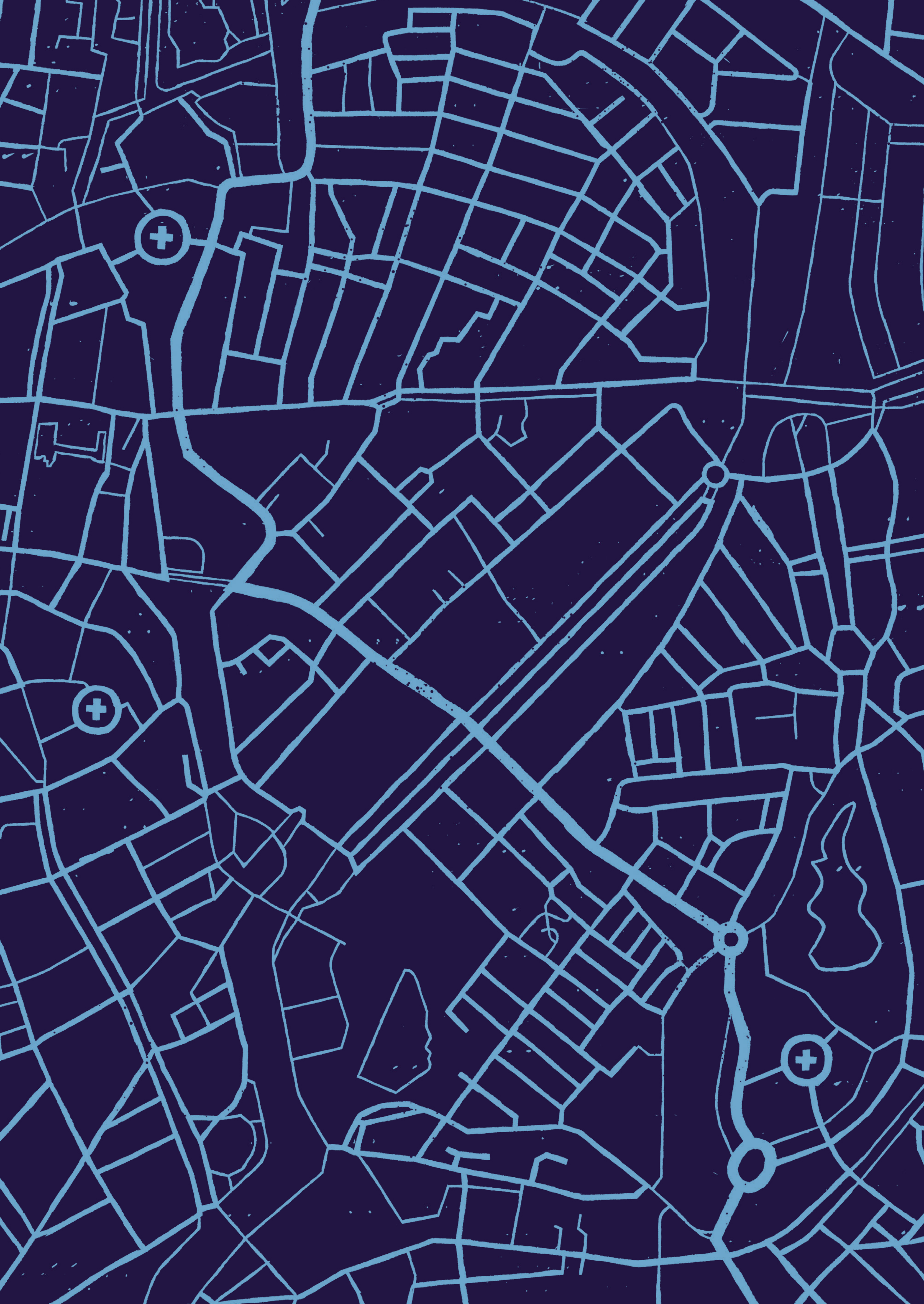

Accuracy of prehospital triage protocols in selecting severely injured patients: a systematic review

E.A.J. van Rein, R.M. Houwert, A.C. Gunning, R.A. Lichtveld, L.P.H. Leenen, M. van Heijl

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Abstract

Background

Prehospital trauma triage ensures proper transport of patients at risk of severe injury to hospitals with an appropriate corresponding level of trauma care. Incorrect triage results in undertriage and overtriage. The American College of Surgeons Committee on Trauma recommends an undertriage rate below 5% and an overtriage rate below 50% for prehospital trauma triage protocols. In order to find the most accurate prehospital trauma triage protocol, a clear overview of all currently available protocols and corresponding outcomes is necessary.

Objectives

The aim of this systematic review was to evaluate the current literature on all available prehospital trauma triage protocols and determine accuracy of protocol-based triage quality in terms of sensitivity and specificity.

Methods

A search of Pubmed, Embase, and Cochrane Library databases was performed to identify all studies describing prehospital trauma triage protocols before November 2016. The search terms included 'trauma,' 'trauma center,' or 'trauma system' combined with 'triage,' 'undertriage,' or 'overtriage.' All studies describing protocol-based triage quality were reviewed. To assess the quality of these type of studies, a new critical appraisal tool was developed.

Results

In this review, 21 articles were included with numbers of patients ranging from 130 to over 1 million. Significant predictors for severe injury were: vital signs, suspicion of certain anatomic injuries, mechanism of injury, and age. Sensitivity ranged from 10% to 100%; specificity from 9% to 100%. Nearly all protocols had a low sensitivity, thereby failing to identify severely injured patients. Additionally, the critical appraisal showed poor quality of the majority of included studies.

Conclusions

This systematic review shows that nearly all protocols are incapable of identifying severely injured patients. Future studies of high methodological quality should be performed in order to improve prehospital trauma triage protocols.

Introduction

The impact of severely injured trauma patients is a significant global concern, causing over 5 million deaths each year and leaving even more patients with lifelong injury-related disabilities.[1] Prehospital trauma triage is essential in providing appropriate care for patients at risk for severe injury in order to improve their chance of survival and to avert disabilities.[2-4]

Incorrect triage results in undertriage and overtriage.[5-8] Undertriage refers to patients with severe injuries not transported to a higher-level trauma center by emergency medical services (EMS) providers. Overtriage occurs when patients without severe injuries are taken to a higher-level trauma center. It has previously been shown that undertriage results in increased mortality and morbidity.[2, 3, 9] In other words, correct prehospital triage can save lives. In addition, undertriage causes delay in diagnosis and treatment, missed injuries, and decreased functional outcome.[2, 3] The American College of Surgeons Committee on Trauma (ACS-COT) recommends aiming for an undertriage rate below 5%.[10] Overtriage, on the other hand, results in unnecessary burden on higher-level trauma center resources and high trauma care costs.[11, 12] Prehospital trauma triage protocols have been developed to improve triage rates. To assess protocol-based triage quality sensitivity and specificity are used, which are the same as 1 – undertriage and 1 – overtriage, respectively.

Prehospital trauma triage protocols have been studied extensively over the last few decades.[13, 14] However, a clear overview of the quality of all currently available protocols and corresponding outcomes is lacking. It is unclear which prehospital trauma triage protocol is most effective. The aim of this systematic review was to determine quality of currently available prehospital trauma triage protocols for trauma patients transported by ground ambulance in terms of sensitivity and specificity.

Methods

Search

A systematic review of all published literature according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines was conducted. A search of Pubmed, Embase, and Cochrane Library databases was performed to identify all studies investigating prehospital trauma triage protocols before November 2016. The search terms included 'trauma,' 'trauma center,' or 'trauma system' combined with 'triage,' 'undertriage,' or ‘overtriage’ (Appendix 1).

Study selection

Studies describing the accuracy of prehospital triage protocols in identifying severely injured patients, regardless of actual destination facility, were included. All articles, regardless of year of publication, or language, were eligible for inclusion. Exclusion criteria were: grey literature (i.e. conference abstracts, editorials, and dissertations), articles describing only helicopter transport or including only pediatric patients. Studies on prehospital protocols seek to identify patients in need of higher-level trauma center care. Whereas articles on helicopter transport use a separate protocol to identify patients requiring helicopter transport among the patients in need of higher-level trauma center care.[15, 16] Estimation of pediatric trauma injury severity and triaging these patients is a challenging task. Protocols for pediatric trauma patients usually differ significantly from the protocols for adults and require a separate review, in our opinion.[17-20]

Critical appraisal

Due to the specific design of the included studies, most available critical appraisal tools were not fully applicable. Criteria from the critical appraisal tools from the Centre for Evidence Based Medicine of the University of Oxford were used for the assessment of the risk of bias.[21] The critical appraisal tool consists of five items that were designed to evaluate the quality of the included studies (Table 1). An accurate assessment of a prehospital triage protocol should include prehospital parameters collected on scene and all trauma patients transported to all levels of trauma centers in a specific geographic region, without a substantial amount of missing data. Therefore, the critical appraisal consisted of the items: study setting, domain, collection of data, timing of measurements, and missing data.

Data extraction

Prior to the selection of relevant articles, all duplicates were excluded. Two reviewers (EvR and MvH) assessed titles, abstracts, and subsequently full-text. All studies were assessed for methodological design and quality by two reviewers (EvR and MvH), using the critical appraisal as described. There were no discrepancies between the two reviewers. References of included articles and related reviews were screened for additional potential articles. In case of multiple publications regarding the same dataset of patients, the article with the largest cohort was selected.

Table 1. Items, importance, and score used for the critical appraisal

Item	Importance	Score
1. Study setting	A study setting including all levels of trauma centers guarantees a realistic analysis of triage rates, eliminating selection bias.	+ Regional study, including higher-level trauma center(s) as well as lower level trauma centers - One type of trauma center or not reported
2. Domain	Including all trauma patients ensures a true representation of the trauma population, eliminating selection bias.	+ All trauma patients or adults only - A specific group
3. Collection of data	Prehospital parameters scored by EMS providers give a valid depiction of the actual use of a prehospital trauma triage protocol.	+ Data acquired and scored on the scene by EMS providers - Data acquisition based on records and scored by data managers or collection method not described
4. Timing of measurements	Measuring prehospital data on the scene and at the same time for all included trauma patients represents the actual situation, for prehospital parameters, such as vital signs, can change due to interventions or over time.	+ Parameters measured at the same (prehospital) time - Not measured at the same time (for example the use of a combination of pre- and in-hospital data or the use of in-hospital data only) or timing of measurements not reported
5. Missing data	Including missing data in analyzes results in a possibly unreliable outcome.	+ No missing data +/- 0-15% missing data - > 15% missing data
Total score	Good quality Intermediate quality Poor quality	Total score of 5 + Total score of 4 + Total score of ≤ 3 +

Outcomes

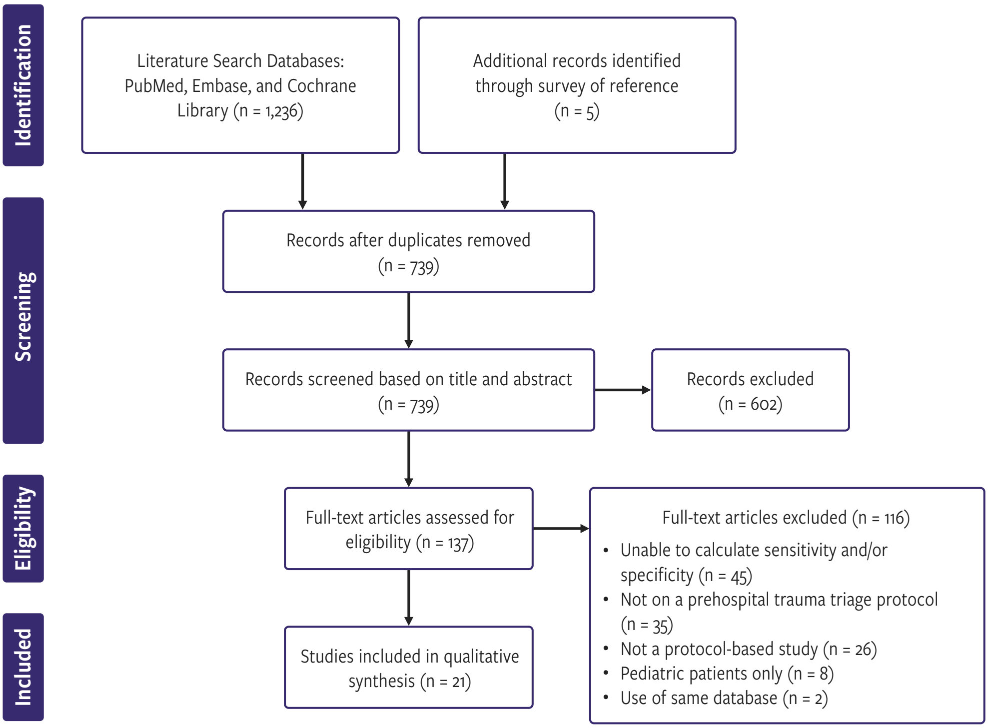
Sensitivity and specificity were used as primary outcome parameters. Sensitivity of a prehospital trauma triage protocol was defined as the proportion of severely injured patients identified as such using the prehospital trauma triage protocol. Specificity of the prehospital trauma triage protocol was defined as the number of patients without severe injuries identified as such using the prehospital trauma triage protocol. When sensitivity and specificity were not mentioned in the article, the percentages were calculated based on the definition of a severely injured patients and information provided by the article. The sensitivity and specificity for similar protocols and criteria were compared in a descriptive manner when possible. Actual triage quality in terms of transport to the correct destination facility -undertriage and overtriage of the system- was not investigated in the present review.

Results

Search results

A total of 721 unique studies were identified and screened based on title and abstract, after which 135 articles remained for full-text review. One full-text could not be retrieved.[22] After full-text review, 17 articles were eligible for inclusion and analysis. A survey of the references led to inclusion of four additional articles, resulting in a total of 21 articles (Figure 1).[23-44]

Figure 1. Flow chart of the selection process



Study characteristics

The included studies were published between 1986 and 2016 (Table 2). Four studies investigated a newly developed prehospital triage protocol.[24, 29, 40, 42] None of the studies described the indication, or level of priority of the ambulance transportation. Protocol-based triage quality in terms of either sensitivity and specificity or undertriage and overtriage were the primary outcome in seventeen articles.[23-36, 39, 40, 42] Sensitivity of prehospital triage protocols ranged from 10% to 100%; specificity ranged from 9% to 100%. The percentage of severely injured patients ranged from 3% to 100% depending on study design and type of participating hospital.

Table 2. Baseline characteristics of all included articles

First author (year)	Patients (n)	Population (year of inclusion)	Type trauma center (location)	Definition of a severely injured patient	Severely injured patients (%)
Baxt (1990)[23]	1,004	Admitted trauma patients > 14 years old (unknown)	1 level I (USA, California)	Non-orthopaedic surgery, fluid resuscitation, invasive CNS monitoring, or death	21.0
Bond (1997)[24]	3,147	Trauma patients > 13 years old (1995)	2 trauma and 2 community centers (Canada, Alberta)	ISS > 15	2.6
Brown (2011)[25]	1,086,764	Transferred, admitted, or deceased trauma patients > 17 years old (2002-2006)	Level I, II, III, IV or undesignated centers (USA)	ISS > 15, ICU admission within 24 h, or urgent surgery	42.0
Brown (2015)[26]	1,555,944	Transferred, admitted, or deceased trauma patients > 15 years (2010-2012)	Not reported (USA)	ISS > 15, ICU admission within 24 h, urgent surgery, or death in ED	Not reported
Champion (1989)[27]	2,166	Admitted trauma patients (1982-1985)	Trauma center, not further specified (USA, Washington)	ISS > 15	30.3
Ciesla (2015)[28]	116,990	Admitted adult trauma patients (2012)	Trauma and non-trauma centers, not further specified (Florida, USA)	ICISS < 0.85	10.0
Dihn (2014)[29]	3,027	Trauma patients > 14 years old (2007-2011)	1 major trauma center	ISS > 15, ICU admission, or in-hospital death	21.6
Gray (1997)[30]	213	Trauma patients admitted to the resuscitation room (1993-1995)	Not reported	ISS > 15, ICU admission, or death	46.0

▸ **Table 2** - Continued from previous page

Hamada (2014)[31]					
Cohort 1	825	Admitted trauma patients (2010-2012)	2 trauma centers, not further specified (France)	ISS > 15	Not reported
Cohort 2	190	Severely injured patients, not further specified (2010-2012)	5 trauma centers, not further specified and peripheral hospitals (France)	ISS > 15	Not reported
Hedges (1987)[32]	130	All trauma patients (1982)	Trauma centers and non-trauma centers, not further specified (USA, Washington)	No vital signs, death in ED, non-orthopaedic surgery, or ICU admittance	31.0
Ichwan (2015)[33]	101,577	Transferred, admitted, or deceased trauma patients > 15 years old (2006-2011)	Trauma centers and non-trauma centers, not further specified (Ohio, USA)	ISS > 15	23.5
Knopp (1988)[34]	1,473	Admitted trauma patients > 1 and < 65 years old (1986)	1 level I and 2 level III trauma centers (USA, California)	ISS > 15	6.6
Lerner (2011)[35]	11,891	All trauma patients > 17 years old (unknown)	1 level I trauma center (USA, Wisconsin, New York, Michigan)	ISS > 15 Non-orthopaedic surgery < 24 h, ICU admission, or death	9.3 11.5
Long (1986)[36]	898	Admitted trauma patients (1983-1985)	1 level I trauma center (USA, Oregon)	ISS > 15	26.8
Matsushima (2016)[37]	3,998	Trauma patients involved in a motor vehicle crash with vehicle intrusion (2002-2012)	Not reported	Intubation at ED, non-orthopaedic surgery, ICU admission, or in-hospital mortality	14.5
Morris (1986)[38]	1,099	Admitted trauma patients > 18 years old (1983-1984)	Trauma center, not further specified (USA, California)	ISS > 20	17.5
Newgard (2016)[39]	17,633	All trauma patients (2011)	5 level I trauma centers, 2 level II trauma centers, 5 level II trauma centers, 5 level IV trauma centers, and 11 non-trauma centers (US, Oregon and Washington)	ISS > 15 Critical resource use within 24h ISS > 15, or critical resource use within 24h	3.1 1.7 4.1

▸ **Table 2** - Continued from previous page

Ocak (2009)[40]	1,396	Admitted trauma patients > 17 years old (2004-2005)	Trauma center, not further specified (the Netherlands)	ISS > 15	12.7
Strums (2006)[41]	451	Patients with an ISS > 15 (2001-2003)	3 level I and 7 non-trauma centers (the Netherlands)	ISS > 15	100
Tamim (2002)[42]	1,291	Trauma patients > 15 years old (1993-1996)	2 level I trauma centers (Quebec, Canada)	Death < 8 days, non-orthopaedic surgery < 4 days, or ICU admission <7 days	45.0
Zimmer-Gembeck (1995)[43]	26,025	Admitted trauma patients (1990-1992)	2 level I trauma centers and 15 non-trauma centers (USA, Oregon)	Non-orthopaedic surgery, fluid resuscitation, invasive CNS monitoring, or death	10.0

CNS: central nervous system, ICU: intensive care unit, h: hours, EMS: emergency medical services, ISS: Injury Severity Score, ICISS: International Classification Injury Severity Score, ED: emergency department.

Critical appraisal

The methodological quality of the included studies was variable; most studies were of poor to intermediate quality (Table 3).

Seven of the studies used prehospital parameters scored by emergency medical services (EMS) providers on the scene.[23, 24, 31, 32, 34, 36, 39] Fifteen studies acquired the parameters in a different way. Lerner et al.[35] interviewed EMS providers at the hospital to obtain the parameters, for example. Whereas Ciesla et al.[28] used trauma alert fees as a proxy for meeting the prehospital triage criteria. Two studies used a combination of pre- and in-hospital data[25, 26] and two used in-hospital data only[29, 37] as prehospital parameters.

Only six studies included all trauma patients or adults only transported by EMS providers. Whereas fifteen studies included a specific group of trauma patients, potentially introducing selection bias.[23, 28, 31-34, 36-38, 41, 43] For instance, Matsushima et al.[37] only included patients involved in a motor vehicle crash. Hamada et al.[31] retrospectively applied the triage protocol to a cohort of patients admitted to a trauma center and a cohort of severely injured patients only.

Nine of the studies calculated sensitivity and specificity based on only patients transported to a higher-level trauma center.[23, 27, 29, 31, 35, 36, 38, 40, 42] Three studies developed a new triage protocol using this study design.[29, 40, 42]

Missing data was a significant problem in most of the studies, with fractions up to 50%.[24, 26, 29, 30, 32-37, 39, 40, 42] Seven studies did not mention the amount of missing data.[27, 28, 31, 33, 37, 41, 42] Three studies used multiple imputation to handle missing data[26, 33, 39], no alternative methods were used by the other articles. None of the studies reported a structural reason for missing data.

Protocol triage quality

Protocol-based studies investigate the quality of triage based on the accuracy of a specific prehospital triage protocol in identifying patients with severe injuries, regardless of destination facility. Sensitivity and specificity were calculated by retrospectively applying the triage protocol on a dataset of prehospital parameters (Table 4).

There are two types of protocol-based studies to be distinguished. The first type investigates the quality of the *original* protocol that was actually used for prehospital triage in the investigated cohort of patients. The second type investigates a *virtual* protocol that is often based on a newly developed set of prehospital parameters. Some studies test a range of protocols on the same dataset.[24, 27, 30, 32-36, 42, 44]

The Trauma Score (TS) assesses respiratory rate and effort, capillary refill, and Glasgow Coma Scale (GCS). Evaluation of the TS resulted in variable, but relatively low sensitivity (43% to 88%), with a more than adequate specificity (88.4 to 98.5%).[32, 34, 38] Adding mechanism of injury and anatomic criteria improved sensitivity and specificity.[34, 36] The mechanism criterion "penetrating trauma" resulted in the highest predictive value for severely injured patients.[34] The Revised Trauma Score for Triage is a revision of the TS and consists of systolic blood pressure, respiratory rate, and GCS. This protocol had a lower sensitivity compared to the TS.[27, 30, 41]

Table 3. Critical appraisal

First author (year)	1. Study setting*	2. Domain*	3. Collection of data*	4. Timing of triage*	5. Missing data*
Baxt (1990)[23]	-	-	+	-	+
Bond (1997)[24]	+	+	+	+	+/-
Brown (2011)[25]	+	-	-	-	+
Brown (2015)[26]	-	-	-	-	-
Champion (1989)[27]	-	-	-	-	-
Ciesla (2015)[28]	+	-	-	-	-
Dihn (2014)[29]	-	+	-	-	+/-
Gray (1997)[30]	-	-	-	-	+
Hamada (2014)[31]					
Cohort 1	-	-	+	+	-
Cohort 2	+	-	+	+	+
Hedges (1987)[32]	+	+	+	+	+
Ichwan (2015)[33]	+	-	-	+	-
Knopp (1988)[34]	+	-	+	-	+
Lerner (2011)[35]	-	+	-	-	+
Long (1986)[36]	-	-	+	+	+
Matsushima (2016)[37]	-	-	-	+	-
Morris (1986)[38]	-	-	-	+	+
Newgard (2016)[39]	+	+	+	-	-
Ocak (2009)[40]	-	-	+	+	+
Strums (2006)[41]	+	-	-	-	-
Tamim (2002)[42]	-	+	-	+	-
Zimmer-Gembeck (1995)[43]	+	-	-	-	+

* Items and scoring system are described in Table 1.

The ACS-COT established the Field Triage Decision Scheme (FTDS) in 1986 and continues to publish modified protocols at regular intervals.[45] It consists of four aspects: mechanism of injury, physiologic criteria, anatomic criteria, and special considerations. The special considerations criterion includes, among others, age > 55 years, comorbidity, and EMS provider judgment. Alterations in the FTDS from 1999 to 2006 resulted in an increase of specificity and a small decrease in sensitivity.[35] Upon analyzing specific aspects of the 2006 FTDS, various criteria predicted the need for higher-level trauma care. Physiologic criteria were predictive when the Injury Severity Score (ISS) was greater than 15, whereas anatomic criteria were better at predicting the need for an urgent operative intervention.[25, 26] A new model that added six new mechanism of injury criteria to the 2006 FTDS increased sensitivity from 84.1% to 92.1%.[40] In the 2011 FTDS, age > 64 years was a strong predictor of the need for higher-level trauma care amongst motor vehicle crash victims.[37]

Gray et al.[30] and Hedges et al.[32] assessed the CRAMS (Circulation, Respiration, Abdomen, Motor, Speech) scale, but reported an over 15% difference in both sensitivity and specificity.

The Prehospital Index (PHI) is a combination of systolic blood pressure, pulse, respiratory rate, and level of consciousness. Three studies assessed PHI > 3 and found a sensitivity ranging from 35% to 73%.[24, 32, 42] Tamim et al.[42] created a new model based on the PHI, combined with age, body region injured, mechanism of injury, and comorbidity. The model was made using logistic regression analysis to produce an algorithm, which resulted in improved triage rates.[42] However, according to the authors, the correct cut-off point has yet to be determined. The combination of PHI and mechanism of injury criterion identified severely injured patients more accurately than PHI score or mechanism of injury alone, with sensitivity and specificity of 78% and 89%, respectively.[24]

Among state-wide or national protocols, the Vittel Triage Criteria of France (consisting of mechanism of injury, physiologic criteria, anatomic criteria, applied resuscitation measures, and medical history) excelled, with a sensitivity of 98-99% and a specificity of 54-64%.[31] Two cohorts were used: one with patients admitted to a higher-level trauma center and one with severely injured patients (without specifying definition).

Ichwan et al.[33] compared Ohio's 2009 geriatric prehospital triage criteria with corresponding adult criteria in a cohort of patients who died, were transferred, or were admitted for ≥ 48 hours. Both protocols included physiologic and anatomic criteria with lower thresholds for higher-level trauma care in the geriatric population (patients aged 70 or older). Considering the geriatric patients only, the geriatric triage criteria resulted in a higher sensitivity compared to the adult criteria (61% versus 93%), but this came at the cost of a decrease in specificity (49% versus 61%).

Assessment of severely injured patients, not identified as such by the Oregon triage criteria (consisting of the mechanism of injury, physiologic, and anatomic criteria) showed that many were elderly (≥ 65 years of age).[43]

Dihn et al.[29] developed a new prehospital triage protocol consisting of age ≥ 65 years, abnormal vital signs, GCS < 14, penetrating injury, multi-region injuries, and falls. The resulting sensitivity and specificity were 90% and 58%, respectively. This cohort was predominantly elderly with low rates of penetrating injuries.

Table 4. Rates of sensitivity and specificity per prehospital trauma triage protocol

First author (year)	Assessment of protocol	Triage protocol	Severely injured patients (%)	Sensitivity	Specificity
Baxt (1990)[23]	Retrospective	TTR	21.0	91.0	91.0
Bond (1997)[24]	Prospective	PHI > 3		40.0	98.0
		Mechanism of injury	2.6	73.0	91.0
		PHI > 3 and mechanism of injury		78.0	89.0
Brown (2011)[25]	Retrospective	Physiologic criteria of 2006 FTDS	42.0	32.0	91.0
		Anatomic criteria of 2006 FTDS		26.0	85.0
		Physiologic or anatomic criteria of 2006 FTDS		49.0	78.0
		Physiologic and anatomic criteria of 2006 FTDS		45.0	73.0
Brown (2015)[26]	Retrospective	Adult (16-65 y)			
		SBP < 110 mmHg		23.0	90.0
		SBP < 90 mmHg		10.0	98.0
		PHY + ANA of 2011 FTDS using SBP < 110 mmHg		67.0	62.0
		PHY + ANA of 2011 FTDS using SBP < 90 mmHg		62.0	67.0
		Geriatric (> 65 y)	Not reported		
		SBP < 110 mmHg		13.0	93.0
		SBP < 90 mmHg		5.0	91.0
		2011 FTDS step 1 +2 using SBP < 110 mmHg		44.0	71.0
		2011 FTDS step 1 +2 using SBP < 90 mmHg		40.0	75.0
Champion (1989)[27]	Retrospective	TS < 13 or GCS < 11		48.0	92.0
		T-RTS < 12	30.3	59.0	82.0
		T-RTS < 11		49.0	92.0
		T-RTS < 10		39.0	96.0
Ciesla (2015)[28]	Retrospective	Field triage of Florida	10.0	57.0	89.0

▶ **Table 4** - Continued from previous page

Dihn (2014)[29]	Retrospective	New model > 4	21.6	90.0	58.0
Gray (1997)[30]	Retrospective	CRAMS < 9	46.0	69.0	75.0
		T-RTS < 12		60.0	90.0
Hamada (2014)[31]	Retrospective	Cohort 1 - Vittel Triage Criteria	Not reported	99.0	64.0
		Cohort 2 - Vittel Triage Criteria		98.0	54.0
Hedges (1987)[32]	Retrospective	Kane's		85.0	65.0
		CRAMS < 9		85.0	54.0
		CRAMS < 7		39.0	89.0
		TS < 13, GCS < 11, or mechanism of injury = 1		78.0	63.0
		TS < 13 or GCS < 11		54.0	93.0
		TS < 13	31.0	46.0	97.0
		Respiratory, systolic pressure, GCS score = 1		73.0	79.0
		PHI > 3		73.0	75.0
		Respiratory/pulse/motor response score < 11		61.0	88.0
		Respiratory/systolic blood pressure/ motor response score < 11		59.0	92.0
		Paramedic severity impression = 3		51.0	96.0
		Mechanism of injury = 1		49.0	69.0
Ichwan (2015)[33]	Retrospective	Adult triage criteria < 70 y	23.5	87.0	44.0
		Adult triage criteria > 69 y		61.0	61.0
		Geriatric triage criteria < 70 y		94.0	35.0
		Geriatric triage criteria > 69 y		93.0	49.0
Knopp (1988)[34]	Prospective	TS < 13		70.1	98.5
		TS < 16	6.6	87.6	86.9
		TS < 15 + 11 MOI/ANA criteria		92.8	76.2
		TS < 13 + 9 MOI/ANA criteria		89.7	87.1
Lerner (2011)[35]	Retrospective	1999 FTDS ISS > 15	9.3	64.0	62.3
		1999 FTDS trauma center need	11.5	77.3	64.7
		2006 FTDS ISS > 15	9.3	56.2	74.7
		2006 FTDS trauma center need	11.5	71.6	77.5

▸ **Table 4** - Continued from previous page

Long (1986)[36]	Prospective	TS < 15 + space violation		82.4	90.4
		TS < 15 + delayed extrication		78.8	96.2
		TS < 15 + patient ejected		83.9	87.7
		TS < 15 + patient fall		81.1	89.2
		TS < 15 + death of other occupant		80.0	91.7
		TS < 15 + child struck by car		100	83.3
		TS < 15 + pedestrian struck by car	26.8	92.9	92.9
		TS < 13 + space violation		77.6	93.6
		TS < 13 + delayed extrication		67.3	98.1
		TS < 13 + patient ejected		74.1	92.6
		TS < 13 + patient fall		64.9	97.3
		TS < 13 + death of other occupant		70.8	95.8
		TS < 13 + child struck by car		94.4	100
		TS < 13 + pedestrian struck by car		71.4	96.4
Matsushima	Retrospective	Motor vehicle intrusion all patients		-	14.5
(2016)[37]		Motor vehicle intrusion < 19 y	14.5	-	10.8
		Motor vehicle intrusion 19-64 y		-	135
		Motor vehicle intrusion > 64 y		-	31.8
Morris (1986)[38]	Retrospective	TS < 13	17.5	43.3	96.8
		TS < 15		63.3	88.4
Newgard (2016)[39]	Prospective	2006 FTDS ISS > 15	3.1	66.2	87.8
Ocak (2009)[40]	Retrospective	PHY, ANA, and MOI criteria of 2006 FTDS	12.7	84.1	77.5
		New model		92.1	79.5
Strums (2006)[41]	Retrospective	T-RTS < 11	100	34.1	-
		T-RTS < 12		47.0	-
Tamim (2002)[42]	Retrospective	PHI > 0		55.0	71.0
		PHI > 1		47.0	77.0
		PHI > 2		46.0	78.0
		PHI > 3		35.0	91.0
		PHI > 4		28.0	94.0
		PHI > 5		20.0	96.0
		PHI > 6		17.0	97.0
		PHI > 7		15.0	98.0
		New Triage Protocol > 2		99.0	9.0
		New Triage Protocol > 3		95.0	24.0

▸ **Table 4** - Continued from previous page

		New Triage Protocol > 4	45.0	85.0	42.0
		New Triage Protocol > 5		64.0	67.0
		New Triage Protocol > 6		51.0	80.0
		New Triage Protocol > 7		43.0	88.0
		New Triage Protocol > 8		36.0	92.0
		New Triage Protocol > 9		29.0	96.0
		New Triage Protocol > 10		21.0	97,0
		New Triage Protocol > 11		15.0	98.0
Zimmer-Gembeck (1995)[43]	Retrospective	Triage criteria by Oregon	10.0	78.5	71.8 (ISS 1-9)

TTR: Trauma Triage Rule, MGAP: Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score, PHI: Prehospital Index, FTDS: Field Triage Decision Scheme, SBP: systolic blood pressure, MOI: mechanism of injury, PHY: physiologic criteria, ANA: anatomic criteria, TS: Trauma Score, GCS: Glasgow Coma Scale, T-RTS: Revised Trauma Score for Triage, CRAMS: Circulation, Respiration, Abdomen, Motor, Speech criteria, HTI-ISS: Hospital Trauma Index Injury Severity Score, ISS: Injury Severity Score.

Discussion

In this systematic review, all currently available studies on prehospital trauma triage protocols were analyzed and showed a wide variety in sensitivity and specificity. A critical appraisal of included studies demonstrated that the majority was of poor quality. Most protocols included an assessment of vital signs, suspicion of specific anatomic injuries, and often mechanism of injury. The use of nearly all protocols resulted in suboptimal or inadequate accuracy. Given the poor methodological quality and inadequate triage rates of the available protocols, it is difficult to determine which protocol is best.

In 1976, the ACS-COT established the first prehospital trauma triage protocol –which included the concept of bypassing the nearest hospital for a high-level trauma center– and initiated the process of accreditation of trauma centers. Both have proven pivotal in the development prehospital trauma triage systems.[13, 45] In this review, we specifically evaluated protocol-based triage quality, or the quality of triage based on the accuracy of a prehospital trauma triage protocol in identifying patients with severe injuries, regardless of destination facility. The protocol-based triage quality was assessed using sensitivity and specificity. A high sensitivity of a protocol identifies severely injured patients as such using the protocol, so these patients are recognized and taken to a high-level trauma center, lowering undertriage. On the other hand, a high specificity ensures that less severely injured patients are identified by the protocol and are taken to a lower level trauma center, to lower overtriage. Since undertriage results in an increased mortality and morbidity rate, efforts should be made to lower undertriage, thus increasing the sensitivity of a triage protocol.

For an accurate and complete view of prehospital triage quality, assessment of an entire trauma system is necessary. This includes prehospital parameters measured on the scene by EMS providers, all types of trauma patients, and all levels of trauma centers. An adequate protocol should be the foundation of a competent trauma system.

As shown by our critical appraisal, most studies were of poor methodological quality. The majority of prehospital trauma triage protocols were judged on unreliable prehospital parameters, used specific subgroups of patients, or were established using only one type of trauma center. Data collection of prehospital variables should take place on the scene and at the same moment throughout the study since the parameters can change over time. The destination facility itself does not influence triage parameters when looking at protocol-based triage quality. However, using only patients transported to a higher-level trauma center potentially excludes an important population of patients: the patients undertriaged to a lower level trauma center, who have severe injuries that may be more difficult to identify. The protocol-based triage quality can only truly be judged based on prehospital parameters determined on-scene by EMS providers and using all trauma patients transported to the different levels of trauma centers in a region. For example, Bond et al.[11] included adult trauma patients transported to all levels of trauma centers in a specific region. The on-scene prehospital parameters consisted of all the variables needed to test the prehospital trauma triage protocol, which were the PHI and mechanism of injury in this case. This study design guarantees a realistic analysis of triage rates using a certain protocol. The sensitivity rates of the protocol in this study were low, however, ranging from 40% to 78%. Analysis of the Vittel Triage Criteria demonstrated excellent sensitivity (98-99%).[21] However, the inclusion of patients was highly selective, which inevitably affected the sensitivity and specificity. Two cohorts were analyzed: one with patients admitted to a higher-level trauma center and one with exclusively severely injured patients (without specifying definition or how this was determined). Both cohorts are not representative of a general trauma population. A significant proportion of patients is missed in both cohorts, one in which identifying patients with severe injuries would likely be even more challenging. In the first cohort, the patients taken to a lower level trauma center were missed, including the severely injured, undertriaged, patients. In the second cohort it is unknown if truly all severely injured patients were included. Additionally, the less severely injured patients, including the potentially overtriaged ones, were missed.

It is important to classify severely injured patients correctly to accurately determine sensitivity and specificity of a trauma triage protocol. Surrogate markers are used to classify severely injured patients. In the included articles, an ISS > 15 was the most commonly used surrogate for a severely injured patient. However, there is much debate on this subject in recent studies.[46-50] Legitimate classification is difficult and depends on the country, regional circumstances, and trauma center level. Although the definitions are different, a common factor is that the severity is determined at the hospital, mostly days after admission and not on-scene. Predicting these outcomes is difficult on-scene, but essential to accurately determine if a patient should be taken to a high-level trauma center. Changing the definition may produce better sensitivity and specificity, but will not affect the quality of trauma care.

Sensitivity was lower among geriatric patients compared to younger patients, which is a well-known problem.[7, 26, 33, 39, 43] Identifying a severely injured younger patient is more straightforward, compared to geriatric patients, due to a difference in mechanism of injury. Even minor geriatric injuries carry a higher mortality rate compared to the young.[51, 52] High mortality of geriatric trauma patients is attributed to the prevalence of pre-existing diseases and masked physiologic derangement, possibly due to medication.[53, 54] Because geriatric injuries are increasing in frequency and these patients are hard to identify, age should be included as a criterion to increase the sensitivity of a trauma triage protocol. The classification of geriatric patients remains ambiguous; cut-off points between 55 and 70 years as lower limit for age are used.[55]
Triage quality may vary greatly between countries, aside from other trauma triage protocols used, differences in geographical distance, compliance to the triage protocol, and education of EMS providers constitute to this. The protocol-based triage quality is not affected by these factors, however a difference in population might be. In a trauma population with a lot of penetrating traumas, the severely injured patients are more easily recognized, compared to a population consisting predominantly of elderly trauma patients for example. In this review differences between countries could not be analyzed, because of the different protocols and definitions for severely injured patients used in each article.

In this review a newly developed critical appraisal was used, based on the critical appraisal tools from the Center for Evidence Based Medicine of the University of Oxford.[21] In this critical appraisal, all items necessary to judge the methodological quality of a study evaluating a prehospital trauma triage protocol were included to eliminate biases and accurately assess a protocol.

The major limitation of this review was the heterogeneity of the included studies, which made it difficult to accurately compare the studies. First, none of the studies described the indication, or level of priority of the ambulance transportation, leading to a possible difference in the population. Also, the studies use of different protocols, definitions, and selection criteria, making the ability to directly compare these studies limited. Therefore, it is impossible to recommend the best protocol. Another limitation is the possibility of publication bias; unpublished work on for example poor performance of a protocol might be missing. Even though the grey literature (i.e. conference abstracts, editorials, and dissertations) was excluded in this review, a thorough search led to only one conference abstract on prehospital trauma triage protocols, minimizing the possibility of publication bias.

Further research should focus on creating and improving prehospital trauma triage protocols. First, all trauma patients and levels of trauma centers of a specific region should be included in the study, to minimize selection bias. Second, prehospital parameters should be scored by EMS providers on the scene, since these are the potential predictors of severe injury of a protocol. Vital signs, anatomic injuries, mechanism of injury, and age were all predictors for severe injury, but to different degrees. Multiple studies found penetrating trauma as a strong predictor of severe injury[23, 29, 34], however these types of relatively obvious injuries are not expected to improve triage significantly, as they will be recognized as such without the use of a protocol. The sensitivity and specificity of a protocol needs to be improved using less obvious, but still strong predictors of severe injury. Other specific strong predictors in a number of the included studies were: pelvic fractures, GCS < 14, and multi-regions injuries.[25, 29, 40] Furthermore, protocols are less sensitive when applied to geriatric patients, compared to younger patients, so age has a strong potential to improve the sensitivity of a protocol. As seen in the study by Tamim et al.[42] creating an algorithm using logistic regression to calculate need for high-level trauma center care improved sensitivity and specificity. In an algorithm, GCS and age could potentially be included as continuous variables, in addition to dichotomous variables, such as multi-region injuries. Future protocols should therefore be more dynamic, preferably with weighted continuous and dichotomous parameters, taking these differences into account. An electronic device could help calculate the chance of severe injury when using weighted prediction parameters. This could improve the accuracy of the protocol as well as increase EMS provider compliance to the protocol.[39] Ultimately, the goal of prehospital trauma triage is to get the right patient to the right hospital at the right time. This will decrease mortality and avert life-long disabilities.

Conclusion

This systematic review shows that nearly all of the studied prehospital trauma triage protocols were unable to adequately identify severely injured patients. In addition, the overall methodological quality was poor. Based on these findings, it is impossible to recommend a superior protocol among those investigated. In order to improve prehospital trauma triage protocols, future studies should be of high methodological quality in order to properly investigate their accuracy. Only then can a proper evidence-based decision be made on which protocol is best.

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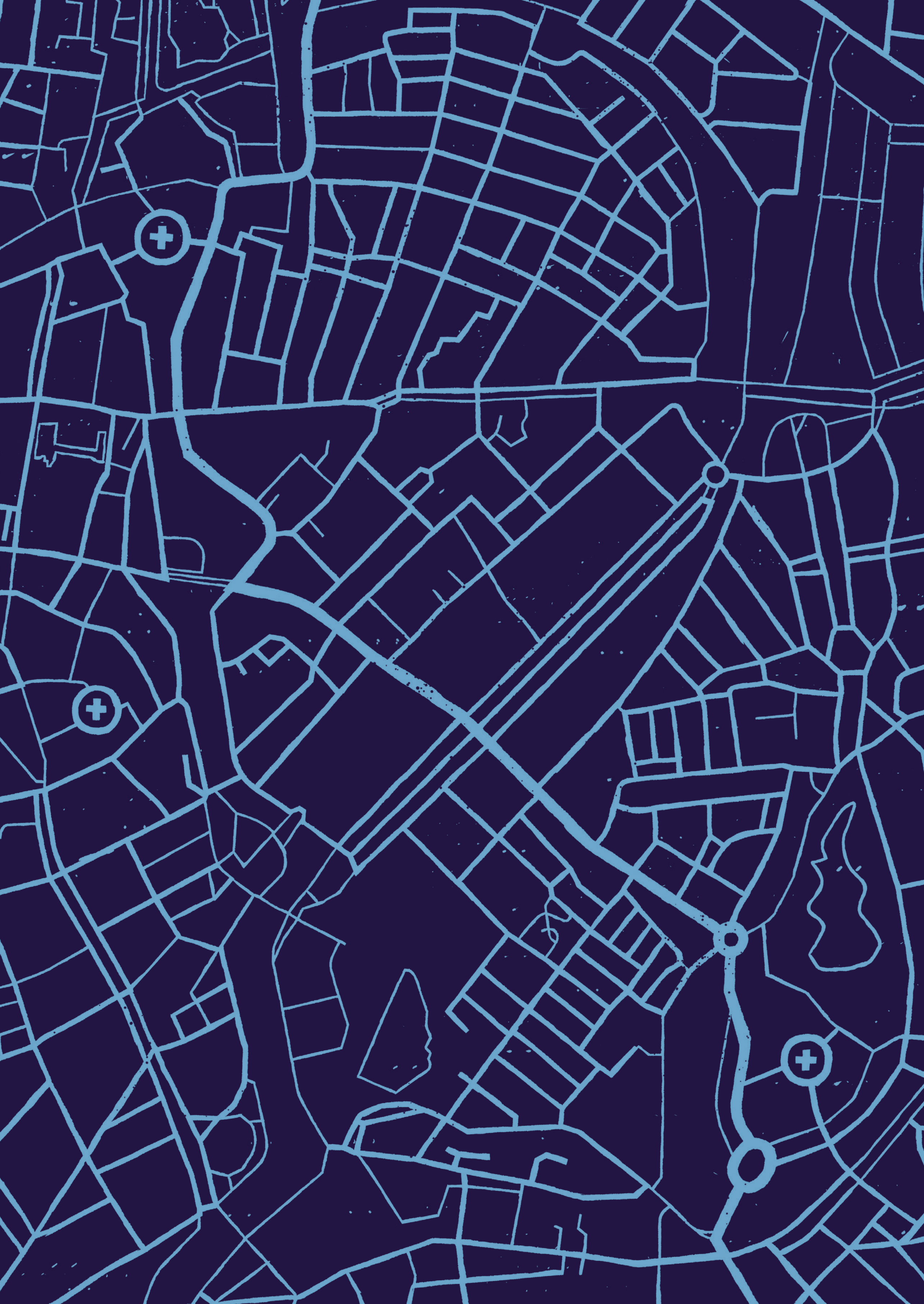
Appendix 1. Search strategy

Search Pubmed 11-05-2016
((under triage[tiab]) OR undertriage[tiab] OR (over triage[tiab]) OR overtriage[tiab] OR triage[tiab]) AND (trauma[tiab] OR injury[tiab]) AND (trauma center* OR traumasystem[tiab] OR (trauma system[tiab]))

Search Embase 11-05-2016
((trauma:ab,ti AND center:ab,ti) OR (trauma:ab,ti AND system:ab,ti)) AND triage:ab,ti AND injury:ab,ti

Search Cochrane Library 11-05-2016
("triage":ti,ab,kw) AND ("trauma":ti,ab,kw OR "injury":ti,ab,kw) AND ("trauma center":ti,ab,kw OR "trauma center":ti,ab,kw OR "trauma system":ti,ab,kw)



Effectiveness of prehospital trauma triage systems in selecting severely injured patients: is comparative analysis possible?

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3

Abstract

Introduction

In an optimal trauma system, prehospital trauma triage ensures transport of the right patient to the right hospital. Incorrect triage results in undertriage and overtriage. The aim of this systematic review is to evaluate prehospital trauma triage system quality worldwide and determine effectiveness in terms of undertriage and overtriage for trauma patients.

Methods

A systematic search of Pubmed/MEDLINE, Embase, and Cochrane Library databases was performed, using 'trauma', 'trauma center,' or 'trauma system', combined with 'triage', 'undertriage,' or 'overtriage', as search terms. All studies describing ground transport and actual destination hospital of patients with and without severe injuries, using prehospital triage, published before November 2017, were eligible for inclusion. To assess the quality of these studies, a critical appraisal tool was developed.

Results

A total of 33 articles were included. The percentage of undertriage ranged from 1% to 68%; overtriage from 5% to 99%. Older age and increased geographical distance were associated with undertriage. Mortality was lower for severely injured patients transferred to a higher-level trauma center. The majority of the included studies were of poor methodological quality. The studies of good quality showed poor performance of the triage protocol, but additional value of EMS provider judgment in the identification of severely injured patients.

Conclusion

In most of the evaluated trauma systems, a substantial part of the severely injured patients is not transported to the appropriate level trauma center. Future research should come up with new innovative ways to improve the quality of prehospital triage in trauma patients.

Introduction

Worldwide, every single minute ten people die as a result of trauma.[1] In order to improve chances of survival, patients at risk for severe injury should be treated at hospitals with corresponding level of trauma care facilities.[2-4] According to the American College of Surgeons Committee on Trauma (ACS-COT), level I and II trauma centers are capable to provide total care for every aspect of injury.[5] In some countries, only level I trauma centers are equipped to care for severely injured patients.[6] When severely injured patients are not taken to a higher-level trauma center, it is referred to as undertriage.[5, 7-9] In addition, overtriage refers to patients without severe injury transported to a higher-level facility. Prehospital trauma triage is essential in this process; it ensures transport to the right type of hospital.

In general, reduction of undertriage is priority, in order to decrease mortality and morbidity.[2, 3] Other consequences of undertriage include: delay in diagnosis and treatment, missed injuries, and decreased functional outcome.[2, 3] The ACS-COT set the goal for undertriage at less than five percent.[10] In order to lower undertriage, more patients –including the patients without severe injury– have to be taken to a higher-level trauma center, which inevitably increases overtriage. However, overtriage also carries disadvantages, such as an unnecessary burden on higher-level trauma center recourses and high trauma care costs.[11, 12]

The effectiveness of a trauma triage system is based on the patient's initial destination facility. Prehospital trauma triage protocols are designed to help emergency medical services (EMS) providers identify severely injured patients. An overview of the quality of protocols used worldwide was recently published.[13] However, the prehospital trauma triage quality is also based on the decision of the EMS providers, distances, and regional circumstances. Trauma system quality has been studied extensively in different countries over the past decades[14-19], but an overview of all available trauma triage system studies is lacking. It is currently unknown which prehospital trauma triage system functions best and if there is need for improvement.[20] The aim of this systematic review is therefore to evaluate prehospital trauma triage system quality worldwide, and determine effectiveness in terms of undertriage and overtriage for trauma patients transported by ground ambulance.

Methods

Search and selection

This systemic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRIMSA) guidelines.[21] A systematic search of Pubmed/MEDLINE, Embase, and Cochrance Library databases was performed, using 'trauma', 'trauma center,' or 'trauma system' combined with 'triage', 'undertriage,' or 'overtriage' as search terms, to include all studies published before November 2017 (Appendix 1). Studies describing the ground transport and actual destination hospital of trauma patients with and without severe injuries, using prehospital trauma triage, were included. All articles, except grey literature (i.e. conference abstracts, editorials, and dissertations), regardless of year of publication or language, were eligible for inclusion. Exclusion criteria were: articles describing only the accuracy of a prehospital trauma triage protocol, including helicopter transport in most patients (> 50%), or including only pediatric patients. Studies on prehospital trauma triage seek to identify patients in need of higher-level trauma center care. Articles on helicopter transport use a separate protocol to identify patients requiring helicopter transport among the patients in need of higher-level trauma center care.[22, 23] Estimation of pediatric trauma injury severity and triaging these patients is a challenging task, very different from triaging adults. Therefore, these studies were excluded from this study.[24-27]

Critical appraisal

Available critical appraisal tools were not fully applicable due to the specific design of the studies. Criteria from the critical appraisal tools from the Center for Evidence Based Medicine of the University of Oxford were used for the assessment of the risk of bias.[28] The critical appraisal tool consists of five items that were designed to evaluate the quality of the included studies (Table 1). These items were: study setting, domain, description of initial destination, description of mode of transport, and missing data.

Table 1. Items, importance, and score used for the critical appraisal

Items	Importance	Score
1. Study setting	A study setting including all levels of trauma centers guarantees a realistic analysis of triage rates, eliminating selection bias	+ Regional study, including higher-level trauma centers and lower-level trauma centers - One type of trauma center
2. Domain	Including all types of trauma patients ensures a true representation of the trauma population, eliminating selection bias	+ All trauma patients or adults only - A specific group
3. Description of initial destination	Data on the initial destination to which the patients was taken is needed to accurately calculate true triage rates. Triage rates after transfer to a higher-level trauma center leads to incorrectly lower undertriage rates.	+ Initial destination clearly described - Not clearly described
4. Description of transport	Data on the mode of transportation, i.e. ground ambulance, helicopter transport or private transportation.	+ Patients transported by ground ambulance +/- Inclusion of ground and helicopter transport - Inclusion of other modes of transport (e.g. private transportation) or not reported
5. Missing data	Including missing data in analyzes results in possibly unreliable outcomes	+ No missing data +/- 0-15% missing data - > 15% missing data or not reported
Total score	Good quality Intermediate quality Poor quality	Total score of 4 + Total score of 3 + Total score of ≤ 2 +

Data extraction

All duplicates were excluded, before the selection of relevant articles. Two reviewers (EvR and MvH) assessed titles, abstracts, and subsequently full-text. Using the critical appraisal tool, all studies were assessed for methodological design and quality by two reviewers (EvR and MvH). There were no discrepancies between the two reviewers. References of included articles and references of related reviews were screened for additional potential articles. In case of multiple publications regarding the same dataset of patients, the article with the largest cohort was selected.

Outcomes

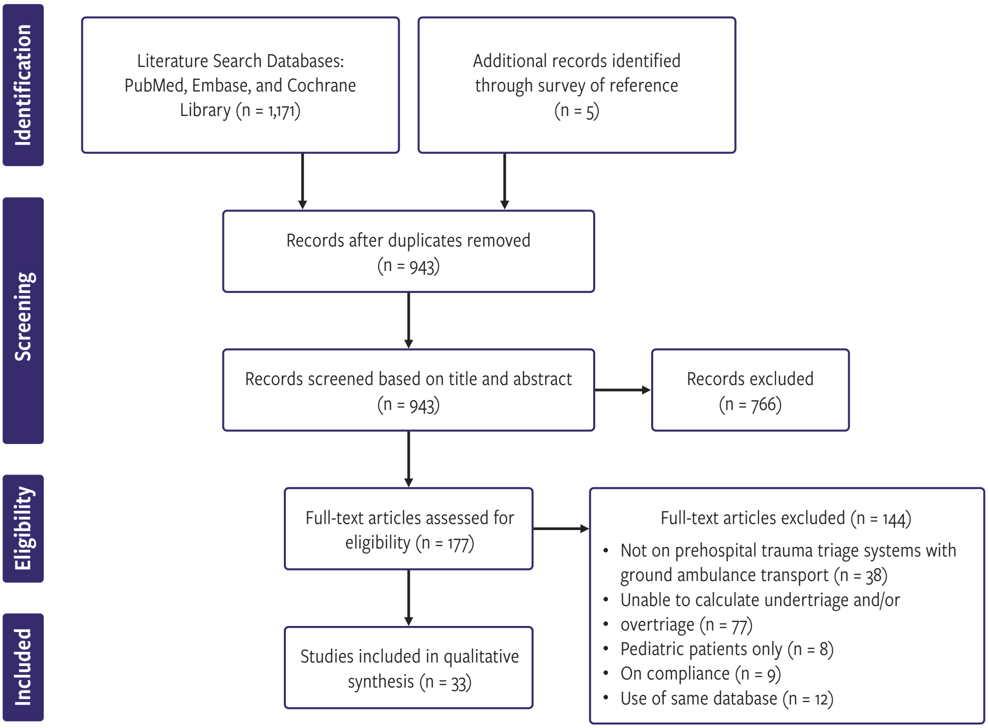
Primary outcome parameters were the rates of undertriage and overtriage. Undertriage was defined as the proportion of severely injured patients taken to a lower-level trauma center, divided by the total number of severely injured patients. Overtriage was defined as the number of patients without severe injuries taken to a higher-level trauma center, divided by the total number of patients without severe injuries.

Results

Search results

A total of 943 unique studies were identified and screened based on title and abstract, after which 177 articles remained for full-text review. One full-text could not be retrieved.[29] After full-text review, 40 articles were eligible for inclusion and analysis. However, 12 articles were excluded due to the use of the same or overlapping databases.[19, 26, 30-38] A survey of the references of the included studies led to the inclusion of five additional articles, resulting in a total of 33 articles (Figure 1).[11, 16-18, 39-65]

Figure 1. Flow chart of the selection process



Study characteristics

The included studies were published between 1986 and 2017 (Table 2). In eighteen studies both level I and II trauma centers were considered higher-level trauma centers; here only level I trauma centers require a certain volume of injured patients to be admitted each year.[11, 19, 39-42, 45, 46, 48, 49, 51-53, 56, 57, 60, 61, 66]

Five European[18, 55, 63, 64, 67] and one Canadian study[62] acknowledged only level I trauma centers to care for severely injured patients. Seven studies distinguished only trauma centers and non-trauma centers, without specifying the level.[16, 30, 43, 44, 50, 54, 58] In eighteen articles, undertriage and overtriage could be calculated, in eight studies undertriage only and in eight overtriage only. The percentage of undertriage ranged from 1.1% to 68%; overtriage ranged from 4.7% to 98.8%. The percentage of severely injured patients in the studied populations ranged from 1.3% to 100%.

Critical appraisal

The methodological quality of the included studies was variable: two were of good quality, eight of intermediate quality, and 24 of poor quality (Table 3).

Eighteen studies included trauma centers of all levels in a region.[16, 18, 19, 26, 30, 38, 40-42, 46, 49-52, 55, 60, 61, 63, 65, 67] Five evaluated the trauma system based on only trauma centers suitable to care for severely injured patients.[17, 44, 45, 50, 62] In this situation the true undertriage rate cannot be calculated, because the patients transported to a lower-level trauma center are not included. In two studies, different levels of trauma centers were included, however not all trauma centers of the analyzed region were included, leading to a misrepresentation of the undertriage rate.[41, 46, 57]

Twenty-six studies included a specific group of patients, potentially introducing selection bias.[17, 18, 30, 38, 40-42, 45, 46, 49-52, 54, 60, 61, 63, 65, 67] Most studies included admitted patients only, excluding the patients who were discharged from the emergency department (ED) –a group of potentially overtriaged patients.[17, 30, 38, 45, 50, 51, 63, 65] Some studies only included patients with severe injury, assessed either on-scene or at the ED.[40, 45, 46, 49, 50] These specific groups are not representative for a general trauma population, leading to skewed triage rates.

The initial destination each patient was transported to was not accurately presented by 22 studies; the reported destination might have been after secondary transport.[16, 17, 30, 40-42, 44, 45, 49-51, 53, 60, 61, 63, 65, 67] Including patients after transfer from a lower-level trauma center to a higher-level trauma center, falsely lowers the undertriage rate.[30, 41, 51, 53, 60, 61, 65, 67] Four studies presented undertriage and/or overtriage rates, but did not show the data used to calculate these rates.[16, 46, 50, 63]

Two studies included patients transported by ground ambulance only.[16, 26] Most studies did not report the mode of transport.[17, 30, 38, 41, 46, 49-52, 55, 60, 61, 63, 65, 67] Patients arriving to the hospital by private transport, in addition to transport by ground ambulance, were included by two studies.[45, 54]

Fifteen studies did not report if missing data was encountered.[16, 17, 30, 40, 42, 45, 46, 49-51, 53, 61, 63, 65, 67] Three studies excluded patients with missing data.[38, 41, 60, 62] In the other studies the percentage of missing data was up to 50%,[16, 18, 19, 55] of these, two used multiple imputation to handle the missing data.[11, 57]

Table 3. Critical appraisal

First author (year)	1. Study setting*	2. Domain*	3. Description of initial destination *	4. Description of transport*	5. Missing data*
Báez (2003)[39]	+	-	-	-	-
Bouzat (2015)[40]	+	-	-	+/-	-
Brown (2011)[41]	-	-	-	-	+
Candefjord (2016)[42]	+	-	-	+/-	-
Ciesla (2017)[66]	+	-	-	-	-
Di Bartolomeo (2004)[43]	+	-	-	+	-
Dihn (2014)[44]	-	+	-	+/-	-
Faul (2016)[45]	-	-	-	-	-
Flottemesch (2016)[46]	-	-	-	-	-
Follin (2016)[47]	-	-	-	-	+/-
Garwe (2017)[48]	+	-	+	-	+
Haas (2012)[49]	+	-	-	-	-
Hamada (2014)[50]					
Cohort 1	-	-	-	-	-
Cohort 2	-	-	-	-	-
Hsia (2010)[51]	+	-	-	-	-
Kodadek (2015)[52]	+	-	+	-	-
Kreis (1988)[53]	-	+	-	+/-	-
Lale (2017)[54]	+	-	+	-	+/-
Long (1986)[17]	-	-	-	-	-
Meisler (2010)[55]	+	+	+	-	-
Newgard (2008)[56]	+	-	-	-	+/-
Newgard (2013)[11]	+	+	+	+	-
Newgard (2017)[57]	-	+	+	+	-

▶ **Table 3** - Continued from previous page

Rubenson Wahlin (2016)[58]	+	-	+	+	-
Santaniello (2003)[59]	-	-	+	-	-
Scheetz (2004)[60]	+	-	-	-	+
Scheetz (2011)[61]	+	-	-	-	-
Strums (2006)[67]	+	-	-	-	-
Tamim (2002)[62]	-	+	+	-	+
Twijnstra (2010)[63]	+	-	-	-	-
Van Laarhoven (2010)[18]	+	-	+	-	+/-
Voskens (2017)[64]	+	+	+	+	+/-
West (1986)[16]	+	+	-	+	-
Zimmer-Gembeck (1995)[65]	+	-	-	-	-

* Items and scoring system are described in Table 1.

Definition of severe injury

Most studies defined a severely injured patient as a patient with an Injury Severity Score (ISS) > 15. Multiple studies defined a severely injured patient based on other outcomes. For example: a patient who either died in the emergency room, required emergency surgery, or who was admitted to the intensive care unit.[19, 41, 53, 62, 65] Newgard et al.[56] showed a discrepancy between ISS and resource use; many patients with an ISS < 15 needed higher-level trauma center resources.

Exclusive and inclusive trauma systems

All but three articles analyzed inclusive trauma systems.[42, 49, 58] When comparing exclusive and inclusive trauma systems, patients without severe injuries were less frequently admitted to a higher-level trauma center, whereas severely injured patients were more often admitted to a higher-level trauma center in an inclusive trauma system.[58, 63] Furthermore, the introduction of an inclusive trauma system resulted in a risk reduction in overall mortality of 16%.[63]

Two articles showed contrasting findings on the impact of care at a higher-level trauma center for severely injured patients.[49, 67] In an exclusive trauma system, severely injured patients (ISS > 15) taken to a higher-level trauma center had a 30 to 40% lower mortality at 24 and 48 hours, compared to severely injured patients taken to a lower-level trauma center.[49] Whereas, in another study describing an inclusive trauma system, no statistical difference in mortality between these groups was found.[67] In both studies, severely injured patients admitted to higher-level trauma centers had a higher ISS.

Prehospital trauma triage protocols

Almost all protocols analyzed in the included articles consisted of vital signs, injury type, and mechanism of injury criteria. Additional criteria were: age, comorbidity, and EMS provider judgment in the Field Triage Decision Scheme (FTDS) and age, comorbidity, and applied resuscitation in the Vittel Triage Criteria.[11, 26, 39-41, 45-48, 50, 56, 57]

West et al.[16] evaluated the differences in overtriage rates using the original protocol and, a few years later, the modified protocol of Orange County. The original triage protocol was based solely on vital signs. The modified criteria also included injury type, mechanism of injury, and age criteria, besides vital signs. Adding criteria logically led to higher overtriage rates from 40% to 60% (Table 4). Undertriage rates could not be calculated.

In a group of high-energy trauma patients, the patients meeting a mechanism criterion only had a higher chance of being undertriaged (17%), compared to the patients meeting vital signs, injury type, or both criteria in addition to a mechanism of injury criterion (2%, 0%, and 6% respectively.[18] Whereas the overtriage rate was lower in the patients meeting only the mechanism of injury criteria (38%), compared to patients who also met the vital signs, injury type, or both criteria in addition to a mechanism of injury criterion (90%, 70%, and 60%, respectively).

In France, the trauma system has physician-staffed ambulances; the emergency physicians use the Vittel Triage Criteria to assess each patient on-scene. Bouzat et al.[40] compared patients assessed by an emergency physician who used the Vittel Triage Criteria (graded group) and patients who were not assessed by this protocol, because no physician was present or the physician did not use the protocol (non-graded group). The patients in the non-graded group had a higher ISS. The undertriage rate was almost 20% lower in the graded group, compared to the non-graded group (18% and 37%, respectively), whereas the overtriage rate was almost 20% higher in the graded group (77% and 57%, respectively). Contrastingly, a study of good methodological quality, analyzing both the quality of the triage protocol and trauma system, showed that the National Protocol of the Netherlands (based on the FTDS) only recognized 36% of the severely injured patients. Still, 78% of the patients were transported to a higher-level trauma center, indicating the possible benefit of non-compliance to the triage protocol and additional value of EMS provider judgment.[64]

The effect of the revision of the 2006 FTDS to the 2011 FTDS on the undertriage between different age groups with severe head injury was analyzed by Flottemesch et al.[46] The 2006 FTDS includes a special consideration for adults aged 55 years and older and in the 2011 FTDS two age-related considerations were added. The undertriage rates decreased for elderly patients (from 53.9%-59.7% to 52.2%-56.5%), however a similar disparity between age groups remained.

Trauma triage system quality

Nine studies found especially high undertriage rates among older patients (Table 4).[19, 42, 44, 46, 48, 52, 55, 60, 65] Other significant predictors for undertriage were: abnormal vital signs, GCS ≤ 13, penetrating injury, brain injury, female gender, multiregional injuries, fall related injuries, and diabetes.[44, 52, 65]

Increased geographical distance to a higher-level trauma center lowered the likelihood of being admitted to a higher-level trauma center as well.[42, 51, 52] Hsia et al.[51] reported that 70% of the severely injured patients were transported to a higher-level trauma center when the facility was within 0-10 miles, compared to 40% for a facility within 26-50 miles, and even 15% when the nearest facility was greater than 50 miles away. Comparing triage rates of two studies on trauma systems in different regions in France showed contrasting findings.[40, 50] Even though the extremely low undertriage rate found by Hamada et al.[50] might be unreliable due to selection bias (as discussed in the critical appraisal), Bouzat et al.[40] argue that the undertriage rate in their study was higher, because their region is more rural, leading to increased geographical distance to a higher-level trauma center. Multiple studies showed that severely injured patients had a higher probability of being transported to a higher-level trauma center in an urban setting, compared to a rural environment.[39, 42, 48]

Reasons reported for high overtriage rates were: the larger market share of higher-level trauma centers, preference of EMS providers, and existing transport patterns.[17, 18, 30, 62]

Table 4. Rates of undertriage and overtriage

First author (year)	Trauma system	Triage protocol	Severely injured patients (%)	Under-triage	Over-triage
Báez (2003)[39]	Inclusive	2009 FTDS	4.5	32.2	-
Bouzat	Inclusive	Vittel Triage Criteria	46.1	17.6	76.6
(2015)[40]	Inclusive	No protocol used	51.7	37.2	57.3
Brown (2011)[41]	Inclusive	2006 FTDS	42.0	11.0	90.0
Candefjord (2016)[42]	None	Rapid Emergency Trauma and Triage System	3.0	62.2*	-
Ciesla (2017)[66]	Inclusive	Triage criteria of Florida 2010 Triage criteria of Florida 2014	9.2 9.3	22.3* 19.0*	31.0* 36.0*
Di Bartolomeo (2004)[43]	Not reported	Not reported	100	24.0	-
Dihn (2014)[44]	Inclusive	New South Wales Ambulance Service major trauma transport protocol	21.6	-	80.0*
Faul (2016)[45]	Inclusive	2011 FTDS	100	52.1*	-
Flottemesch (2016)[46]	Inclusive	2006 FTDS 18-44y 45-64 y 65-84 y 85+ 2011 FTDS 18-44y 45-64 y 65-84 y 85+	100	47.8 32.5 40.7 53.9 59.7 46.2 30.3 39.3 52.2 56.5	-
Follin (2016)[47]	Inclusive	Vittel Triage Criteria	36.0	-	64.0
Garwe (2017)[48]	Inclusive	FTDS < 55 y FTDS ≥ 55 y	25.9 20.7	18.0 38.0	- -
Haas (2012)[49]	Exclusive	Not reported	97.0	54.4*	-
Hamada	Inclusive	Cohort 1 Vittel Triage criteria	Not reported	-	42.0
(2014)[50]	Inclusive	Cohort 2 Vittel Triage Criteria		1.1*	57.0
Hsia (2010)[51]	Inclusive	Not reported	10.5	6.5*	84.7*
Kodadek (2015)[52]	Inclusive	Not reported	14.9	61.3	23.9*
Kreis (1988)[53]	Inclusive	TS < 13, mechanism of injury or injury type criteria	53.9	-	46.1
Lale (2017)[54]	Inclusive	Not reported	2.2	2.1*	98.8*
Long (1986)[17]	Inclusive	Not reported	26.8	-	73.2*
Meisler (2010)[55]	Inclusive	Triage protocol of Denmark	12.6	68.0*	24.0*
Newgard (2008)[56]	Inclusive	FTDS	21.9	54.3*	50.9*

▸ **Table 4** - Continued from previous page

Newgard (2013)[11]	Inclusive	2011 FTDS	4.1	37.9	41.5
Newgard (2017)[57]	Inclusive	2006 FTDS	3.3 1.7	36.4 12.7	29.7 29.8
Rubenson Wahlin (2016)[58]	Exclusive Inclusive	No triage protocol Triage protocol of Sweden	100	39.0 19.8	- -
Santaniello (2003)[59]	Inclusive	1999 FTDS	11.0	-	88.6
Scheetz (2004)[60]	Inclusive	Triage protocol not reported, 25-64 y	15.0	21.5*	54.7*
		Triage protocol not reported, ≥ 65 y		39.6*	39.4*
Scheetz	Inclusive	1999 FTDS in 2004	12.3	42.0*	54.0*
(2011)[61]	Inclusive	2006 FTDS in 2007	11.7	35.0*	56.0*
	Inclusive	2006 FTDS in 2008	14.1	22.0*	48.0*
Strums (2006)[67]	Inclusive	National protocol of Ambulance Services	100	22.0	-
Tamim (2002)[62]	Inclusive	Urgences-santé trauma triage protocol	45.0	-	55.4*
Twijnstra	Exclusive	Not reported	1.7	-	5.5*
(2010)[63]	Inclusive	National protocol of Ambulance Services	1.3	-	4.7*
Van Laarhoven (2014)[18]	Inclusive	National protocol of Ambulance Services	13.8	10.9	39.5
Voskens (2017)[64]	Inclusive	National protocol of Ambulance Services	8.8	21.6	30.6
West (1986)[16]	Inclusive	Original Orange county triage criteria	59.9	-	40.0
	Inclusive	Modified Orange county triage criteria	40.1	-	60.0
Zimmer-Gembeck (1995)[65]	Inclusive	Triage protocol of Oregon	10.0	21.5*	28.2* (ISS 1-9)

* Calculated by authors
FTDS: Field Triage Decision Scheme, ISS: Injury Severity Score, y: years.

Transfer

Eight studies reported the number of transferred patients.[18, 26, 43, 45, 46, 49, 55, 64] Secondary transfer of severely injured patients from a lower-level trauma center to a higher-level trauma center occurred in 5-57% of the undertriaged patients.[26, 43, 45, 46, 49, 54] Mortality was lower for severely injured patients transferred to a higher-level trauma center, compared to severely injured patients receiving definitive care at a lower-level trauma center.

Discussion

To our knowledge, this is the first systematic review describing all currently available evidence on prehospital triage in trauma systems. We evaluated the quality of prehospital triage, based on the actual destination facility the patients were transported to, regardless of the prehospital findings and the triage protocol used. The included studies showed a wide variety of efficiency in terms of undertriage and overtriage rates. None of the trauma systems had an undertriage rate below 5%, combined with an overtriage rate below 50%, as recommended by the ACS-COT.[5, 10] Most of the included studies were of intermediate to poor methodological quality, as shown by the critical appraisal. The studies showed contrasting results on the effect of triage protocols on undertriage. Factors associated with undertriage were: older age, female gender, multiregional injuries, falls, and increased geographical distance. Mortality rates are lowered by secondary transfer of undertriaged patients to a higher-level trauma center.

A prehospital trauma triage protocol is the base of a trauma system; it is designed to help EMS providers identify severely injured patients. However, the quality of prehospital trauma triage is not only based on the quality of the triage protocol, but also influenced by the compliance to the protocol by EMS providers. In this review, very different triage rates were found, even when comparing trauma systems using the same triage protocol. A study of good methodological quality, assessing the quality of the triage protocol and the trauma system, showed the triage protocol could only identify a little over a third of the severely injured patients.[64] Yet, almost 80% of the severely injured patients were transported to a higher-level trauma center, indicating the potential benefit of EMS provider judgment.

In general, priority has been given to the reduction of undertriage by the ACS-COT, because this results in preventable morbidity and mortality.[26, 68] Unfortunately, the results of most of the investigated trauma systems are unsatisfactory. The factor most associated with undertriage was older age.[19, 42, 44, 46, 48, 52, 55, 60, 65] Even in trauma systems using a triage protocol that included age as a criterion, such as the FTDS, elderly trauma patients are an underestimated group with potential severe injury.[19, 46, 69, 70] Elderly trauma patients showed less physiologic derangement, possibly due to the use of medication, making correct triage a challenge. Other factors associated with undertriage were: female gender, multiregional injuries, and falls.[19, 44, 52, 65]

To get more severely injured patients to a higher-level trauma center, the overtriage rate increases inevitably. The ACS-COT stated an overtriage rate up to 50% can be accepted, to lower the undertriage rate.[5, 10] The percentage of overtriage ranged from 5% to 90%, a little over half of the articles found an overtriage rate below 50%. These differences in overtriage rates could be due to the triage protocol, regional circumstances, and resources of a higher-level trauma center. Reported reasons to transport patients without severe injuries to higher-level trauma centers were: the large market share of higher-level trauma centers, preference of EMS providers, and existing transport patterns.[17, 18, 30, 62]

The critical appraisal, based on Centre for Evidence Based Medicine of the University of Oxford critical appraisal tools[28], contains all items necessary for an unbiased evaluation of a trauma system and helps to place the triage rates in perspective. An accurate assessment of a trauma triage system should include all trauma patients transported to all levels of trauma centers in a specific geographic region, clearly describing the initial destination and mode of transportation, without a substantial amount of missing data. The overall quality of the included studies was low to intermediate, only one was of good quality. Most studies included only one type of trauma center and/or a specific group of trauma patients, leading to selection bias and skewed triage rates. Analyzing a specific group of patients, such as only the admitted patients, excludes the big group of discharged –and for the higher-level trauma centers, overtriaged- patients.[57] These patients form a burden on the higher-level trauma centers and should be included in the analysis to give an accurate representation of the trauma system quality. Additionally, the critical appraisal included the item "missing data" which potentially introduces selection bias. Over half of the studies did not report if missing data was encountered –and if so– how this was dealt with.

In the included articles, ISS > 15 was the most used definition for a severely injured patient. However, recent studies show a debate on the subject.[71-75] For this reason, multiple articles used a surrogate marker for the definition of a severely injured patient, such as: a patient who either died in the emergency room, required urgent non-orthopedic surgery, or was admitted to the intensive care unit.[19, 41, 53, 62, 65] Newgard et al.[57] showed a 25% higher undertriage rate when using ISS > 15 as a definition for severely injured patients, compared to critical recourse use. This discrepancy might partly be a result of an incorrectly low ISS for patients who died in the ED, but also indicates the deficit in an anatomic or resource based definition only. The definition of higher-level trauma center care need should embody the patients who are most likely to benefit from this level of care; perhaps a combination of an anatomic, resource, and quality of life based definition. Incorrectly classifying trauma patients might improve triage rates; however, it does not improve trauma care and patient outcome.

A limitation of this systematic review is the possibility of publication bias. The grey literature (i.e. conference abstracts, editorials and dissertations) was excluded; unpublished work might be missing. Another limitation is the heterogeneity of the included studies. None of the studies described the indication or level of priority of the ambulance transportation and all use different definitions and selection criteria, leading to a possible difference in the population. Also, in five articles, a minority of the patients was transported by helicopter, because the majority of the patients was transported by ground transport, these studies were included.[19, 40, 42, 44, 53] Even studies assessing the same protocol showed large differences in undertriage and overtriage rates.[11, 48, 57, 59, 61] In almost half of the articles, both the undertriage and overtriage rates were not, or could not, be calculated. These limitations make it impossible to accurately compare the quality of trauma triage systems and decide which type functions best.

Future research should focus on improving prehospital trauma triage systems as a whole. The protocol should not only include vital signs, injury type, and mechanism of injury criteria, but also age, to reduce undertriage. Adequate prehospital triage protocols will improve EMS provider compliance and therefore enhance triage rates of trauma systems resulting in improved survival for trauma patients.

Conclusion

This systematic review shows that in most of the evaluated prehospital trauma triage systems a substantial part of the severely injured patients is not transported to the appropriate level trauma center. In addition, the overall methodological quality of most of the reviewed studies was low to intermediate. The two studies with good methodological quality showed inadequate triage quality. This results in a higher chance of mortality and morbidity for the severely injured patients. Future research –with the focus on every aspect of the trauma system and including all trauma patients and trauma centers of a region– should come up with new innovative ways to improve the quality of prehospital trauma triage systems.

Acknowledgments

None.

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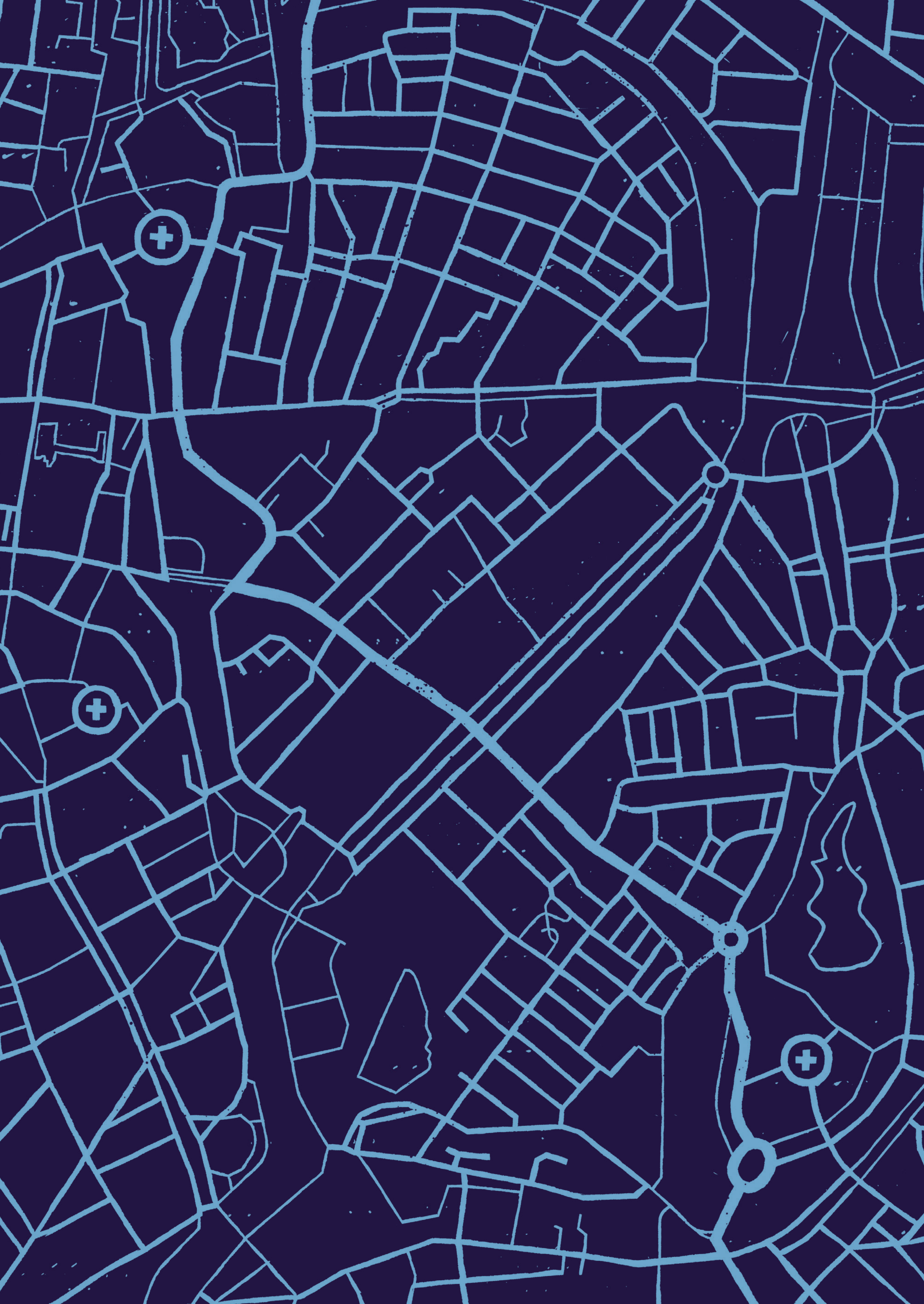
Appendix 1. Search strategy

Search Pubmed 11-10-2017
((under triage[tiab]) OR undertriage[tiab] OR (over triage[tiab]) OR overtriage[tiab] OR triage[tiab]) AND (trauma[tiab] OR injury[tiab]) AND ((trauma center[tiab]) OR (trauma center[tiab]) OR traumasystem[tiab] OR (trauma system[tiab]))

Search Embase 11-10-2017
((trauma:ab,ti AND center:ab,ti) OR (trauma:ab,ti AND system:ab,ti)) AND triage:ab,ti AND injury:ab,ti

Search Cochrane Library 11-10-2017
(“triage”:ti,ab,kw) AND (“trauma”:ti,ab,kw OR “injury”:ti,ab,kw) AND (“trauma center”:ti,ab,kw OR “trauma center”:ti,ab,kw OR “trauma system”:ti,ab,kw)



Compliance to prehospital trauma triage protocols worldwide: a systematic review

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Injury. 2018; 49(8): 1373-1380

4

Abstract

Introduction

Emergency medical services (EMS) providers must determine the injury severity on-scene, using a prehospital trauma triage protocol, and decide on the most appropriate hospital destination for the patient. Many severely injured patients are not transported to higher-level trauma centers. An accurate triage protocol is the base of prehospital trauma triage; however, ultimately the quality is dependent on the destination decision by the EMS provider. The aim of this systematic review is to describe compliance to triage protocols and evaluate compliance to the different categories of triage protocols.

Methods

An extensive search of MEDLINE/Pubmed, Embase, CINAHL and Cochrane library was performed to identify all studies, published before May 2018, describing compliance to triage protocols in a trauma system. The search terms were a combination of synonyms for 'compliance,' 'trauma,' and 'triage'.

Results

After selection, 11 articles were included. The studies showed a variety in compliance rates, ranging from 21% to 93% for triage protocols, and 41% to 94% for the different categories. The compliance rate was highest for the criterion: penetrating injury. The category of the protocol with the lowest compliance rate was: vital signs. Compliance rates were lower for elderly patients, compared to adults under the age of 55. The methodological quality of most studies was poor. One study with good methodological quality showed that the triage protocol identified only a minority of severely injured patients, but many of whom were transported to higher-level trauma centers.

Conclusions

The compliance rate ranged from 21% to 94%. Prehospital trauma triage effectiveness could be increased with an accurate triage protocol and improved compliance rates. EMS provider judgment could lower the undertriage rate, especially for severely injured patients meeting none of the criteria. Future research should focus on the improvement of triage protocols and the compliance rate.

Introduction

Each year, over 5 million people die as a result of trauma, accounting for 9% of the world's deaths. However, many more patients who survive their injury are left with temporary or permanent disabilities.[1] Timely and adequate treatment is crucial for patient outcomes.[2] Prehospital trauma care by emergency medical services (EMS) providers marks the start of trauma care. The EMS providers must start initial treatment and transport the patient to the most appropriate trauma center. To improve chances of survival and avert life-long disabilities, severely injured patients should be treated at higher-level trauma centers that have the appropriate trauma care facilities.[3, 4] On the other hand, patients without severe injuries must be transported to lower-level trauma centers, in order to lessen unnecessary burden on higher-level trauma centers and prevent relatively high costs.[3, 4]

EMS providers use a prehospital trauma triage protocol to evaluate injury severity on-scene, and subsequently decide the most appropriate level trauma center for the patient.[2, 5, 6] The accuracy of the triage protocol itself is fundamental: it must be able to discriminate between patients in need of specialized trauma care. Secondly, compliance to triage protocols by EMS providers is important in order to guarantee transportation to a higher-level trauma center when indicated by the criteria. Previous studies have shown that many severely injured patients are not transported to higher-level trauma centers.[7-12]

Prehospital trauma triage protocols have been extensively studied over the past decades[7, 13-16]; however, it is currently unknown to what extent compliance to triage protocols influences prehospital trauma triage quality. The aim of this systematic review is to describe compliance to triage protocols and evaluate compliance to the different categories of triage protocols.

Methods

Search

An extensive search of MEDLINE/Pubmed, Embase, CINAHL and Cochrane library was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[17] All studies published before May 2018 on compliance to prehospital trauma triage protocols were eligible for inclusion. The search terms were a combination of synonyms for 'compliance,' 'trauma' and 'triage' (Appendix 1).

Eligibility criteria

Studies describing the compliance rate to prehospital trauma triage protocols were included. All articles, regardless of year of publication or language, were eligible for inclusion. Exclusion criteria were: grey literature (i.e. conference abstracts, editorials and dissertations), articles describing only helicopter transport or including only pediatric patients. Studies on helicopter transport use a separate triage protocol to identify patients requiring helicopter transport among the patients in need of higher-level trauma center care.[18, 19] Pediatric trauma patients differ significantly from adults in for example physiology and mechanism of injury.[20-23] Studies on compliance to triage protocol for helicopter transport and pediatric trauma patients require, in our opinion, a separate review.

Critical appraisal

Due to the specific design of the studies, none of the available critical appraisal tools were fully applicable. To assess the risk of bias of the included studies, criteria from the critical appraisal tools from the Centre for Evidence Based Medicine of the University of Oxford were used.[24] The critical appraisal was specifically designed to assess the methodological quality of studies on the compliance to prehospital trauma triage protocols. It consisted of six items: study setting, domain, collection of data, time of measurements, description of initial transport and missing data (Table 1). Two reviewers (EvR and MvH) assessed the risk of bias independently, discrepancies were discussed until consensus was reached.

Data extraction

Prior to the selection of relevant articles, all duplicates were excluded. Two reviewers (EvR and AR) independently assessed titles, abstracts and full-texts, subsequently, eligible studies were included. Discrepancies were discussed with a third reviewer (MvH) until consensus was reached. One reviewer (EvR) screened the references of included articles for other potential articles. In cases where multiple publications regarding the same dataset of patients existed, the article with the largest cohort was selected.

Table 1. Items, importance, and score used for the critical appraisal

Item	Importance	Score
1. Study setting	A study setting including all levels of trauma centers guarantees a realistic analysis of triage rates, eliminating selection bias.	+ Regional study, including higher-level trauma center(s) as well as lower-level trauma centers - One type of trauma center or not reported
2. Domain	Including all trauma patients or all patients meeting at least one triage criterion ensures a true representation of the compliance rate, eliminating selection bias.	+ All (adult) trauma patients or all (adult) trauma patients meeting at least one triage criterion - A specific group
3. Collection of data	Prehospital parameters scored by EMS providers give a valid depiction of the actual use of a prehospital trauma triage protocol.	+ Data acquired and triage criteria scored on-scene by EMS providers - Data acquisition based on records and scored by data managers or collection method not described
4. Time of measurements	Measuring prehospital data on-scene and at the same time for all included trauma patients represents the actual situation, for prehospital parameters such as vital signs can change due to interventions or over time.	+ Parameters measured at the same (prehospital) time - Not measured at the same time (for example the use of a combination of pre- and in-hospital data or the use of in-hospital data only) or timing of measurements not reported
5. Description of transport	Data on the initial destination to which the patients were taken is needed to accurately calculate true triage rates. Triage rates after secondary transfer to a higher-level trauma center leads to incorrectly lower undertriage rates.	+ Initial destination clearly described - Not clearly described
6. Missing data	Including missing data in analyzes results in a possibly unreliable outcome.	+ No missing data +/- 0-15% missing data - > 15% missing data or not reported
Total score	Good quality Intermediate quality Poor quality	Total score of 5 + Total score of 4 + Total score of ≤ 3.5 +

EMS: emergency medical services

Outcomes

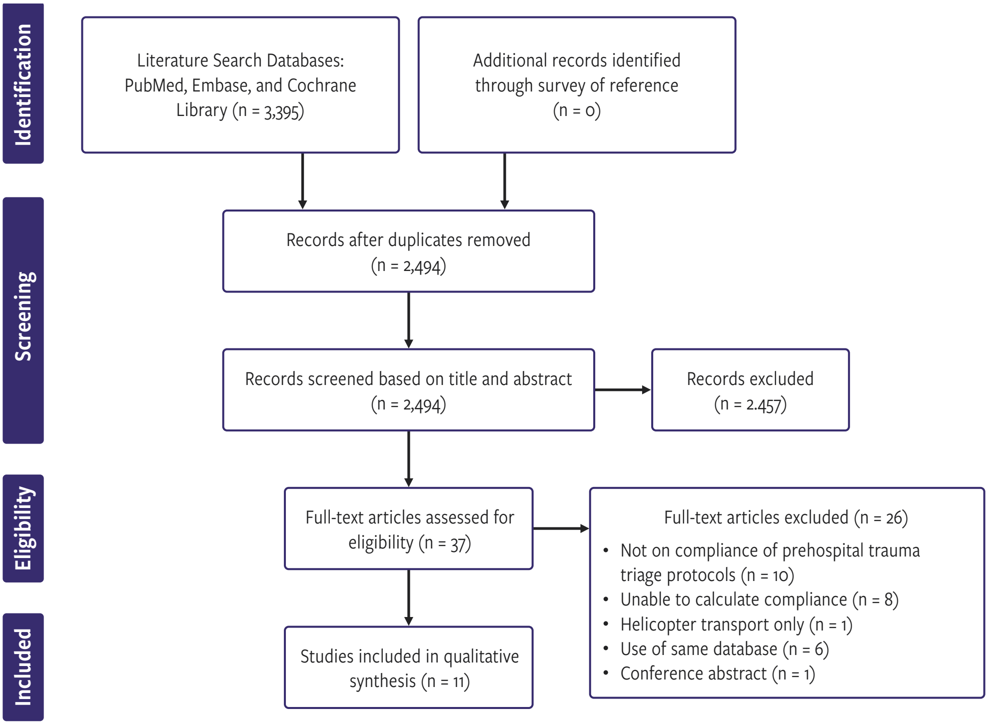
Primary outcomes of this study were compliance percentages. Compliance to a triage protocol is defined as transport of a patient meeting one or more triage criteria to a higher-level trauma center. When available, compliance rates of the categories of triage protocols (e.g. vital signs, injury type or mechanism of injury criteria) were reported. The compliance rates for the triage protocols and categories of the triage protocols were compared in a descriptive manner when possible. A meta-analysis was considered but assumed trivial due to the difference in patient populations, regions and prehospital triage protocols used in the included articles.

Results

Search strategy results

The search of all studies describing compliance to prehospital trauma triage protocols identified 2,494 unique studies. After title and abstract selection, 37 articles remained. After full-text review, 17 articles were eligible for inclusion and analysis.[9, 22, 25-33] Six studies were excluded due to an overlapping database.[16, 30, 34-37] Additionally, a survey of the references of these articles did not lead to the inclusion of more articles, leaving 11 articles in total (Figure 1).

Figure 1. Flow chart of the selection process



Study characteristics

The included studies were published between 2003 and 2017. The studies all originated from high-income countries; US, Australia, Canada and the Netherlands (Table 2). Overall, seven different prehospital trauma triage protocols were evaluated by the articles, almost all described triage protocols consisting of at least three categories: vital signs, injury type and mechanism of injury.[9, 22, 26-29, 31, 33, 38] The triage protocols use different criteria for each category and use different cut-off points for the criteria. The Toronto Prehospital Triage Guideline, 1999 Field Triage Decision Scheme (FTDS) and 2006 FTDS include EMS provider judgment as an additional category. The 2006 FTDS and Louisiana Emergency Response Network trauma triage criteria also include age > 55 years as a special criterion for considering transport to a higher-level trauma center. Two studies only analyzed two out of four categories of the 1999 Field Triage Decision Scheme (FTDS): the vital signs and injury type criteria.[25]

Critical appraisal

The methodological quality was poor in nine[22, 25-29, 32, 33, 38] of the included studies, intermediate in one[31] and good in one (Table 3).[9]

Eight studies[9, 22, 25-28, 31, 33] included all trauma centers of any level in a certain region and three studies [25, 29, 38] did not report the number of participating trauma centers. Six studies included a specific group of patients.[25, 26, 28, 29, 31, 38] One study included only high-energy trauma patients.[31] Doumouras et al.[28] included patients meeting one or more triage criteria only. Even though this does not represent the general trauma population, selection bias is not introduced, as only these patients and their initial destination are necessary to calculate the compliance rate. In six studies, the collection of patient data and scoring of the triage protocol was done on-scene by EMS providers.[9, 27, 28, 31, 32, 38]

In three studies the initial destination of the patient was not reported.[25, 27, 32] In one study, patients transferred from a lower-level trauma center to a higher-level trauma center were considered as a patient initially transported to a higher-level trauma center.[25]

One study excluded all patients with missing data, but did not report the amount of excluded patients.[29] The amount of missing data was not reported in three studies.[25, 26, 28] Multiple imputation was used in three studies to handle missing data.[9, 27, 32]

Table 2. Baseline characteristics of all included articles

First author (year)	Patients (n)	Population (year of inclusion)	Type trauma center (location)	Service area (square mile)
Báez (2003)[24]	37,276	Admitted trauma patients > 17y (1996)	Level I and II TCs and non-TCs (Pennsylvania, US)	46,055
Brice (2017)[32]	190,307	Trauma patients transported by EMS providers (2009-2010)	6 level I, 3 level II, and 3 level III TCs (North Carolina, US)	53,819
Chang (2008)[25]	26,565	Trauma patients meeting triage criteria and declared high priority by EMS providers (1995-2004)	2 level I, 4 level II, and 2 level III TCs (Maryland, US)	Not reported
Cox (2014)[26]	326,035	Trauma patients > 15y (2007-2011)	2 level I TCs and lower-level TCs (Victoria, Australia)	87,873
Doumouras (2012)[27]	898	Trauma patients > 15y meeting triage criteria, with a non-TCs as closest hospital (2005-2010)	2 level I TCs and 11 non-TCs (Ontario, Canada)	250
Fitzharris (2012)[28]	57,775	Trauma patients meeting triage criteria (2006-2007)	Major and regional TCs (New South Wales, Australia)	243
Martinez (2017)[35]	14,071	Trauma patients meeting triage criteria for whom the EMS contacted the call center (2014)	Not reported (Louisiana, US)	Not reported
Newgard (2011)[21]	122,345	Trauma patients transported by EMS providers (2006-2008)	2 level I and 1 level II TCs, 1 Veterans Affairs hospital, and 12 community hospitals (Washington, California, Colorado, and Utah, US)	Not reported
Newgard (2017)[31]	17,633	Trauma patients transported by EMS providers (2011)	5 level I, 2 level II, 5 level III, 5 level IV, and 11 non-TCs (Oregon and Washington, US)	Not reported
Van Laarhoven (2014)[30]	1,607	High energy trauma patients > 17y (2008-2011)	1 level I, 2 level II, and 9 level III TCs (the Netherlands)	535
Voskens (2017)[8]	4,950	Trauma patients > 16y transported by EMS providers (2012-2014)	1 level I and 9 level II/III TCs (the Netherlands)	535

y: years old, TCs: trauma centers, EMS: emergency medical services

Table 3. Critical appraisal

First author (year)	1. Study setting*	2. Domain*	3. Collection of data*	4. Time of asurements*	5. Description of transport*	6. Missing data*
Báez (2003)[24]	+	-	-	-	-	-
Brice (2017)[32]	+	+	-	-	+	-
Chang (2008)[25]	+	-	+	-	+	-
Cox (2014)[26]	+	+	+	+	-	+/-
Doumouras (2012)[27]	+	-	+	+	+	-
Fitzharris (2012)[28]	-	+	-	-	+	-
Martinez (2017)[35]	-	-	+	+	+	+/-
Newgard (2011)[21]	+	+	-	-	+	+/-
Newgard (2017)[31]	-	+	+	+	-	-
Van Laarhoven (2014)[30]	+	-	+	+	+	+/-
Voskens (2017)[8]	+	+	+	+	+	+/-

* Items and scoring system are described in Table 1.

Protocols and compliance

Eight studies evaluated the compliance rate to the complete prehospital trauma triage protocol, this ranged from 21% to 93% (Table 4).[9, 22, 26-29, 32, 33, 38] In the study with the highest compliance rate, the EMS providers contacted a call center that directed the EMS providers to the most appropriate trauma center, based on the triage criteria.[38] This call center was staffed with registered paramedics and maintained a real-time database of the capability and capacity of most of the state's hospitals.

Four studies assessed the complete triage protocol on a general trauma population. The compliance rate was 60% to the 2006 FTDS, 72% for the 2011 FTDS and 73% to the National Protocol of Ambulance Services of the Netherlands.[9, 22, 32] Brice et al.[33] reported the lowest compliance rate (21%), which was the compliance rate for level I trauma centers, in a trauma system where level I and II trauma centers are considered as higher-level trauma centers. Additionally, the triage protocol was recently implemented, but it was unknown how and if the EMS providers were trained to use the triage protocol.

Table 4. Rates compliance per prehospital trauma triage protocol

First author (year)	Triage protocol and criteria	Compliance
Báez (2003)[24]	Vital signs and injury type criteria of 1999 FTDS	39.9
Brice (2017)[32]	North Carolina Trauma Triage and Destination Plan – not mandatory	21.2**
	North Carolina Trauma Triage and Destination Plan - mandatory	20.8**
Chang (2008)[25]	1999 FTDS - adult patients (16-64 years old)	82.2
	Meeting vital signs criteria	74.3
	Meeting injury type criteria	90.8
	Meeting mechanism of injury criteria	88.4
	1999 FTDS - elderly patients (≥ 65 years old)	50.1
	Meeting vital signs criteria	40.5
	Meeting injury type criteria	81.7
	Meeting mechanism of injury criteria	79.6
Cox (2014)[26]	Prehospital trauma triage criteria of Victoria	
	Adult patients (16-55 years old)	87.6
	Elderly patients (> 55 years old)	66.9
Doumouras (2012)[27]	Prehospital trauma triage criteria of Toronto	53.0*
Fitzharris (2012)[28]	Prehospital trauma triage criteria of New South Wales	74.0
	Meeting vital signs criteria	63.5
	Meeting injury type criteria	65.9
	Meeting mechanism of injury criteria	77.4
	Meeting vital signs, injury type, and mechanism of injury criteria	85.4
Martinez (2017)[35]	Louisiana Emergency Response Network trauma triage criteria	92.7
Newgard (2011)[21]	2006 FTDS	59.9
Newgard (2017)[31]	2011 FTDS	71.9
Van Laarhoven (2014)[30]	National Protocol of Ambulance Services 7.1	
	Meeting mechanism of injury criteria	78.7
	Meeting vital signs and mechanism of injury criteria	94.1
	Meeting injury type and mechanism of injury criteria	86.4
	Meeting vital signs, injury type, and mechanism of injury criteria	90.2
Voskens (2017)[8]	National Protocol of Ambulance Services 7.1	72.6

FTDS: Field Triage Decision Scheme
* Calculated by authors as (number of patients transported to a higher-level trauma center meeting one or more criteria) / (number of patients meeting one or more triage criteria)
** Compliance for level I trauma centers only, in a trauma system where level I and II trauma centers are considered higher-level trauma centers.

Vital signs and compliance

The compliance rate to vital signs criteria was the lowest of the three categories of a triage protocol.[26, 29] This could be because in most protocols, it is allowed to transport patients to the nearest hospital in case of acute deterioration. However, the study analysing this showed this occurred in only two patients (0.1%).[31] Fitzharris et al.[29] showed that the percentage of higher-level trauma center transports was not significantly different between patients meeting vital signs criteria and patients meeting none of the triage criteria. The compliance rate differed for some criteria of the vital signs category; compliance was higher for patients with an abnormal respiratory rate or Glasgow Coma Scale, compared to patients with an abnormal pulse or hypotension.[28]

Injury type criteria and compliance

The compliance rate to injury type criteria varied; in one study, the compliance rate was highest and in another, intermediate, compared to the other categories.[26, 29] Penetrating trauma had the highest rate of compliance of the specific injury type criteria.[26-28]

Mechanism of injury and compliance

The compliance rate for mechanism of injury criteria ranged from 77% to 88%.[29, 31] Patients involved in car crashes were most likely to be transported to a higher-level trauma center.[25, 27, 28] Injuries as a result of a fall were associated with transport to a lower-level trauma center.[28]

Multiple categories and compliance

Patients meeting multiple categories showed higher compliance rates. Still, 10%-15% of the patients meeting criteria of all three categories were not transported to a higher-level trauma center.[29, 31]

Age and compliance

EMS providers transported elderly trauma patients more often to lower-level trauma centers, even when the patient met one or more triage criteria.[8,25, 27-30] The odds of being transported to a higher-level trauma center decreased by 2% for every year increase in age.[27] The compliance rate was especially low for elderly patients meeting only vital signs criteria, compared to injury type or mechanism of injury criteria.[26] In the FTDS, age is included as a special consideration;

yet, the compliance rate was low in elderly patients, especially when a fall was the cause of injury.[25]

Location and compliance

Increased distance to a higher-level trauma center led to a lower compliance rate.[28] The compliance was also lower in rural regions compared to urban regions.[38] This might be influenced by a reduced availability of higher-level trauma centers in rural areas, leading to a greater distance to a higher-level trauma center.[25] On the other hand, even in a relatively small geographical region with higher-level trauma centers within short reach, often the nearest trauma center was chosen.[28]

Other factors and compliance

Other factors associated with the compliance rate were EMS provider experience and level of training. The compliance rate was highest for inexperienced EMS providers and for the most experienced EMS providers who supervised EMS providers in training.[29] The compliance rate was lowest for EMS providers with higher levels of training.[26, 29] Studies analysing a triage protocol that included 'EMS provider judgment' did not specifically report on the use or effect of this criterion.[22, 26, 28] However, Voskens et al.[9] showed the indirect effect of EMS provider judgment, as the triage protocol only identified 36% of the severely injured patients, but 78% of the severely injured patients were transported to a higher-level trauma center.

Patients meeting none of the triage criteria

Newgard et al.[22] reported that 27% of the trauma patients who met none of the triage criteria were transported to a higher-level trauma center. It was not reported how many of these patients were severely injured. Furthermore, 46% of the severely injured patients meeting none of the triage criteria were still transported to a higher-level trauma center.[22]

Two studies –using similar triage protocols– reported a difference in results: in one study (where in total 10% met one of the triage criteria), 64% of the patients meeting none of the criteria were severely injured.[9] In the other (where in total over half of the patients met one of the triage criteria), 27% of the patients meeting none of the criteria were severely injured.[32]

Consequences of non-compliance

One study reported that the rate of secondary transfer was higher in the non-compliance group; 30%, whereas the secondary transfer rate was 4% in the compliance group ($p < 0.05$).[38] This study also found that the mortality rate was higher in the non-compliance group; 2.0% vs. 0.6% in the compliance group ($p < 0.05$). The authors analyzed two potential confounders that could have led to the higher mortality rate; frequency of injury types and age. Both did not contribute to the higher mortality rate. Two studies showed that if the triage protocol was strictly applied, the undertriage rate would be slightly lower.[9, 32] However, EMS provider judgment in patients meeting none of the triage criteria had a big impact in the improvement of the undertriage rate.[9]

Discussion

This is the first systematic review, to our knowledge, to describe the compliance to prehospital trauma triage protocols worldwide. The included studies show a wide range in compliance rates; 21% to 93% for triage protocols and 41% to 94% for different categories of the triage protocol. The methodological quality of most of the included studies was poor. The compliance rate was highest for the criterion penetrating injury and lowest for the vital signs category. Compliance rates were lower for elderly patients, compared to adults under the age of 55.

The prehospital trauma triage protocol forms the base of a trauma system. The triage protocol is used by EMS providers to help identify severely injured patients. Worldwide, different prehospital trauma triage protocols exist. According to a triage protocol, patients meeting one or more triage criteria should be transported to a higher-level trauma center. The triage protocol is a guideline. Ultimately, the destination of the patient is decided by the EMS provider –in compliance with the triage protocol or not. Thus, the quality of prehospital trauma triage is not only based on the quality of the triage protocol but also influenced by the compliance to the triage protocol.[2]

As can be expected, among all criteria, the compliance rate was highest for penetrating injury; an obvious cause of severe injury.[26-28] Compliance was lowest for vital signs. Physiologic abnormalities may frequently be atypical and a less obvious indicator of severity of trauma and might improve during transport. The percentage of patients transported to a higher-level trauma center was similar amongst the patients meeting vital signs criteria and those meeting none of the criteria.[29, 30] Triage protocols differ in criteria included in the vital signs category and in cut-off points used. Most include the Glasgow Coma Scale, however, cut-off points vary between 9 and 14.[9, 22, 25-28, 31-33]

The critical appraisal contains all items necessary for an unbiased evaluation of compliance rates and helps to place the results in the right perspective. An accurate assessment of compliance rates should include at least all trauma patients meeting one or more triage criteria, transported to all levels of trauma centers in a specific geographic region, using a triage protocol, assessed on-scene by EMS providers, with a clear description of the initial destination and without a substantial amount of missing data. The overall quality of the included studies was low. Even though almost all studies included all types of trauma centers of a region, most introduced selection bias or bias in data collection. By including only a specific group of patients, selection bias was introduced. All (adult) trauma patients should be included to represent the general trauma population the EMS providers treat every day. Bias in data collection was introduced when the triage protocol was not assessed on-scene by EMS providers, but retrospectively applied by data managers. This does not serve as the actual use of the triage protocol by the EMS providers.

EMS providers can choose to deviate from the triage protocol for multiple reasons: EMS provider expertise and experience, trauma center proximity and preferences of the EMS provider or patient.[28, 33, 35, 38-40] Previous studies showed that EMS providers feel a knowledge gap exists in education and feedback.[28, 40] Compliance might improve with longer training periods, regular practice audits and feedback on decision making. In most countries, the EMS providers cannot obtain information from the hospital on specific patients when the EMS medical care is finished, due to privacy regulations. Consequently, the EMS providers do not get the feedback they need to learn from possible mistakes. Additionally, involvement of EMS providers in the development of a triage protocol might increase compliance to the triage protocol.[39] When EMS providers believe the triage protocol functions well, they are more inclined to comply with the triage protocol.

Multiple studies reported a tendency of EMS providers to transport elderly trauma patients to lower-level trauma centers, even if the patient met one or more triage criteria.[8,25, 27-30] One article speculated that this could be due to the fear of EMS providers that patients might deteriorate during transport, resulting in transport to the nearest hospital for initial management.[30] The mortality rate was higher for severely injured elderly patients transported to a lower-level trauma center, compared to those transported to a higher-level trauma center in one study.[27] Chang et al.[26] held a survey to find reasons for the higher non-compliance rate for elderly trauma patients. According to the interviewed EMS providers, non-compliance was a result of lack in training, unfamiliarity with the triage protocol and a feeling that it is not worth it to spend expensive trauma center recourses on elderly patients. Additionally, EMS providers reported that they felt unwelcome at higher-level trauma centers when presenting an elderly trauma patient.

EMS providers are expected to use triage protocols; however, previous studies showed that the destination decision is typically made early at the scene and mainly based on gut feeling.[35, 41] EMS providers can use their own experience and assess each patient individually, contrary to static triage protocols, possibly resulting in a low compliance rate. Three studies analyzed triage protocols that included the criterion 'EMS provider judgment'.[22, 26, 32] However, these studies did not report any data on the use of this criterion. It has been previously reported that the criterion 'EMS provider judgment' is one of the most used criteria.[42, 43] The literature on the additional value of EMS provider judgment is inconclusive.[6, 44-49] It has previously been shown that currently available triage protocols are incapable to adequately discriminate between the patients with and without severe injuries, to achieve triage rates as recommended by the American College of Surgeons Committee on Trauma (ACS-COT).[13] Voskens et al.[9] indirectly showed that the additional value of the EMS provider judgment, as the triage protocol itself only identified a minority of the severely injured patients, but the majority was transported to a higher-level trauma center. In general, the reduction of undertriage is given priority. However, this inevitably increases the overtriage rate. For each trauma region, an acceptable maximum overtriage rate should be determined to lower the undertriage rate as much as possible. The ACS-COT recommends an undertriage rate of < 5% and an overtriage of < 50% for a trauma system.[13] The combination of an accurate protocol and EMS provider judgment could be the key to realize these triage rates.

A limitation of this systematic review is the possibility of publication bias. The grey literature was excluded; unpublished work might be missing. Another limitation is the heterogeneity of the included studies. All articles analyzed different triage protocols, different countries and different populations. These limitations make it challenging to accurately compare the compliance rates and decide which categories and criteria of a triage protocol lead to the highest compliance rate.

An accurate triage protocol is the base of prehospital trauma triage; therefore, improvement of the triage protocol should have priority. The triage protocol needs improvement and EMS provider judgment as a triage criterion could be of additional value. Feedback, additional training and education of EMS providers could promote triage quality and compliance even more. To analyze and improve the compliance rate further, future research should focus on the transparency of triage decisions, reasons of non-compliance to a prehospital trauma triage protocol and the consequences of non-compliance. This could be analyzed in a prospective study according to the STROBE guidelines[50], where the EMS provider judgment is evaluated independently from the triage protocol. In this type of study, the quality of the triage protocol, compliance and performance of the system can be evaluated separately. This could help in the efforts to improve the public health problem of insufficient quality of prehospital triage of trauma patients.

Conclusion

Worldwide, the compliance rate to prehospital trauma triage protocols and categories of triage protocols varies. Compliance was highest for the criterion penetrating injury, and lowest for the vital signs category. Additionally, compliance rates were lower for elderly trauma patients, compared to adults under the age of 55. The overall methodological quality was poor. The study with good methodological quality showed that the EMS provider judgment lowered the undertriage rate, as the triage protocol itself only identified a minority of severely injured patients, but many were transported to a higher-level trauma center. Future research should focus on improvement of prehospital trauma triage protocols and compliance rates.

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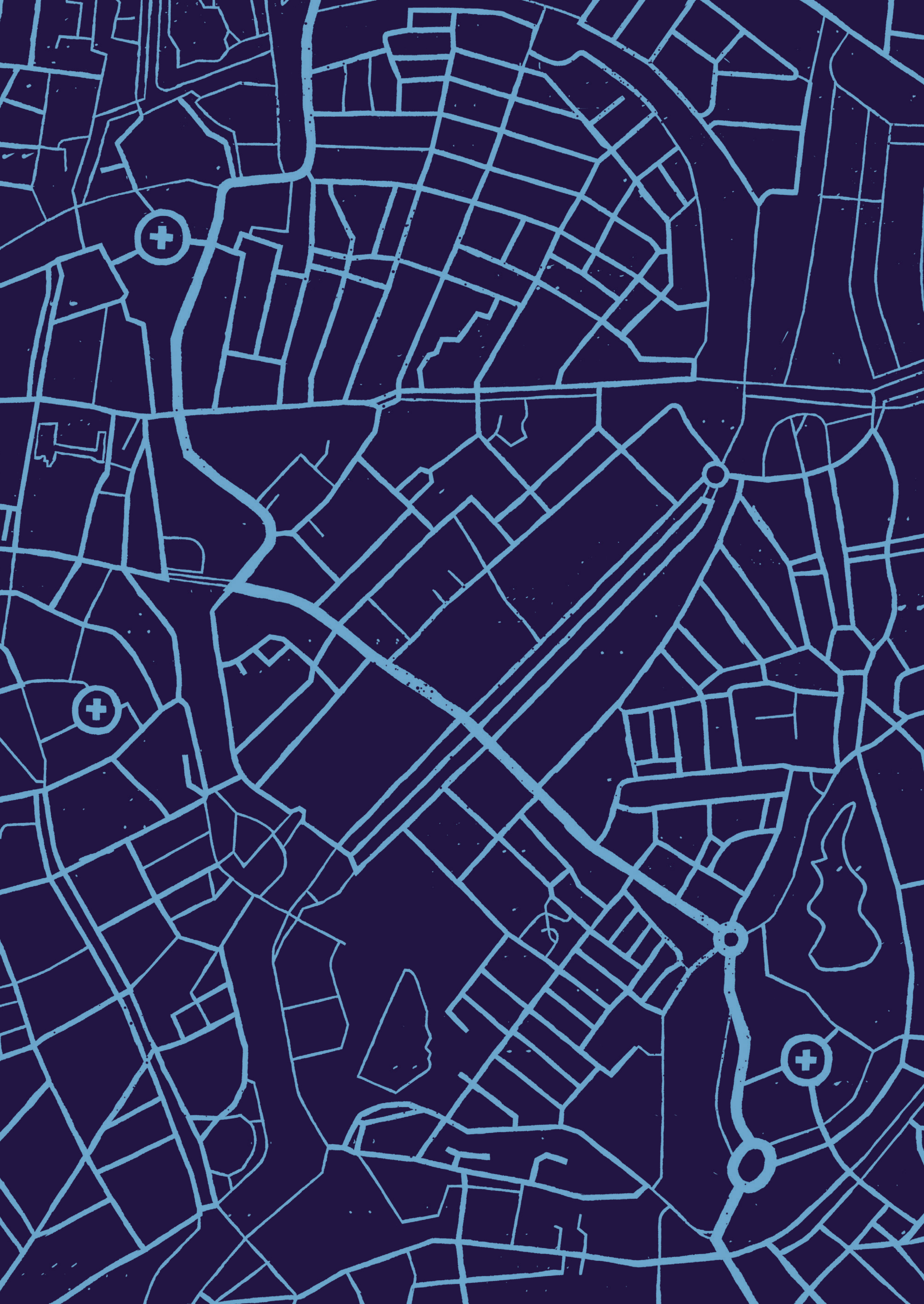
Appendix 1. Search strategy

Search MEDLINE / Pubmed 05-02-2018
(undertriage[tiab] OR overtriage[tiab] OR triage[tiab] OR protocol[tiab] OR criteria[tiab] OR (decision scheme[tiab])) AND (trauma[tiab] OR injury[tiab] OR (wounds and injuries[MeSH])) AND (Compliance[tiab] OR compliance[MeSH] OR (cognitive reasoning[tiab]) OR adherence[tiab] OR (guideline adherence[MeSH]) OR conformity[tiab])

Search Embase 05-02-2018
('triage'/exp OR 'triage':ab,ti OR 'undertriage'/exp OR 'undertriage':ab,ti OR 'overtriage'/exp OR 'overtriage':ab,ti OR 'protocol'/exp OR 'protocol':ab,ti OR 'criteria'/exp OR 'criteria':ab,ti OR 'decision scheme'/exp OR 'decision scheme':ab,ti) AND ('injury'/exp OR 'injury':ab,ti OR 'trauma'/exp OR 'trauma':ab,ti) AND ('protocol compliance'/exp OR 'protocol compliance':ab,ti OR 'adherence'/exp OR 'adherence':ab,ti OR 'conformity'/exp OR 'conformity':ab,ti)

Search Cochrane Library 05-02-2018
("triage":ti,ab,kw OR "undertriage":ti,ab,kw OR "overtriage":ti,ab,kw) AND ("trauma":ti,ab,kw OR "injury":ti,ab,kw) AND ("compliance":ti,ab,kw OR "adherence":ti,ab,kw OR "conformity":ti,ab,kw)

Search CINAHL 05-02-2018
(TI compliance OR AB compliance OR TI adherence OR AB adherence OR TI conformity OR AB conformity) AND (TI triage OR AB triage OR TI protocol OR AB protocol OR TI undertriage OR AB undertriage OR TI overtriage OR AB overtriage OR TI criteria OR AB criteria OR TI decision scheme OR AB decision scheme) AND (TI trauma OR AB trauma OR TI injury OR AB injury)



Accuracy of prehospital triage in pediatric trauma patients: a systematic review

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Abstract

Importance

Field triage of pediatric trauma patients is critical to get the right patient to the right hospital. Mortality and life-long disabilities are potentially attributable to erroneously transporting a patient in need of specialized care to a lower-level trauma center.

Objective

To quantify the accuracy of field triage and associated diagnostic protocols to identify children in need of specialized trauma care.

Evidence Review

MEDLINE, Embase, PsycINFO, and Cochrane Register of Controlled Trials were searched from database inception to November 6, 2017, for studies describing the accuracy of diagnostic tests to identify children in need of specialized trauma care in a prehospital setting. Identified articles with a study population including patients not transported by emergency medical services were excluded. Quality assessment was performed using a tailored version of Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2).

Findings

After deduplication, 1,430 relevant articles were assessed, 38 articles were reviewed on full-text, after which five articles were included. All studies were observational, and time of data collection was prospective in one study. Three different protocols were studied that analyzed a combined total of 1,222 children in need of specialized trauma care. One protocol was specifically developed for a pediatric out-of-hospital cohort. The proportion of patients requiring specialized trauma care varied between 2.5% and 54.7%. Sensitivity of prehospital triage tools ranged from 49.1% to 87.3%, specificity ranged from 41.7% to 84.8%. No prehospital triage protocol alone complied with the international standard of ≥95% sensitivity. Undertriage and overtriage rates, representative of the quality of the full diagnostic strategy to transport a patient to the right hospital, were not reported for inclusive trauma systems or emergency medical services regions.

Conclusions and Relevance

It is crucial to transport the right patient to the right hospital. Yet, quality of the full diagnostic strategy to determine the optimal receiving hospital is unknown. None of the investigated field triage protocols complied to current targets. Improved efforts are needed to develop accurate child-specific tools to prevent undertriage and its potential life-threatening consequences.

Introduction

Injury is a leading cause of death and disability among children worldwide.[1] Field triage in inclusive trauma systems is critical to get the right patient to the right hospital, to achieve optimal patient outcomes. Transporting an injured child in need of specialized trauma care to a lower-level, non-pediatric trauma center (PTC), is considered undertriage, and is associated with higher mortality rates.[2-5] Conversely, overtriage (patients without need for specialized trauma care transported to higher-level trauma centers) results in overuse of valuable trauma resources and increased costs.[6]

It is crucial that emergency medical services (EMS) providers correctly determine the definitive care facility on-scene, to prevent delay of care and to avoid inter-hospital transfers.[7,8] A multitude of comparable triage protocols, that predict need of specialized trauma care, were developed to aid decision-making during field triage. However, most of these protocols were developed for adults or in a different setting, leaving it unclear whether test performance upholds for injured children triaged by EMS providers.[9,10]

Field triage research focuses on the full diagnostic strategy to directly transport a patient to the right facility, with undertriage and overtriage as key quality metrics. Triage protocols to predict injury severity are crucial elements of this strategy and their performance can be expressed in terms of sensitivity and specificity. The objective of this systematic review is to summarize evidence on triage accuracy among children suspected of injury during field triage.

Methods

Data sources and search

The review was conducted according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines (PRISMA).[11] Studies were searched in MEDLINE, PsycINFO, Embase, and the Cochrane Libraries from database inception through November 6, 2017. Search terms included pediatric trauma (study population), triage protocols (index tests), accuracy (outcomes), and field triage (setting; Appendix 1). Reference lists of studies reviewed on full-text were checked for eligible studies.

Eligibility criteria

Eligible were cross-sectional studies, cohort studies, and randomized controlled trials of patients suspected of injury who were evaluated and transported by EMS in a prehospital setting. We included studies using composite outcome measures of early critical resource use or surrogate markers for severe injury as reference standards for test performance. Studies including all patients presenting to the emergency department, regardless of transportation type (i.e. including private transportation), were excluded. Studies were excluded when accuracy metrics for children (0 to <18 years of age) were not reported separately and could not be calculated. No language, publication date, or publication status restrictions were imposed.

Outcomes

Performance measures were calculated for each index test with its corresponding reference standard. Sensitivity and specificity were calculated along with 95% confidence intervals for triage protocols, whereas undertriage (proportion of severely injured patients initially transported to a lower-level trauma center) and overtriage (proportion of patients without severe injuries initially transported to a higher-level trauma center or PTC) would be calculated to define overall triage accuracy of a region. Confidence intervals incorporating between-variance and within-variance could not be calculated if studies used multiple imputation to address missing values. Pooled estimates were considered, but assumed trivial due to heterogeneous index tests and limited number of studies covering this subject.

Study Selection and Data Extraction

Eligibility assessment was performed by two reviewers in a standardized manner. Non-duplicate records were screened by title and abstract, after which remaining records were reviewed on full-text. Two reviewers extracted relevant study characteristics using a data extraction template based on the Standards for Reporting Diagnostic Accuracy Studies (STARD) checklist (Appendix 2).[12] Information was extracted on: (1) design, setting, and inclusion criteria; (2) index tests and reference standards; (3) 2 2 tables were derived for each index test and corresponding reference standard after which accuracy metrics were calculated. Assessment of risk of bias was performed using a tailored version of the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool by two reviewers independently.[13] Discrepancies in study selection, data extraction, and quality ratings were resolved by consensus.

Results

Search

The initial search yielded 1,429 unique records (eFigure in Supplement). After screening on title and abstract, 37 records remained for full-text review. One additional record was identified through a survey of reference lists. Five studies met our pre-specified eligibility criteria.

Table 1. Summary of Included Studies on Field Triage Protocols in a Pediatric Population

Source	Study design and setting	Age, y	Index test	Reference standard
Johnson, 1996	Observational study with retrospective data collection. Multiple local trauma centers in 9 counties in Florida, US, in 1993.	≤ 15	Pediatric Trauma Triage Checklist	MacKenzie algorithm
Phillips, 1996	Observational study with retrospective data collection. Acute care facilities in 9 counties Florida, US, in 1991.	≤ 14	Trauma Scorecard	MacKenzie algorithm
Newgard, 2011	Observational study with retrospective data collection. Seven sites, with 122 acute care hospitals, facilitated by 94 EMS providers across the Western US were evaluated from 2006-2008.	≤ 17	Multiple adaptations of the Field Triage Decision Scheme (2006)	ISS ≥ 16
Lerner, 2016	Prospectively collected data in an observational study. Three pediatric trauma centers across the US were involved from 2009-2012.	≤ 15	Physiologic criteria of the Field Triage Decision Scheme (2011)	ICU admission, death, or non-orthopedic surgery within 24 hours
Newgard, 2016	Observational study with retrospective data collection. Acute care facilities facilitated by 44 EMS agencies in 7 counties in Oregon and Washington in the US in 2011.	≤ 14	Multiple adaptations of the Field Triage Decision Scheme (2006)	ISS ≥ 16

Abbreviations: EMS, emergency medical services; ISS, Injury Severity Score; ICU, Intensive Care Unit.

Study characteristics

All included studies investigated accuracy of a single field triage protocol. None of the studies reported regional triage accuracy based on initial destination facility. Most triage protocols were applied retrospectively to prehospital parameters collected by run-reports, existing hospital databases and registries. Study characteristics on design, setting, age, index test, and reference standard are presented in Table 1. Included studies were published between 1996 and 2016. All studies were conducted in the US. One study collected data in a prospective manner by interviewing EMS providers in the emergency department.[14] Four studies investigated (a part of) the protocol used in daily practice in the study region.[14-17] A new protocol was virtually tested on available data in one study.[18] The proportion of severely injured patients was between 2.5% and 54.7%. Sensitivity of prehospital triage tools ranged from 49.1% to 89.7%, specificity ranged from 41.7% to 84.8%.

Quality assessment

Assessment of risk of bias is shown in Table 2. Patient selection ranged from satisfactory to poor quality. Patients were sometimes unnecessarily excluded due to missing values[17], inability to match prehospital data to hospital or registry records[16,17], or unavailable research coordinators[14], leading to non-consecutive and non-random samples. Conduct of the index was often poorly described and not according to daily practice. In two studies, clinical parameters were used as surrogate for missing prehospital parameters, giving rise to biased test accuracy.[14,17] It is unclear whether the MacKenzie algorithm, and early critical resource use are applicable to identify patients in need of specialized trauma care.[19] Mapping functions were used in three studies to generate Injury Severity Scores (ISS) or Abbreviated Injury Scale scores from ICD-9 codes and missing reference standards were imputed, leading to an imperfect conduct of the reference standard and potential misclassification.[16-18,20] Inclusion of patients only transported to trauma centers raised applicability concerns regarding patient selection in two studies.[14,18] It is unlikely that test accuracy of patients only transported by advanced life support extrapolates to the complete pediatric out-of-hospital population as defined in the review question.[18]

Table 2. Critical Appraisal of the Included Articles

	Risk of bias				Applicability concerns		
Source	Patients	Index test	Reference standard	Flow and timing	Patients	Index test	Reference standard
Johnson, 1996	+	+	-	+	-	+	?
Phillips, 1996	-	-	-	+	-	+	?
Newgard, 2011	-	+	-	+	+	+	+
Lerner, 2016	-	-	+	-	-	+	?
Newgard, 2016	+	+	-	+	+	+	+

Definition of symbols: '+', low suspicion of bias; '-', potential bias; '?', insufficient formation.

Trauma triage protocols

Accuracy metrics of prehospital triage protocols are shown in Table 3. The Pediatric Trauma Triage Checklist (PTTC) is an adaptation of the Pediatric Trauma Score (PTS) designed to make the PTS more user-friendly.[18] The original PTS consists of the assessment of six anatomic or physiologic components. Components include airway, systolic blood pressure, level of consciousness, fractures and cutaneous injuries. Each component is assigned a value of -1, +1, or +2 and a cumulative score is calculated.[21] The PTS was originally developed with inpatient data aimed at predicting injury severity and mortality. Early studies concluded that it was relatively hard to calculate and components had little or no meaning to EMS providers.[18,22] The PTTC modifies component criteria to make them clearer and easier to use. Additionally, checkboxes were introduced for each component to eliminate the need to calculate a score. Each item is color-coded and one red box or two blue boxes indicate transport to a specialized trauma center. The sensitivity of the PTTC was 86.2% with a specificity of 41.7% in one study.[18]

The Trauma Scorecard (TS) was used for adult field triage in Florida since 1990, however, no uniform guidelines for pediatric patients existed at the time.[17] Components of the TS are systolic blood pressure, respiratory rate, Glasgow Coma Scale, burns, paralysis, ejection from vehicle, amputation proximate to wrist or ankle, and penetrating injury. The ability of this adult-specific protocol to predict pediatric injury severity was investigated and the reported sensitivity was 66.7% with 84.8% specificity.[17]

The Field Triage Decision Scheme (FTDS) was established in 1986 by the American College of Surgeons Committee on Trauma (ACS-COT).[23] Modified versions of the FTDS appeared at regular intervals. The protocol consists of four triage steps: physiologic criteria, anatomic criteria, mechanism of injury, and special patient or system considerations. Patients should be transported to the highest level of care available in a trauma system when an anatomic or physiologic criterion is fulfilled. Physiologic and anatomic components are Glasgow Coma Scale, systolic blood pressure, respiratory rate, penetrating injuries, flail chest, two or more proximal long-bone fractures, crushed extremities, amputation proximal to wrists and ankle, pelvic fractures, skull fractures and paralysis. Special considerations include EMS provider judgment and age (children should be triaged preferentially to pediatric-capable trauma centers). The FTDS was evaluated in three studies.[14-16] One study only evaluated the physiologic criteria of the 2011 version.[14] Two studies evaluated all criteria (including mechanism of injury and special considerations) of the FTDS 2006 version (or slightly different versions).[15,16] These studies used the reference standard (ISS ≥ 16) as suggested by the ACS-COT.[24] The physiologic criteria had a sensitivity of 49.1% and a specificity of 82.4%. The full decision scheme had a sensitivity ranging from 84.1% to 87.3% and specificity of 66.4% to 79.3%.

Table 3. Accuracy of Pediatric Trauma Field Triage Tools

Index test	Positive RS, no. (%)	TP	FN	FP	TN	Sensitivity (95% CI)	Specificity (9% CI)
Pediatric Trauma Triage Checklist	58 (54.7%)	50	8	28	20	86.2% (74.8-93.1)	41.7% (28.8-55.7)
Trauma Scorecard	78 (5.2%)	52	26	217	1210	66.7% (55.6-76.2)	84.8% (82.8-86.6)
Multiple adaptations of FTDS (2006)	697 (4.7%)	586	111	4763	9414	84.1% (81.1-86.6)	66.4% (65.6-67.2)
FTDS (2011) Physiologic Criteria	279	137	142	935	4380	49.1% (43.3-54.9)	82.4% (81.4-83.4)
Multiple adaptations of FTDS (2006)	110 (2.6%)	96	14	844	3243	87.3% (79.6-92.4)	79.3% (78.1-80.6)

Abbreviations: FTDS, Field Triage Decision Scheme; RS, reference standard; TP, True positive; FN, False negative; FP, False positive; TN, True negative; CI, Agresti-Coull confidence interval.

Discussion

This systematic review included five studies, with a combined number of 1,222 patients requiring specialized trauma care, classified by three different reference standards. Maximum sensitivity of all evaluated protocols was 87.3%. These findings are important because of the potentially life-threatening consequences of erroneous field triage.

In 1976, the ACS-COT published criteria for categorizing hospitals according to their resources and expertise to treat traumatic injuries. Regionalization of trauma care is often based on these criteria and evidence is suggestive of decreased mortality rates compared to exclusive systems.[25,26] The ACS-COT recommends an undertriage rate of less than 5% in inclusive trauma systems.[24] This review shows that no existing protocol attains >95% sensitivity to achieve this goal in a pediatric prehospital population. This finding is congruent with a recent review of protocol accuracy in a slightly broader out-of-hospital population of adults.[10]

Triage protocols are a single component of the diagnostic strategy to determine the optimal definitive care facility. Besides triage protocols, this diagnostic strategy often includes EMS provider judgment, trauma center proximity, regional agreements, and is depended on trauma center capacity. This strategy ultimately leads to an optimal or suboptimal choice of receiving hospital. In this review, no study evaluated regional undertriage and overtriage rates. Evidence suggests that undertriage rates are over 20% for children aged 0-10 and 11-20 years, but no exact numbers could be computed.[27] Pediatric undertriage rates over 20% are also reported for patients admitted to US emergency departments.[28,29] However, one-third of these injured patients used private transportation and accuracy cannot be extrapolated to EMS triaged patients.[30]

The PTTC was the only included child-specific triage protocol. The PTS, on which the PTTC was based, is perhaps the most studied child-specific protocol, but no study met our inclusion criteria. Application of adult physiologic criteria to children will presumably lead to misclassification of need of specialized trauma care.[14,31,32] Even use of child-specific cut-points for physiologic criteria will likely result in false predictions, due to the great variability in normal ranges across childhood.[33] Besides differences in physiology, pediatric injury patterns and mechanism of injury are very unlike their adult counterparts. School-aged children are at greatest risk from traumatic brain injuries, mostly due to motor vehicle crash-related trauma, whereas toddlers and preschoolers are most commonly victim of falls. Developing a diagnostic test with acceptable accuracy across all age ranges is consequently burdensome.

The FTDS was evaluated in three studies, of which two defined a positive triage status as any positive criterion in the full scheme. In daily practice, only patients with any positive physiologic or anatomic criterion are advised to be treated in the highest level of trauma center available. This leads to an overestimation of sensitivity and underestimation of specificity. EMS provider judgment was the most applied field criterion, further emphasizing this assumption. It remains unclear how accurate the FTDS is in daily practice. EMS provider judgment is highly dependent on education and experience, and therefore protocol accuracy could be very different within and between regions.

Quality assessment of triage protocols requires large sample sizes. Subsequently, test accuracy was mostly evaluated retrospectively.[15-18] In this case, interpretation of protocol criteria by EMS providers is assumed to be identical to interpretation of retrospectively collected data by investigators. This simplification of reality will likely lead to biased diagnostic test accuracy, even more when hospital data is used to replace missing prehospital data.

Three incomparable reference standards were used as surrogate markers for need of specialized trauma care. To date, it remains controversial which pediatric patients need expertise and resources of higher-level trauma centers and PTCs. Treating severely injured children (ISS ≥ 16) in higher-level trauma centers and PTCs was shown to increase survival rates.[3,4] Major evidence for alternative reference standards is lacking. Compared to adult and mixed trauma centers, children with ISS ≥ 25 showed lower mortality rates in PTCs.[5] However, due to the limited number and geographic distribution of PTCs, adult and mixed trauma centers provide care for the majority of children.[34]

In our opinion, an appropriate way to investigate test accuracy of triage protocols would be with a study population consisting of all children suspected of injury during field triage by EMS providers, independent of initial transport destination. Current literature often does not adhere to these requirements. Differences in spectrum of disease, prevalence of patients requiring specialized trauma care, and patient characteristics lead to altered diagnostic performance. Thus, results might not be representative for regional triage accuracy or protocol accuracy.[35] Undertriage and overtriage rates should be evaluated for complete trauma regions and EMS regions, as these are the cornerstones to improve prehospital trauma triage.

Strengths and limitations

Strengths of this review include use of current methods for evidence searching and quality assessment. The review was limited to studies in a prehospital setting, discarding information from triage tools used in the emergency department or those used for prognostic purposes. This increased validity and clinical relevance of our findings for use in field triage.

The study results, although important, have several limitations. First, a lack of evidence on full diagnostic strategies in field triage of pediatric trauma patients exists. Isolated performance of a diagnostic test is difficult to interpret and could differ from a multivariable context. Second, included studies were of intermediate or low quality. Most studies retrospectively evaluated triage protocols, not resembling daily practice. Thirdly, study populations were heterogeneous and triage protocols evaluated by different reference standards are impossible to compare. Additionally, all current evidence is from US trauma systems, leaving it unclear whether results are transferable to trauma systems in other countries.

Conclusions

The goal of a field triage tool is to match the level of care needed by a trauma patient, to an acute care facility with the required amount of resources and expertise. Quality of the full diagnostic strategy to get the right patient to the right hospital is lacking. Current field triage tools misclassify a substantial number of injured children during field triage, potentially resulting in erroneous transportation destinations and preventable mortality. Increased efforts are needed to develop a highly sensitive and specific pediatric trauma triage tool to aid decision-making by EMS providers.

Acknowlegdements

None.

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Appendix 1. Search strategy

No.	Search MEDLINE via OvidSP	Results
#1	((p?ediatric* or child* or teenager? or infant* or adolescen* or youth*).ti,ab. or exp child/ or exp adolescent/) and ((injur* or trauma? or wound*).ti,ab. or exp "Wounds and Injuries"/)	266485
#2	exp Emergency Medical Services/ or exp Emergency Service, Hospital/ or Rescue Work/ or exp Ambulances/ or (ambulance* or GEMS or HEMS or pre?hospital or out-of-hospital or field or ED).ti,ab.	685305
#3	(protocol? or flow?chart or decision scheme? or decision schema* or scoring* or score? or tool? or criteri* or triag* or priorit* or sort* or categoriz* or classif*).ti,ab. or exp Triage/	2312129
#4	(sensitivit* or specificit* or under?triage or over?triage or predictive value? or accurac* or roc or receiver operating characteristic?).ti,ab. or exp "Sensitivity and Specificity"/	1420242
#5	1 and 2 and 3 and 4	862

No.	PsycINFO via OvidSP	Results
#1	(p?ediatric* or child* or teenager? or infant* or adolescen* or youth*).ti,ab. and ((injur* or trauma? or wound*).ti,ab. or exp injuries/)	123314
#2	exp emergency services/ or (ambulance* or GEMS or HEMS or pre?hospital or out-of-hospital or field).ti,ab.	663633
#3	(protocol? or flow?chart or decision scheme? or decision schema* or scoring* or score? or tool? or criteri* or triag* or priorit* or sort* or categoriz* or classif*).ti,ab.	2741248
#4	exp test performance/ or exp test scores/ or exp test sensitivity/ or exp test specificity/ or (sensitivity* or specificit* or under?triage or over?triage or predictive value? or accuracy* or roc or receiver operating characteristic?).ti,ab.	1303288
#5	1 and 2 and 3 and 4	100

No.	Search Embase	Results
#1	('p?ediatric*' OR 'child*' OR 'teenager?' OR 'infant*' OR 'adolescen*' OR 'youth*' OR 'child'/exp OR 'adolescent'/exp OR 'juvenile'/de) AND ('injur*' OR 'trauma?' OR 'wound*' OR 'injury'/exp)	401840
#2	'pre-hospital':ab,ti OR 'out-of-hospital':ab,ti OR 'ambulance*' OR 'emergency medical service?' OR 'gems':ab,ti OR 'ems':ab,ti OR 'accident?' OR 'rescue*' OR 'emergency health service'/exp OR 'emergency medicine'/exp OR 'emergency'/exp OR 'paramedical personnel'/de OR 'rescue personnel'/exp	327215
#3	'protocol*' OR 'flow?chart?' OR 'scheme?' OR 'schema?' OR 'tool?' OR 'method*' OR 'system?' OR 'criteri*' OR 'priorit*' OR 'sort*' OR 'referr*' OR 'triag*'	15165827
#4	'sensitivit*' OR 'specificit*' OR 'under?triage' OR 'over?triage' OR 'predictive value?' OR 'accurac*' OR 'sensitivity and specificity'/exp OR 'predictive value'/exp OR 'diagnostic accuracy'/exp	1902743
#5	#1 and #2 and #3 and #4	778

No.	Search Central	Results
#1	(‘p?ediatric*’:ab,ti or ‘child*’:ab,ti or ‘teenager?’:ab,ti or ‘infant*’:ab,ti or ‘adolescen*’:ab,ti or ‘youth*’:ab,ti or MeSH descriptor: [Child] explode all trees or MeSH descriptor: [Adolescent] explode all trees) and (‘injur*’:ab,ti or ‘trauma?’:ab,ti or ‘wound*’:ab,ti or MeSH descriptor: [Wounds and Injuries] explode all trees)	19748
#2	MeSH descriptor: [Emergency Medical Services] explode all trees or MeSH descriptor: [Emergency Service, Hospital] explode all trees or MeSH descriptor: [Rescue Work] explode all trees or MeSH descriptor: [Ambulances] explode all trees or ‘ambulance*’:ab,ti or ‘GEMS’:ab,ti or ‘HEMS’:ab,ti or ‘pre?hospital’:ab,ti or ‘out-of-hospital’:ab,ti or ‘field’:ab,ti or ‘ED’:ab,ti	22008
#3	‘protocol?’:ab,ti or ‘flow?chart’:ab,ti or ‘decision scheme?’:ab,ti or ‘decision schema*’:ab,ti or ‘scoring*’:ab,ti or ‘score?’:ab,ti or ‘tool?’:ab,ti or ‘criteri*’:ab,ti or ‘triag*’:ab,ti or ‘priorit*’:ab,ti or ‘sort*’:ab,ti or ‘categoriz*’:ab,ti or ‘classif*’:ab,ti or MeSH descriptor: [Triage] explode all trees	175298
#4	‘sensitivit*’:ab,ti or ‘specificit*’:ab,ti or ‘under?triage’:ab,ti or ‘over?triage’:ab,ti or ‘predictive value?’:ab,ti or ‘accurac*’:ab,ti or ‘roc’:ab,ti or ‘receiver operating characteristic?’:ab,ti or MeSH descriptor: [Sensitivity and Specificity] explode all trees	19079
#5	#1 and #2 and #3 and #4	19

Appendix 2. Study Characteristics and Critical Appraisal

Title	Evaluation of the pediatric trauma triage checklist as a prehospital pediatric trauma triage tool for the state of Florida
Authors	Johnson WP
Year	1996
Methods	
Study design	Retrospective observational study (diagnostic)
Setting	Multiple local trauma centers in 9 counties in Florida, USA. Unclear which facilities participated. The study included patients between July and September 1993.
Participants	Eligibility criteria: the study population was identified by reviewing the prehospital run report records and outcome data for all injured, pediatric patients (≤15 years of age) transported by an advanced life support prehospital provider to a local trauma center.
Test methods	Index test: the pediatric trauma triage checklist (PTTC) was developed and retrospectively applied to available data to assess its quality. If two blue boxes were checked and/or one red, a patient was flagged as in need of specialized trauma care. Reference standard: the MacKenzie algorithm was used to define retrospectively whether a patient required high-level trauma care or not.
Analysis	Sensitivity and specificity were calculated for the PTTC.
Results	
Participants	In total 106 patients transported by advanced life support were included.
Test results	Cross-tabulation: true positive (TP) 50; false positive (FP) 28; false negative (FN) 8; true negative (TN) 20. The PTTC had a sensitivity of 86.2% and a specificity of 41.6%. No information on missing data was provided. No baseline characteristics of included patients were reported.
Other information	
Funding	"Supported in part by a grant from the U.S. Department of Health and Human Services Bureau of Health Resources Development, Division of Trauma and Emergency Medical Systems grant number BRP 61002-012."
QUADAS-2	
Patient selection	All prehospital run-reports of consecutive pediatric trauma cases transported by advanced life support to a local trauma center were reviewed. It is unclear whether all facilities participated in Dade County. No inappropriate exclusion criteria were reported. This study only included patients transported by advanced life support which is a more restricted population than stated in our review question.
Index test	The index test (PTTC) was retrospectively applied using factors from the prehospital run-reports. This does not resemble daily practice but might not introduce bias if there were little missing values. There was no information on missing values. A pre-specified threshold (1 red box and/or 2 blue) was used to define a positive index test.
Reference standard	The MacKenzie algorithm was used as a reference standard. Although it is based on the Abbreviated Injury Scale (AIS) and has some similarities with the Injury Severity Score (ISS), it remains unclear whether it correctly classifies severe injury. There is no indication of incorporation bias.
Flow and timing	All patients received the same reference standard, and all patients were included in the analysis. Information on the reference standard was collected for each case.

Title	The need for pediatric-specific triage criteria: results from the Florida trauma triage study
Authors	Philips S, et al.
Year	1996
Methods	
Study design	Retrospective observational study (diagnostic)
Setting	Acute care facilities in 9 counties Florida, USA. It was unclear which facilities participated. Inclusion of patients was between July and December 1991.
Participants	Eligibility criteria: patients transported by prehospital emergency medical services professionals to any acute care hospital within the nine selected Florida counties. Trauma records of patients (<15 years of age) from the Florida Trauma Registry were linked to the Florida Hospital Patient Discharge Database with a 72.7% match rate. Patients were excluded when: the injury was an isolated burn; an invalid emergency department (ED) discharge code was recorded; the patient was transferred from the ED to a different hospital; one or more triage criteria were missing.
Test methods	Index test: the trauma scorecard was retrospectively applied to the data. The variables were extracted from the aforementioned database (clinical factors). Reference standard: the MacKenzie algorithm was used as a reference standard.
Analysis	The proportions of hospitalized patients and deaths were calculated. Accuracy metrics were calculated for the index test including sensitivity and specificity. Logistic regression was used to identify coefficients for each individual criterion of the index test. Patients with missing data were excluded from the analysis.
Results	
Participants	In total 1505 pediatric cases were included. Of these cases, 210 patients (14.0%) required hospitalization and 17 patients (1.1%) died after hospital admission or in the ED.
Test results	Cross-tabulation: TP 52; FP 215; FP 26; TN 1210. The trauma scorecard's specificity was 84.4% and sensitivity was 66.7%.
Other information	
Funding	"The Florida Trauma Triage Study was funded by Grant BRP 61000201-1 from the U.S. Health Resources and Services Administration, Division of Trauma and Emergency Medical Systems, and conducted by the Institute for Health and Human Services Research."
QUADAS-2	
Patient selection	An inconsecutive sample of patients was enrolled due to the exclusion of cases with missing data or secondary transfers. Furthermore, unnecessary constrains were posed on eligibility criteria.
Index test	The index test (trauma scorecard) was retrospectively applied using clinical data from several databases. This does not resemble daily practice. Physiological factors are likely to be different than in the prehospital setting.
Reference standard	The MacKenzie algorithm was used as a reference standard. Although it is based on the AIS and has some similarities with the ISS, it remains unclear whether it correctly classifies severe injury. There was no indication of incorporation bias.
Flow and timing	All patients received the same reference standard, and all patients were included in the analysis. Information on the reference standard was collected for each case.

Title	A multi-site assessment of the ACSCOT Field Triage Decision Scheme for identifying seriously injured children and adults
Authors	Newgard CD, et al.
Year	2011
Methods	
Study design	Retrospective observational study (diagnostic)
Setting	This study involved 94 EMS agencies and 122 hospitals (including 15 Level I, 8 Level II, 3 Level III, 4 Level IV, 1 Level V and 91 community/private/federal hospitals) in 7 regions of the Western U.S. from January 2006 through December 2008. The 7 sites included: Portland, OR/Vancouver, WA (4 counties); King County, WA; Sacramento, CA (2 counties); San Francisco, CA; Santa Clara, CA (2 counties); Salt Lake City, UT (4 counties), and Denver County, CO.
Participants	Eligibility criteria: all patients (children [<18 years of age] and adults) for whom the 9-1-1 EMS system was activated with a primary recorded impression of "trauma" or "injury" by the EMS professionals. Patients without a matched hospital record were excluded, as well as interhospital transfers without an initial presentation involving EMS. Patients that were not transported were also excluded.
Test methods	Index test: the triage processes in all sites used standardized triage protocols based on the ACSCOT Field Triage Decision Scheme (FTDS) although different localized versions were used. "The presence of trauma triage criteria was determined as follows: trauma triage criteria specified in the EMS chart; EMS prfessional documented 'trauma system entry' (or similar charting, depending on local terminology); EMS-recorded trauma identification number (used at some sites as a mechanism for tracking injured patients entered into the trauma system); a matched record from the local trauma registry specifying 'scene' origin (i.e., EMS-identified trauma patient); or other surrogate EMS charting markers used in local EMS electronic health records to denote triage-positive patients. All other patients were considered triage negative." Reference standard: Injury Severity Score (ISS) ≥ 16. ICD9 codes and a mapping function were used to generate AIS and ISS scores for patients in all sites.
Analysis	Descriptive characteristics were used to characterize the sample of patients. Accuracy metrics for the index test were calculated, including sensitivity, specificity, positive/negative predictive values, and likelihood ratio's. Missing values, including the reference standard (missing in <1%) were multiply imputed.
Results	
Participants	No descriptive characteristics were available for children specifically. The percentage of linkage was unclear. In total 14,874 children were included.
Test results	Cross-tabulation: TP 586; FP 4763; FN 111; TN 9414. Sensitivity 84.1%, specificity 66.4%. PPV 10.9% and NPV 98.8%. A total of 697 patients were severely injured.
Other information	
Funding	"This project was supported by the Robert Wood Johnson Foundation Physician Faculty Scholars Program; the Oregon Clinical and Translational Research Institute (grant # UL1 RR024140); UC Davis Clinical and Translational Science Center (grant # UL1 RR024146); Stanford Center for Clinical and Translational Education and Research (grant # 1UL1 RR025744); University of Utah Center for Clinical and Translational Science (grant # UL1-RR025764 and C06-RR11234); and UCSF Clinical and Translational Science Institute (grant # UL1 RR024131)."

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QUADAS-2	
Patient selection	Patients without a matching hospital record were excluded, possibly introducing selection bias. Probabilistic matching was used to match ambulance records to registry data, but the matching percentage was not reported. The out-of-hospital population is representative of the population in our review question (a study population as perceived by EMS professionals).
Index test	The index test was retrospectively applied to prehospital factors collected from multiple sources. This strategy is not equal to daily practice, but the authors tried to resemble daily practice as good as possible. Multiple versions of the FTDS were used, so outcomes are averaged over these different versions, but are not specific to a single version of the FTDS. Missing data were imputed using a multiple imputation strategy.
Reference standard	The reference standard was an ISS ≥ 16. Adequate assessment of the reference standard is essential and using a mapping function from ICD9 codes to AIS/ISS measures can potentially lead to bias. Multiple imputation was used and validated for variables from the index test. However, less than 1% of the reference standards were also multiply imputed.
Flow and timing	All patients received the same reference standard. There was an appropriate time interval between the index test and reference standard and all patients were included in the analysis.

Title	Prospective validation of the national field triage guidelines for identifying seriously injured persons
Authors	Newgard CD, et al.
Year	2016
Methods	
Study design	Retrospective observational study (diagnostic)
Setting	This study involved 44 EMS agencies in 7 counties in Oregon (Multnomah, Washington, Clackamas, Jospehine) and Washington (King, Clark, Skamania) in the US. The study included patients from January 1, 2011 through December 31, 2011. A total of 28 hospitals were included (25 of 37 non-federal EMS receiving hospitals, plus 3 additional hospitals located just outside county lines). Participating hospitals included 5 Level I trauma centers (including 2 children's hospitals), 2 Level II trauma centers, 5 Level III trauma hospitals, 5 Level IV hospitals, and 11 nontrauma hospitals.
Participants	Eligibility criteria: all injured children and adults with EMS evaluation at the scene of injury, with a primary impression of "injury" or "trauma" by the EMS professional. Interhospital transfers that did not have an initial EMS response within the 7 counties were excluded. A probability sampling design was used for chart abstraction based on the following strata: urban vs rural county type, triage status (positive or negative), age group (0 to 14 years, 15 to 54 years, and 55 years and older), and type of receiving hospital (major trauma center vs non-trauma hospital).
Test methods	Index test: multiple versions ("local adaptations based on the needs of each region") of the 2006 national field triage guidelines were used as the index test. The test was positive when a patient met any of the triage criteria listed in the entire algorithm as determined by EMS professionals. Triage status (positive vs negative) was based on any of the following: "triage criteria specified in the EMS chart; EMS professional documented 'trauma system entry'; EMS-recorded trauma identification number; a matched trauma registry record specifying a "scene" (EMS-identified) trauma patient; or a matched base hospital phone record specifying a patient entered into the trauma system." Reference standard: major injury defined as an Injury Severity Score (ISS) > 15. The conduct of reference standard (ISS) was not described. Undertriage and overtriage rates (based on hospital destination) were calculated for the general population, but not specifically reported for children.

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Analysis	Sample size was calculated based on previous research and confidence interval values for triage sensitivity of major injured patients. Multiple accuracy metrics were calculated for each pair of index test/reference standard. Missing values were multiply imputed, as well as ISS which was missing in 21.1% of the cases.
Results	
Participants	In total 2,832 patients age <14 years were included, of which 660 were triage positive and 2,172 were triage negative.
Test results	Field triage sensitivity for identifying seriously injured children (0-14 years) was 87.4% (95% CI, 71.9% - 95.0%). No further results specific for children were presented.
Other information	
Funding	"This project was supported by the National Center for Injury Prevention and Control, Centers for Disease Control and Prevention, grant R01CE001837. The sponsor was not involved in the design and conduct of the study; collection, management, analysis, or interpretation of the data; preparation, review, or approval of the manuscript; or the decision to submit the manuscript for publication."
QUADAS-2	
Patient selection	A non-consecutive but random sample of patients was enrolled by a probability sampling design. Not all hospitals within the studied counties participated, potentially leading to non-representative accuracy metrics for the region. The study population resembles the patients as seen through the lens of EMS professionals during field triage.
Index test	The index test was retrospectively applied to prehospital parameters collected on a variety of sources. This strategy does not equal daily practice, but the authors tried to resemble the situation in usual care as good as possible. Multiple versions of the 2006 FTDS were used, so outcomes are averaged over these different versions, but are not specific to a single version of the FTDS. Missing data were imputed using a multiple imputation strategy.
Reference standard	The reference standard for analysis regarding children was an ISS ≥ 16. Multiple imputation was used and validated for variables from the index test. However, 21.1% of the reference standards were also multiply imputed possibly introducing bias.
Flow and timing	Differential verification bias might have been introduced by imputing a substantial percentage of the reference standards. There was an appropriate time interval between the index test and reference standard and all patients were included in the analysis.

Title	Ability of the physiologic criteria of the field triage guidelines to identify children who need the resources of a trauma center
Authors	Lerner EB, et al.
Year	2016
Methods	
Study design	Prospective observational study (diagnostic)
Setting	Three pediatric trauma centers: Children's Hospital of Wisconsin, WI; Golisano Children's Hospital at the University of Rochester, NY; and Children's Medical Center at the University of Texas Southwestern, TX. Inclusions were between June 2009 and August 2012.
Participants	Eligibility criteria: patients age 15 years and younger who were transported by ground or air EMS to the ED with a traumatic mechanism of injury. Research assistants enrolled patients and were available for a minimum of 8 hours per day, seven days per week resulting in a non-consecutive sample.
Test methods	Index test: physiologic criteria of the FTDS (2011 version). Actual values for systolic blood pressure, respiratory rate and Glasgow Coma Scale were recorded at the ED if they were not recorded by EMS professionals, and the physiologic criteria of the FTDS were retrospectively applied during analysis. Reference standard: Trauma center need was defined as intensive care unit admission, death or non-orthopedic surgery within 24 hours of hospital arrival. Data were obtained retrospectively from medical records using a structured data collection tool. Each site had a single research coordinator. Abstracting of the research coordinator was compared to a physician-site investigator prior to the study.
Analysis	Rates of sensitivity and specificity (here defined as undertriage and overtriage, but regardless of hospital destination) were calculated following the recommendations of the CDC's expert panel. Positive likelihood ratios with confidence intervals were also calculated for the overall physiological criteria and for each individual criterion. Only those with complete outcome data (99.7%) were included in the analysis.
Results	
Participants	EMS professional interviews were conducted 5,610 times (68% capture rate). Complete outcome data was available for 5,594 subjects. The average age was 7.5 years, and 60% were male.
Test results	Cross-tabulation: TP 137; FP 935. FN 142; TN 4,380. A total of 19% of the patients were marked triage positive by the index test, whereas 5% fulfilled one of the criteria of the reference standard.
Other information	
Funding	"This project was supported by grant: R01CE001835 from the Centers for Disease Control and Prevention (CDC). It contents are solely the responsibility of the authors and do not necessarily represent the official views of the CDC."
QUADAS-2	
Patient selection	A non-consecutive, potentially non-random sample of patients was enrolled due to the necessity of inclusion by research assistants and EMS professionals interviews. Only children's hospitals participated making it uncertain whether results can be generalized to trauma systems or EMS regions.

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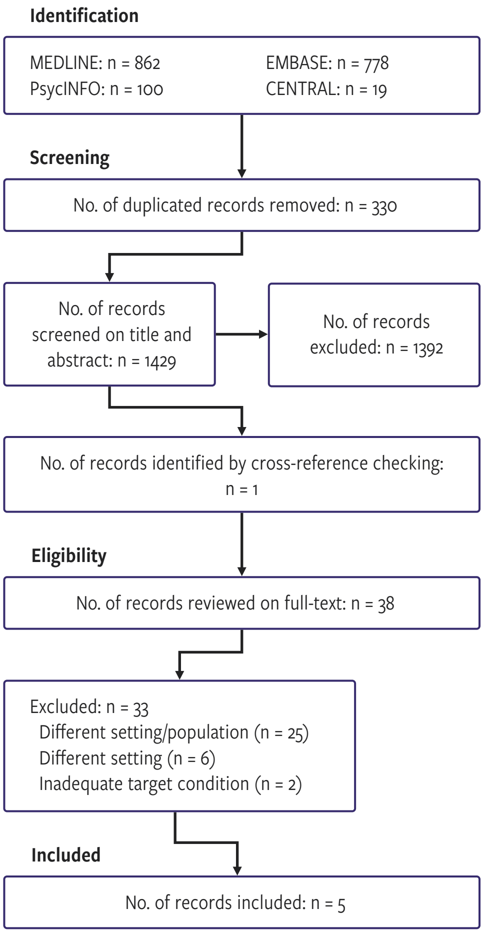
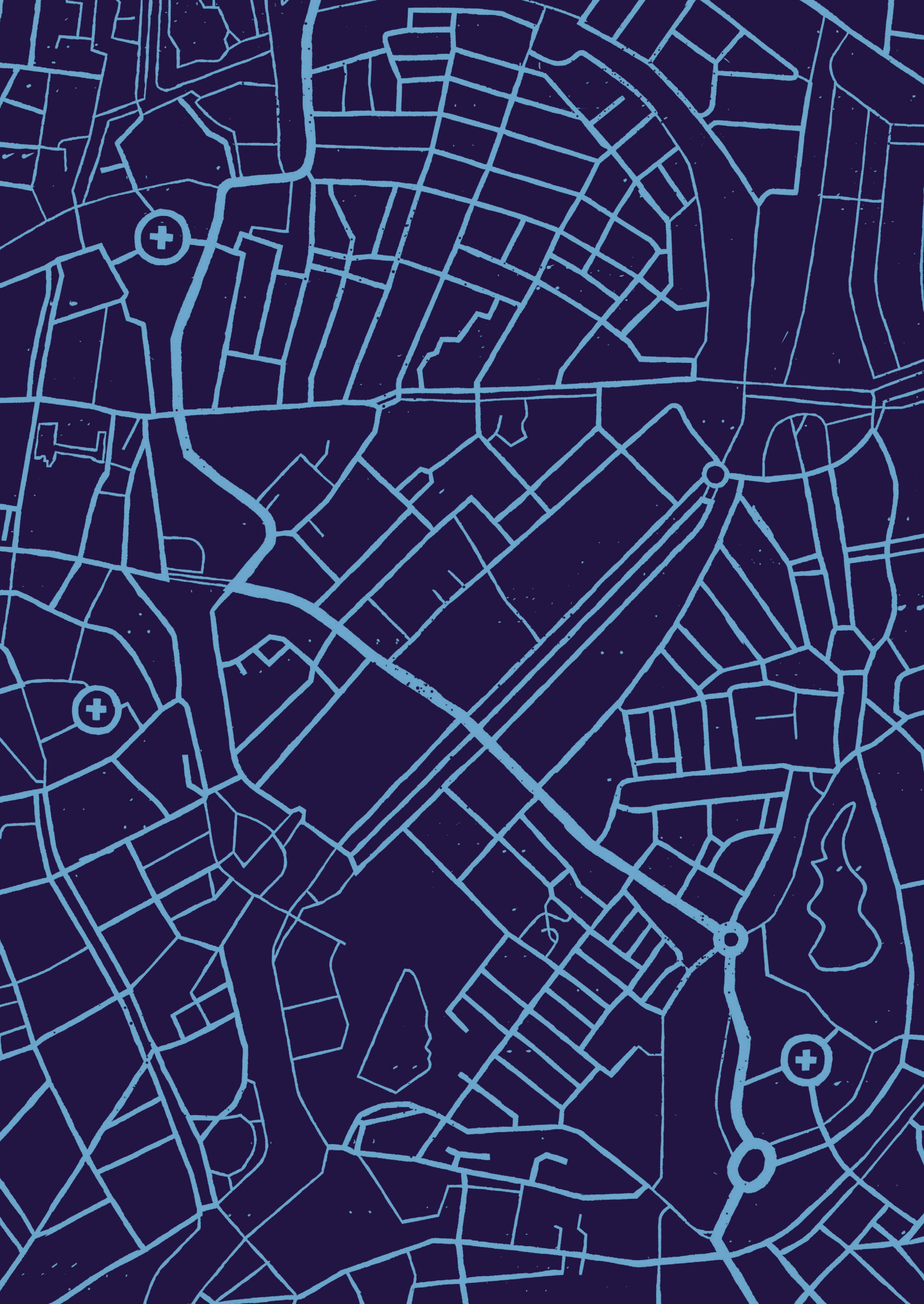
Index test	The conduct of the index test was not according to daily practice. EMS professionals were interviewed after ED admission, and missing values were replaced by physiological variables from ED data. This could have introduced bias. Also, patients are also triaged to higher-level trauma centers by criteria in step 2 of the FTDS. Therefore, these results cannot be extrapolated to real-life situations.
Reference standard	It is unclear whether the reference standard correctly classifies injury severity. It is also unclear whether results of the reference standard were interpreted without knowledge of the index test.
Flow and timing	All patients received the same reference standard, and all enrolled patients were included in the final analysis.

Appendix 3. Study Flow Diagram





Accuracy of prehospital triage in selecting severely injured trauma patients

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6

Abstract

Importance

A major component of trauma care is adequate prehospital triage. In order to optimize the prehospital triage system, it is essential to gain insight in the quality of prehospital triage of the entire trauma system.

Objective

To prospectively evaluate the quality of the field triage system to identify severely injured adult trauma patients.

Design, Setting, and Participants

Prehospital and hospital data of all adult trauma patients during 2012-2014 transported with the highest priority by the EMS provider to 10 hospitals in the region Central Netherlands were prospectively collected. Prehospital data collected by the EMS providers were matched to hospital data collected in the trauma registry. An Injury Severity Score (ISS) ≥ 16 was used to determine severe injury.

Main Outcomes and Measures

The quality and diagnostic accuracy of the field triage protocol and compliance of the EMS provider to the protocol.

Results

A total of 4,950 trauma patients were evaluated of which 436 (8.8%) patients were severely injured. The undertriage rate based on actual destination facility was 21.6% (95% CI 18.0 – 25.7) with an overtriage rate of 30.6% (95% CI 29.3 – 32.0). Analysis of the protocol itself, regardless of destination facility, resulted in an undertriage of 63.8% (95% CI 59.2 – 68.1) and overtriage of 7.4% (95% CI 6.7 – 8.2). The compliance to the field triage trauma protocol was 72.6% for patients with a level I indication.

Conclusions and Relevance

Over 20% of the patients with severe injuries were not transported to a level I trauma center. These patients are at risk for preventable morbidity and mortality. This finding indicates the need for improvement of the prehospital triage protocol.

Introduction

Adequate prehospital trauma triage of injured patients is imperative for optimal trauma care. In an inclusive trauma system, it is essential to transport patients with severe injuries to a level I trauma center and patients without severe injuries to lower level hospitals.[1, 2] Previous studies have clearly shown lower mortality rates in patients with severe injuries treated at a level I trauma center compared to patients treated at a lower level hospitals.[1-6]

Management of care of the injured trauma patient on scene remains challenging and situations can be chaotic. After a rapid trauma assessment of clinical and physiological parameters, EMS providers must identify patients at risk for severe injury and select the proper destination. Prehospital triage protocols are used to help define the patients' destination. However, triage of patients without evident pathology and instability at presentation remains challenging given the limited facilities on scene.

In the Netherlands allocation of trauma patients to the appropriate level of trauma care is guided by the Dutch field triage protocol; the LPA 7.1 (National Protocol of Ambulance Services), for emergency medical services (EMS) providers (Figure 1).[7] This protocol is based on the Field Triage Decision Scheme established by the American College of Surgeons Committee on Trauma (ACS-COT).[8, 9]

Quality of prehospital triage can be determined by rates of undertriage and overtriage. Undertriage is defined as the proportion of patients with severe injuries not transported to a level I trauma center. Overtriage is defined as the proportion of patients without severe injuries transported to a level I trauma center. Undertriage results in higher mortality and delay of adequate care, whereas overtriage limits the available level I resources for patients who do suffer from severe injuries.[2, 8] In order to optimize the prehospital triage system, it is essential to gain insight in the quality of prehospital triage of the entire trauma system or region. The benchmark level in the ACS guidelines is a maximum undertriage rate of 5% allowing for an overtriage rate of up to 50%.[8] In a Dutch population consisting of high-energy trauma patients only, the undertriage rate was 11%.[10] The quality of triage in the complete trauma population is however unknown.

This present study aims to evaluate the quality of the Dutch field triage system for identifying severely injured trauma patients in a population consisting of adult trauma patients transported by the EMS with the highest priority in the region Central Netherlands.

Methods

Study design and setting

The present study was performed in the region Central Netherlands using prospectively collected prehospital and hospital data of all adult trauma patients transported with the highest priority by the Regional Ambulance Service Utrecht to one of the 10 hospitals in the region Central Netherlands between January 2012 and July 2014. The region Central Netherlands consists of 9 level II/III hospitals and one level I trauma center, embracing a 930-square mile region with a population of 1.2 million people. The University Medical Center Utrecht is designated as a level I trauma center, offering trauma care at the highest level for severely injured patients. The nine surrounding level II and III hospitals are designed to treat patients without severe injuries. This regional trauma network is based on an inclusive and integrated trauma system.[8] The ambulance care system is nurse based. Ambulance nurses are licensed to administer medical treatment at Advanced Life Support (ALS) level and ambulance drivers are qualified to provide medical assistance to the ambulance nurses. The present study protocol was reviewed and approved by the local Medical Ethical Committee.

Patients

All trauma patients aged 16 years and older transported by the EMS with the highest priority were included in the study. Patients transported to a hospital outside the region Central Netherlands and patients transported by helicopter were excluded. Patients were also excluded if insufficient data were available in the receiving hospital to properly calculate the Injury Severity Score (ISS).

Data collection

Prehospital reports from the EMS providers were prospectively collected and included patient demographics, description of the trauma mechanism, physical examination data on site, prehospital treatment, and receiving hospital. Furthermore, the report included a standardized digital report of specific vital parameters: i.e. Glasgow Coma Scale (GCS), respiratory rate, systolic blood pressure, heart rate, pupil deficit, and Revised Trauma Score (RTS).

The Dutch National Trauma Database registers in-hospital data regarding injuries and complications for all trauma patients admitted to a hospital. For patients who were discharged from the emergency department, data were extracted from the electronic patient documentation. Injuries were encoded according to the Abbreviated Injury Scale 90 Update 98

(AIS 98).[11] ISS scores were calculated and used to assess overall injury severity.

Outcome

Severe injury was defined as an ISS ≥ 16. The primary outcome of this study was the quality of the field triage system in terms of undertriage and overtriage. Undertriage was defined as the proportion of severely injured patients (ISS ≥ 16) erroneously transported to a level II or III hospital. Overtriage was defined as the proportion of patients with an ISS < 16 transported to a level I trauma center.[8, 12, 13]

Secondary, the diagnostic accuracy of the Dutch field triage protocol was calculated for identifying patients with or without severe injuries, regardless of actual destination facility. For this purpose the level I triage criteria were retrospectively applied to the dataset. For this part of the analysis undertriage was defined as the proportion of patients with severe injuries not identified by the prehospital trauma triage protocol, divided by the total number of severely injured patients. Overtriage was defined as the proportion of patients without severe injuries identified as severely injured patients using the prehospital trauma triage protocol. Prehospital level I criteria were penetrating injury (head, thorax and/or abdomen), ≥ 2 fractures of long bones (humerus and/or femur), amputation proximal to wrist or ankle, neurological failure in ≥ 1 extremity, unstable pelvic fracture, pupil difference, flail chest, GCS > 9, deteriorating GCS, RTS < 11, vitally compromised in airway, breathing or circulation and body temperature ≤ 32 °C.

Finally, the compliance of the EMS provider for correct transportation of patients with prehospital level I trauma center criteria according to the Dutch field triage protocol was determined.

Statistical analysis

Data were analyzed using descriptive statistics and results were shown in frequencies, and percentages. Undertriage and overtriage rates were presented with 95% confidence intervals (95% CI). Multiple imputation was used for missing prehospital values and was performed with SPSS 23.0. Missing values were predicted based on all other predictors, as well as the outcome (ISS). All logistic regression analyzes were performed on 5 imputed datasets independently and pooled afterwards for missing prehospital values. Multiple imputation for missing prehospital values has been previously validated.[14] Multiple imputation was used for: pulse in 6.76%, respiratory rate 6.52%, systolic blood pressure 6.96%, RTS in 8.14%, and GCS in 4.59%.

Results

A total of 6,581 trauma patients were transported by the EMS provider with the highest priority in the region Central Netherlands. Inclusion criteria were met in 4,950 patients for the current analysis (Figure 2). Characteristics of the study sample are shown in table 1. Patients were relatively equally distributed between the hospitals: level I 1,724 (35%) patients, level II 1,326 (27%) patients and level III 1,900 (38%) patients. Median age was 45 years, 2,887 (58%) of the patients were male, and 436 (9%) patients had an ISS ≥ 16. Severe injury in one of the body regions (AIS score ≥ 3) was most frequently diagnosed in the regions head and extremities.

A total of 94 out of 436 patients with severe injuries were erroneously transported to a level II/III hospital resulting in an undertriage of 21.6% (95% CI 18.0 – 25.7). Transportation of 1,382 out of 4,514 patients without severe injuries to the level I trauma center resulted in an overtriage of 30.6% (95% CI 29.3 – 32.0) (Table 2).

The diagnostic accuracy of the Dutch field triage protocol is shown in table 2. The protocol based undertriage was 63.8% (95% CI 59.2 – 68.1) while the protocol based overtriage was 7.4% (95% CI 6.7 – 8.2). The compliance of the EMS providers to the field triage was 72.6%. Thirty percent of the patients with a positive injury and/or physiology criteria were not transported to a level I trauma center.

Table 3 illustrates the undertriage and overtriage rates for different subgroups of the study population regarding correct destination facility. The undertriage rate in elderly patients is high; 38.6% (30.8%-47.2%). A high energy trauma mechanism resulted in an undertriage rate of 9.1% (5.8%-14.2%). The group of patients with a positive injury and/or physiological criteria showed low undertriage rates (0%, 2.6% respectively).

Table 1. Characteristics of the study population (2012-2014)

	Study group N = 4950
Male	2887 (58.3)
Age in years, median (IQR)	45 (27-63)
Elderly, age > 65 years,	1085 (21.9)
Prehospital GCS < 9	141 (2.8)
Triage criteria	
Mechanism of injury	1300 (26.3)
Physiological criteria	289 (5.8)
Injury criteria	256 (5.2)
Assistance of air medical services	119 (2.4)
Out of hospital intubation	49 (1)
Transfer to	
Level I hospital	1724 (34.8)
Level II hospital	1326 (26.8)
Level III hospital	1900 (38.4)
ISS, median (IQR)	2 (5)
Seriously injured (ISS≥16)	436 (8.8)
AIS score ≥ 3 per region	
Head & neck	435 (8.8)
Face	26 (0.5)
Thorax	318 (6.4)
Abdomen	61 (1.2)
Extremities	496 (10)
External	12 (0.2)
In-hospital stay	2047 (41.2)
Mortality	61 (1.2)

Values represent absolute numbers (%), unless stated otherwise.
GCS, Glasgow Coma Scale; ISS, Injury Severity Score; AIS, Abbreviated Injury scale. IQR, Inter Quartile Range

Table 2. Quality of field triage system regarding correct destination facility for patients with and without severe injuries

	Patients with severe injuries, ISS ≥ 16 (n=436)	Patients without severe injuries, ISS < 16 (n=4514)
Level I (n)	342 (78.4%)	1382 (30.6%)
Level II/III (n)	94 (21.6%)	3132 (69.4%)
Undertriage [(a)], 95% CI	21.6% (18 – 25.7%)	
Overtriage [(b)], 95% CI		30.6% (29.3 – 32%)
Diagnostic accuracy of the Dutch prehospital field triage protocol for identifying patients with and without severe injuries		
	Patients with severe injuries, ISS≥16 (n=436)	**Patients without severe injuries, ISS < 16 (n=4514)**
Level I indication	158 (36.2%)	334 (7.4%)
No level I indication	278 (63.8%)	4180 (92.6%)
Undertriage[(c)], 95% CI	63.8% (59.2 - 68.1%)	
Overtriage[(d)], 95% CI		7.4% (6.7 – 8.2%)

[(a)] Proportion of patients with severe injuries (ISS ≥ 16) not transported to level I trauma center
[(b)] Proportion of patients without severe injuries (ISS < 16) transported to level I trauma center
[(c)] Proportion of patients with severe injuries (ISS ≥ 16) without positive prehospital level I criteria according to the field triage protocol.
[(d)] Proportion of patients without severe injuries (ISS < 16) with positive prehospital level I criteria according to the field triage protocol.
ISS injury severity score; CI confidence interval

Table 3. Quality of field triage system regarding correct destination facility for different subgroups

	Patients n	Patients with severe injuries, n (%)	Undertriage (a), 95% CI	Overtriage (b) , 95% CI
Men	2887	295 (10.2%)	19.7% (15.5%-24.6%)	32.8% (31%-34.6%)
Women	2063	141 (6.8%)	25.5% (19.1%-33.3%)	27.7% (25.8-29.8%)
Adults, age ≤ 65 years	3865	304 (7.9%)	14.1% (10.7%-18.5%)	33.2% (31.6%-34.7%)
Elderly, age >65 years	1085	132 (12.2%)	38.6% (30.8%-47.2%)	21.1% (18.6%-23.8%)
Mechanism criteria	1301	186 (14.3%)	9.1% (5.8%-14.2%)	55.3% (41.8%-47.6%)
Injury criteria	256	81 (31.6%)	0 (0 – 4.5%)	33.1% (26.6%-40.4%)
Physiological criteria	289	116 (40.1%)	2.6% (0.9%-7.3%)	55.5% (48.1%-62.7%)
Head injury	2143	304 (14.2%)	22% (17.7%-27.1%)	32.7% (30.6%-34.9%)

CI: confidence interval

Discussion

This study presents a quality assessment of prehospital triage in identifying severely injured trauma patients using prospectively collected data. Prehospital data were collected from EMS perspective and included every type of trauma patient transported with the highest priority, whether admitted or discharged from the emergency department in all types of hospitals.
The quality of the Dutch field triage system remains relatively low. The overall rate of undertriage of the prehospital trauma triage system was 22% and is significantly higher than the benchmark level of five percent as set by the ACS-COT.[15] This implies that a significant group of severely injured trauma patients does not receive the appropriate level I trauma care. These patients are therefore at risk for increased morbidity and mortality.[6, 8, 16]

A variety of causes can be identified for undertriage. Closer examination of the elderly patients (age ≥ 65 years) in the present study showed a high undertriage rate of 39%. The undertriage rate among the elderly patients was 25% higher compared to the younger adults. These findings are in accordance with previous studies showing increased undertriage rates in elderly patients.[17, 18] Elderly patients tend to have more cognitive and physical impairments with preexisting co-morbidity and therefore low energy trauma mechanisms may result in serious injuries.[18] Undertriage of the elderly patients remains a substantial problem. Modifications to the adult criteria of the ACS-COT triage protocol have been made, to accentuate these physiological and anatomical differences of the elderly population.[19] However, the effect of these modifications has not yet been evaluated.

A considerable proportion of trauma patients in our study population suffered from traumatic brain injury (TBI). Patients suffering from TBI are at risk of undertriage, since the identification of significant TBI can be demanding in the prehospital setting. Previous studies already showed high risk of undertriage in patients with isolated head injuries.[20, 21] In our study population, more than 75% of the undertriaged patients were diagnosed with a cranial AIS score of at least 3. These patients need access for direct neurosurgical care.

Overtriage is also an important outcome parameter to monitor, because high overtriage rates lead to reduced system efficiency, unnecessary burden to the level I trauma center and lower cost-effectiveness.[22, 23] Our study showed an acceptable overtriage rate of 31% (95% CI 29.3 – 32.0). As undertriage and overtriage rates are inversely proportional quantities, overtriage will increase as undertriage is lowered. Overtriage rates of up to 50% are acceptable for prehospital triage in order to keep undertriage rates to a minimum.[8, 15] Therefore, an overtriage rate of 31% should provide room for improvement of undertriage rates.

Our findings support the results of recent studies and confirm that especially undertriage rates remain high. However, past studies were retrospective. One exception is a recent prospective study investigating the ACS-COT triage protocol including 17,633 trauma patients of which 3% were seriously injured (ISS ≥ 16).[17] A large group of patients was excluded due to study sampling design and this study reported a significant amount of missing hospital data. The authors reported an undertriage rate of 36.4% and an overtriage rate of 28.7%, based on the initial receiving hospital. After accounting for inter-hospital transfers, the undertriage rate was 22%. This higher undertriage rate compared to our results cannot be explained by the difference in protocols, since the Dutch triage protocol has a higher threshold for transport to a level I trauma center. However, there are significant regional differences. Hospitals in the region Central Netherlands are clustered in a relative close proximity. The level I trauma center is always within a 15 minute drive for an ambulance, whereas this could be over 60 minutes in some of the regions studied by Newgard et al. The significant lowering of the undertriage rate after accounting for inter-hospital transfers in the study of Newgard et al. could suggest at least some role of hospital proximity. Previous research show higher mortality rates in trauma patients after inter-hospital transfers. This emphasizes the need to correctly identify and transport severely injured patients directly to a level I trauma center.[16]

A previous evaluation of the Dutch field triage by our study group revealed undertriage and overtriage rates of 10.9% and 39.5%, respectively.[10] However, this study exclusively included high-energy trauma patients, which could very well explain the difference in triage rates compared to the present study. Although high energy trauma is not a strict level I criterion in the current field triage protocol, it can be hypothesized that patients who suffered from an obvious high energy trauma are more prone to be transported to a level I trauma center due to EMS provider judgment. Other studies have demonstrated that the use of a mechanism of injury criterion could lower undertriage and suggest that specific high energy trauma criteria should be included in the level I criteria.[24] Evaluation of the subgroup of patients after a high energy trauma in the present study also revealed a lower undertriage rate of 9%, supporting the suggestion to include mechanism of injury as level I criterion.

The exceptionally high undertriage rate calculated for the prehospital protocol itself reflects the shortcomings of the currently used protocol. It truly fails to support the EMS provider to correctly identify severely injured patients in need of level I trauma care. Fortunately, due to EMS provider judgment, a large group of the severely injured trauma patients was still transported to the trauma center and received appropriate care. The discrepancy in undertriage rates between the protocol itself (64%) and actual undertriage based on destination facility (22%) is probably best explained by the correct assessment of the EMS providers based on experience, regardless of protocol. Previous studies also showed improved triage rates after including EMS provider judgment as a triage criterion.[25, 26] The preference of the patient and existing transport patterns could also influence the decision for destination facility, the impact of these factors could however not be assessed.

The strength of this study is the prospective prehospital data collection and study design, to include all trauma patients transported to all types of hospitals in a specific region. Furthermore the triage protocol currently investigated is based on the ACS-COT triage protocol, what is adopted as a standard in many organizations worldwide. Therefore this study is of international importance.

This study has several limitations. The exclusion of patients transported to hospitals outside the study region could be a limitation, possibly resulting in sampling bias, the extent of which is unknown.

As mentioned, the Dutch National trauma database does not register patients who are not admitted to the hospital. Although data of admitted trauma patients were prospectively collected by a dedicated group of trained data managers, our research group collected the hospital data of patients discharged from the emergency department retrospectively. These retrospectively collected data are not expected to affect the study results, since this group of consists of patients with minor injuries.

A validated definition of the severely injured patient does not yet exist in prehospital trauma triage. A panel of international experts advised to use a set of parameters for the definition, including two injuries with an AIS ≥ 3 and one or more additional diagnosis.[27] This would predict a mortality rate of 30% or greater for this group. We defined a severely injured patient as ISS ≥ 16.[27, 28] Patients' needs should be matched to the hospitals capability. In this study region only one level I trauma center offers round the clock availability of a designated trauma team and continue availability of neurosurgical care. Most patients with an ISS ≥ 16 are likely to benefit from level I trauma care.[23, 29]

Conclusion

The present study shows that over 20% of the patients with severe injuries were not transported to a level I trauma center. These patients are at risk for preventable morbidity and mortality. It also showed that the accuracy of the Dutch field triage protocol in selecting patients with severe injuries is low and therefore of insufficient help to the EMS providers. Our findings indicate the need for improvement of the prehospital triage protocol.

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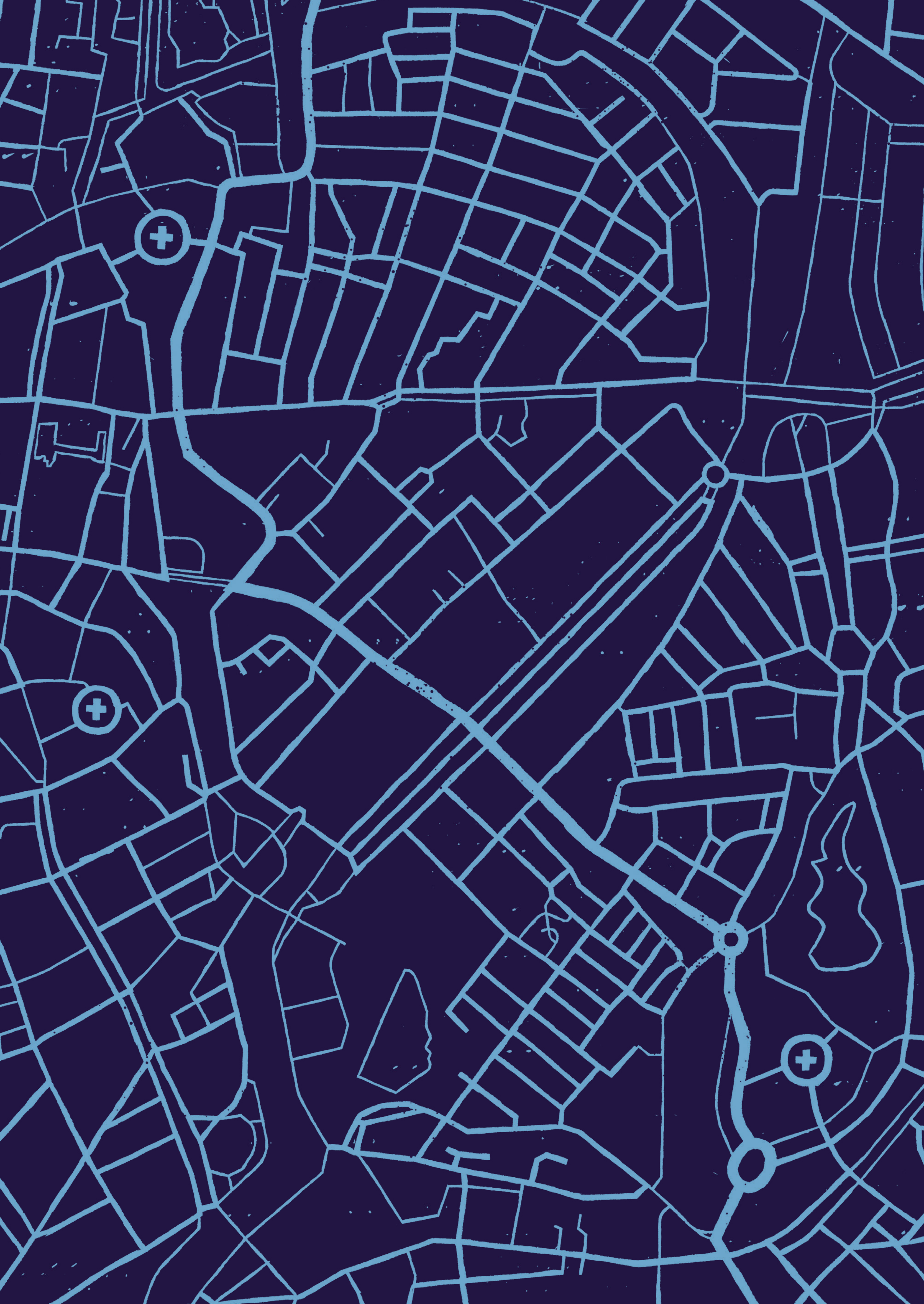

The role of the judgment of emergency medical services providers in the decision-making process of prehospital trauma triage

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Abstract

Purpose

Severely injured patients should be treated at higher-level trauma centres, to improve chances of survival and avert life-long disabilities. Emergency medical services (EMS) providers must try to determine injury severity on-scene, using a prehospital trauma triage protocol, and decide the most appropriate type of trauma centre. The objective of this study is to investigate the role of EMS provider judgment in the prehospital triage process of trauma patients, by analysing the compliance rate to the protocol and administering a questionnaire among EMS providers.

Methods

All trauma patients transported to a trauma centre in two different regions of the Netherlands were analysed. Compliance rate was based on the number of patients meeting the triage criteria, transported to the corresponding level trauma centre. The questionnaire was administered among EMS providers. Descriptive statistics were used to analyse the data.

Results

For adult patients, the compliance rate to the level I criteria of the triage protocol was 72% in *Central-Netherlands* and 42% in *Brabant*. For paediatric patients, this was 63% and 38% in *Central-Netherlands* and *Brabant*, respectively. The judgment on injury severity was mostly based on the injury type criteria. Additionally, the distance to a level I trauma centre influenced the decision for destination facility in the *Brabant* region.

Conclusion

The compliance rate varied between regions. Improvement of prehospital trauma triage depends on the accuracy of the protocol and compliance rate. A new protocol, including EMS provider judgment, might be the key to improvement in the prehospital trauma triage quality.

Introduction

Prehospital trauma triage is for vital importance to ensure transport to a trauma centre with the appropriate level of care for trauma patients. Patients with severe injuries should be treated at higher-level trauma centres, to reduce mortality and morbidity. Patients without severe injuries should be transported to a lower-level facility, to reduce burden on the higher-level trauma centres unnecessary costs.[1-3]

A prehospital trauma triage protocol is in place to help emergency medical services (EMS) providers discriminate between patients with and without severe injuries and decide the most appropriate type of trauma centre.[4;5] The accuracy of a triage protocol is essential, but ultimately it is the EMS provider who determines the destination of the patient. The literature is undecided on the additional value of EMS provider judgment. Previous reports have shown that cognitive reasoning processes contribute to the identification of severely injured patients, potentially missed by triage criteria.[6-9] Others found the judgment of EMS providers to be less accurate.[5;10]

Prehospital trauma triage protocols have been studied extensively over the past decades.[11-14] However, it is currently unknown what factors are associated with EMS provider judgment and to what extent compliance to the triage protocol influences quality of prehospital trauma triage. The objective of this study is to gain insight in the role of EMS providers, in terms of their judgment as well as their reasoning in the prehospital triage process of trauma patients through 1) an analysis of the compliance rate to the triage protocol in a prospectively collected dataset and 2) a survey among EMS providers in two regions of the Netherlands.

Methods

Study design

This study consists of two parts: (1) an evaluation of compliance to the prehospital trauma triage protocol in a prospective cohort, and (2) a survey, both performed in two regions of the Netherlands: *Central-Netherlands* and *Brabant*. The survey was web-based and conducted among EMS providers to gain insight in their judgment in the prehospital trauma triage process (Appendix 1). These two regions were chosen because both differ in geographical distance to trauma centres, mechanism of injury and prevalence of severe injury.[15]

In the Netherlands, level I trauma centres are designated to provide the appropriate level of care for severely injured patients.[16] *Central-Netherlands* has one level I trauma centre (University Medical Centre Utrecht) and seven level II or III trauma centres. The region covers 535 square miles and serves 1.3 million residents. *Brabant* has one level I trauma centre (Elisabeth-TweeSteden Hospital Tilburg) and 11 level II or III trauma centres. This region covers 1,343 square miles and has 1.7 million residents.

In the Netherlands, all ambulances are staffed by: an ambulance nurse (in this article referred to as EMS provider), who is skilled and trained in medical knowledge and procedures, and an ambulance driver who is able to assist the EMS provider.[17] The ambulance nurses are registered nurses with additional mandatory seven-month national training in prehospital care, which includes experience in the field and knowledge of the triage protocol. The triage protocol used in the Netherlands; the National Protocol for Ambulance Services (Figure 1), is based on the Field Triage Decision Scheme established by the American College of Surgeons Committee on Trauma.[4;18]

This study was judged by the Medical Ethical Committee of University Medical Centre Utrecht as not subject to the Medical Research Involving Human Subjects Act.

Participating trauma patients

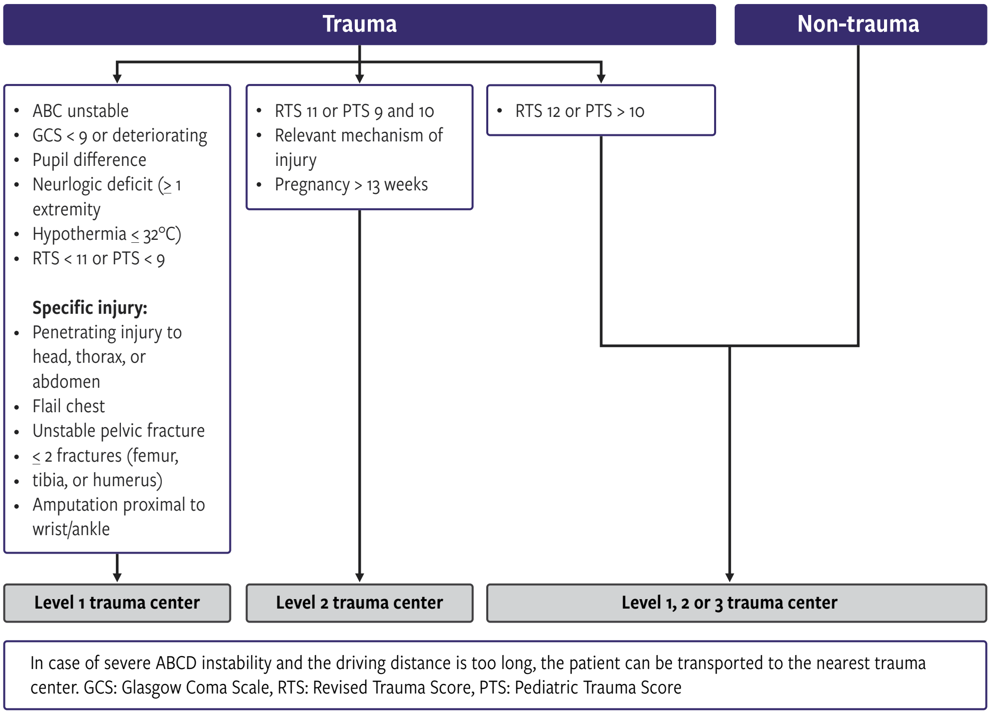
All trauma patients transported with highest priority (siren and lights) to trauma centres in one of the two regions were analysed to determine the compliance rate. Patients were included between January 2012 and June 2014 in the *Central-Netherlands* region and between January 2015 and December 2015 in the *Brabant* region. Patients transported outside of the studied regions were excluded.

Data collection of trauma patients

For each patient, the EMS providers record all prehospital information in an electronic prehospital report. These reports were prospectively collected and included: patient demographics, vital signs criteria, injury type criteria, mechanism of injury criteria and initial receiving hospital.

Hospital data were collected from the institutional trauma registry and electronic medical records. The Dutch National Trauma Database registered receiving hospital, Abbreviated Injury Scale (AIS) and mortality for all patients admitted to a hospital. For *Central-Netherlands*, data were also extracted from the electronic patient documentation for patients discharged directly from the emergency department (ED). The injuries were recorded using the Abbreviated Injury Scale (AIS) 1990, Update 1998 and coded by trained data managers after discharge or 30 days after admission. In *Brabant*, the AIS 2005, update 2008 was used. The data managers were blinded for triage criteria positivity. To determine injury severity, the Injury Severity Score (ISS) was calculated based on the AIS scores.

Figure 1. The National field triage protocol of the Netherlands



Questionnaire and recruitment

The questionnaire focussed on: factors influencing the triage decision, timing of destination decision and possible reasons for, and consequences of undertriage and overtriage. The questions were formulated based on previous research and consensus among the authors. To capture the agreement, the questions were based on a 5-point Likert scale ranging from 1 (factor has no influence) to 5 (factor is highly influential). To get a more accurate understanding of the rationale in the destination decision process, a free text section was included in yes/

no questions and at the end for any general comments. The data managers of the specific region sent the 150 EMS providers of *Central-Netherlands* and 220 EMS providers of *Brabant* a weblink to the questionnaire. A reminder was sent after four weeks.

Outcomes and definitions

For both regions, the compliance rates to the whole triage protocol and the level I criteria were determined for pediatric (< 16 years old) and adult (≥ 16 years old) patients separately. The compliance rate was calculated as:

$$\textit{Whole protocol} = \frac{\textit{Patients meeting triage criteria, transported to the corresponding level trauma center}}{\textit{Patient meeting one or more triage criteria}}$$

$$\textit{Level I criteria} = \frac{\textit{Patients meeting level I criteria, transported to a level I trauma center}}{\textit{Patients meeting one or more level I criteria}}$$

A severely injured patient was defined as a patient with an ISS > 15.

Missing data

Multiple imputation for missing prehospital variables was used for both regions separately, to calculate the compliance rate. Missing values were predicted based on all other predictors, as well as ISS. In the database of Brabant, the paediatric trauma score was missing in the paediatric patients and the ISS was available for admitted patients only. An ISS < 15 was assumed for patients discharged from the ED, as it has previously been shown all discharged patients had an ISS < 15 in *Central-Netherlands*.[19] The Revised Trauma Score[20] was based on the multiply imputed Glasgow Coma Scale, systolic blood pressure and respiratory rate for both regions.

Statistical analysis

The data were analysed using descriptive statistics. The response to the questions of the questionnaire was anonymous and the data was managed by data managers. The questions based on the 5-point Likert scale allowed detection of presence and degree of influence for certain factors on EMS provider judgment in the triage process. Three months after the questionnaire was sent the data of the questionnaires were assessed. All statistical analyses were performed using SPSS v 24.0.

Results

Compliance rate

Central-Netherlands region

In *Central-Netherlands*, 4,950 adults and 594 paediatric trauma patients were transported with highest priority to a trauma centre by EMS providers (Table 1). In total, 435 (8.8%) of the adult patients and 26 (4.4%) of the paediatric patients were severely injured (ISS > 15).

Table 1. Baseline patient characteristics Central-Netherlands and Brabant regions

Variables	Central-Netherlands ≥ 16 years old (n = 4,950)	Central-Netherlands < 16 years old (n = 594)	Brabant ≥ 16 years old (n = 6,859)	Brabant < 16 years old (n = 976)
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Age (years)	47 (21.3)	9 (4.7)	51 (22.1)	8 (5.0)
ISS	5 (7.1)	4 (5.1)	-	-
	Number (%)	**Number (%)**	**Number (%)**	**Number (%)**
Male gender	2,887 (58.3)	331 (55.7)	3,583 (52.2)	223 (61.4)
ISS > 16	435 (8.8)	26 (4.4)	165 (2.4)	2 (0.2)
Destination				
Level I trauma center	1,724 (34.8)	287 (48.3)	1,882 (27.4)	300 (30.7)
Level II trauma center	1,326 (26.8)	163 (27.4)	4,208 (61.4)	563 (57.7)
Level III trauma center	1,900 (41.2)	144 (24.2)	769 (26.9)	113 (11.6)
Admission to hospital	2,039 (41.2)	68 (11.4)	1,842 (26.9)	363 (37.2)
In-hospital death	63 (1.3)	1 (0.2)	57 (0.8)	0 (0)

SD: standard deviation, ISS: Injury Severity Score
Brabant region: ISS was only available for patients who were admitted or died before admission. Gender missed in 858 (12.5%) adult patients and in 613 (62.8%) pediatric patients.

The compliance rate to the whole triage protocol was 72.6% for adult trauma patients (Table 2). The compliance rate to the level I triage criteria for the adult trauma patients was 72.4%. Only 36.3% of the severely injured adult patients met one or more level I triage criteria. Still, 78.4% of the severely injured adult patients were transported to a level I trauma centre. Among the severely injured patients not meeting any of the level I criteria, 67.5% were transported to a level I trauma centre. The compliance rate was lower for elderly patients (> 75 years old): 61.6%, compared to 73.5% for young adults (16-75 years old).

Among the paediatric patients, the compliance rate to the whole triage protocol was 75.3% and

63.1% for the level I criteria (Table 3). Only 26.9% of the severely injured paediatric patients met one or more of the level I criteria, however, 80.0% of the severely injured paediatric patients were transported to a level I trauma centre. In the group of severely injured paediatric patients not meeting any of the level I criteria, 78.9% were transported to a level I trauma centre.

Table 2. Distribution of adult trauma patients

Region	Criteria	Level I	Level II	Level III
Central-Netherlands n = 4,950	**LPA level I criteria**	357 (72.4)	54 (11.0)	82 (16.7)
	ISS > 15	155 (98.1)	1 (0.6)	2 (1.3)
	LPA level I or II criteria	503 (53.6)	179 (19.1)	257 (27.4)
	ISS > 15	126 (91.3)	6 (4.3)	6 (4.3)
	Vital signs level I criteria	207 (72.6)	31 (10.9)	48 (16.8)
	ISS > 15	113 (97.4)	1 (0.9)	2 (1.7)
	Vital signs level I or II criteria	136 (52.7)	40 (15.5)	82 (31.8)
	ISS > 15	50 (92.6)	2 (3.7)	3 (5.6)
	Injury type level I criteria	200 (76.9)	25 (9.6)	35 (13.5)
	ISS > 15	81 (100)	0 (0)	0 (0)
	Injury type level I or II criteria	26 (45.6)	23 (40.4)	8 (21.6)
	ISS > 15	9 (100)	0 (0)	0 (0)
	Mechanism of injury level I or II criteria*	369 (54.5)	137 (20.2)	171 (25.3)
	ISS > 15	79 (91.9)	4 (4.7)	3 (3.5)
Brabant n = 6,859	**LPA level I criteria**	213 (41.8)	249 (48.8)	48 (9.4)
	ISS > 15	53 (89.8)	5 (8.5)	1 (1.7)
	LPA level I or II criteria	174 (29.9)	346 (59.6)	61 (10.5)
	ISS > 15	27 (77.1)	6 (17.1)	3 (8.6)
	Vital signs level I criteria	179 (42.8)	201 (48.1)	39 (9.3)
	ISS > 15	50 (92.6)	3 (5.6)	1 (1.9)
	Vital signs level I or II criteria	107 (37.2)	145 (50.3)	36 (12.5)
	ISS > 15	20 (20.0)	3 (12.0)	3 (12.0)
	Injury type level I criteria	41 (41.0)	49 (49.0)	10 (10.0)
	ISS > 15	8 (80.0)	2 (20.0)	0 (0)
	Injury type level I or II criteria	8 (20.0)	30 (75.0)	2 (5.0)
	ISS > 15	2 (100)	0 (0)	0 (0)
	Mechanism of injury level I or II criteria*	66 (24.8)	176 (66.2)	24 (9.0)
	ISS > 15	6 (66.7)	3 (33.3)	0 (0)

LPA: National Protocol of Ambulance Services, ISS: Injury Severity Score
Central-Netherlands region: multiple imputation was used for systolic blood pressure in 5.9%, respiratory rate in 6.3% and Glasgow Coma Scale in 6.5% of the adult patients.
Brabant region: multiple imputation was used for systolic blood pressure in 16.7%, respiratory rate in 28.8% and Glasgow Coma Scale in 4.2% of adult patients.
* Mechanism of injury criteria indicate transport to either level I or II trauma centers, no separate criteria with a level I indication exist in the triage protocol.

Brabant region

A total of 6,859 adults and 976 paediatric trauma patients were transported with highest priority by EMS providers in *Brabant* (Table 1). In total, 165 (2.4%) adult patients and two (0.2%) paediatric patients were severely injured.

The compliance rate to the whole protocol was 67.2% for adult trauma patients and 41.8% for the level I criteria (Table 2). The level I triage criteria identified 35.8% of the severely injured adult patients, still, 72.7% were transported to a level I trauma centre. Among the severely injured adult patients not meeting any triage criteria, 63.2% were transported to a level I trauma centre. In this region, the compliance rate to the level I criteria was higher for elderly patients (> 75 years old): 45.9%, compared to 41.1% for young adults (16-75 years old).

For paediatric patients, the compliance rate to the whole triage protocol was 48.0% and 38.0% for the level I criteria (Table 3). Both severely injured paediatric patients were transported to a level I trauma centre. One (50.0%) met more than one of the level I criteria and the other did not meet any of the level I criteria.

Survey analysis

Responders and Background

In total, 60 EMS providers from *Central-Netherlands* and 48 EMS providers from *Brabant* filled out the questionnaire. The years of experience ranged from less than a year to 30 years (mean: 10 years, standard deviation: 7.3). Almost all EMS providers (95.0%) were familiar with the triage protocol. In *Central-Netherlands*, the levels of the trauma centres within the region were well-known by most responders. However, in *Brabant* one third of the EMS providers did not know the level of four of the eleven level II or III trauma centres. Almost all knew which hospitals were level I trauma centres.

Factors influencing choice of hospital

How the patient is received by the hospital had more influence on the choice of hospital, than how the EMS providers are received as a professional.

Factors influencing choice of level trauma center

In the assessment of the patient, the type of injury was the most influential factor when deciding to transport an adult or paediatric patient to either a level I or lower-level trauma centre (Figure 2). Age had the least influence on the destination decision (Table 4). However, the EMS providers did report that they were more easily inclined to transport paediatric patients to a level I trauma centre, compared to adult patients.

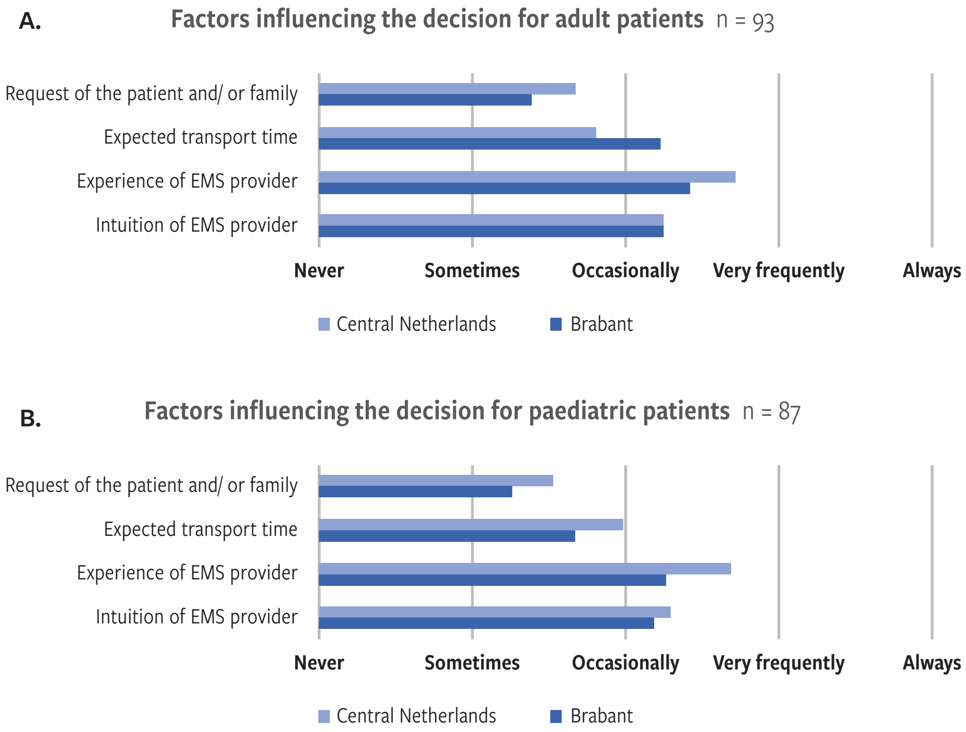
Also, EMS provider experience was reported to play an important role in the decision between a level I or lower-level trauma centre.

Table 3. Distribution of pediatric trauma patients

Region	Criteria	Level I	Level II	Level III
Central-Netherlands	**LPA level I criteria**	41 (63.1)	13 (20.0)	8 (12.3)
n = 594	ISS > 15	6 (85.7)	0 (0)	1 (14.3)
	LPA level I or II criteria	139 (63.9)	26 (11.9)	41 (18.7)
	ISS > 15	14 (93.3)	0 (0)	1 (6.7)
	Vital signs level I criteria	31 (77.5)	6 (15.0)	3 (7.5)
	ISS > 15	6 (100)	0 (0)	0 (0)
	Vital signs level I or II criteria	76 (65.5)	21 (18.1)	19 (16.4)
	ISS > 15	9 (100)	0 (0)	0 (0)
	Injury type level I criteria	16 (53.3)	9 (30.0)	5 (6.7)
	ISS > 15	1 (50.0)	0 (0)	1 (50)
	Mechanism of injury level I or II criteria*	81 (72.3)	13 (11.6)	18 (16.1)
	ISS > 15	9 (100)	0 (0)	0 (0)
Brabant	**LPA level I criteria**	68 (38.0)	94 (52.5)	17 (9.5)
n = 976	ISS > 15	1 (100)	0 (0)	(0)
	LPA level I or II criteria	85 (38.1)	117 (52.5)	21 (9.4)
	ISS > 15	1 (100)	0 (0)	0 (0)
	Vital signs level I criteria	66 (38.2)	91 (52.6)	17 (9.8)
	ISS > 15	1 (100)	0 (0)	0 (0)
	Vital signs level I or II criteria	-	-	-
	ISS > 15			
	Injury type level I criteria	3 (50.0)	3 (50.0)	0 (0)
	ISS > 15	1 (50.0)	1 (50.0)	0 (0)
	Mechanism of injury level I or II criteria*	16 (39.0)	22 (53.7)	3 (7.3)
	ISS > 15	1 (100)	0 (0)	0 (0)

LPA: National Protocol of Ambulance Services, ISS: Injury Severity Score
Central-Netherlands region: multiple imputation was used for systolic blood pressure in 41.1%, respiratory rate in 6.2%, pediatric trauma score in 12.8% and Glasgow Coma Scale in 6.2% of pediatric trauma patients.
Brabant region: multiple imputation was used for systolic blood pressure in 58.3%, respiratory rate in 39.1, and Glasgow Coma Scale in 7.5% of the pediatric trauma patients. The pediatric trauma score missed in all patients.
* Mechanism of injury criteria indicate transport to either level I or II trauma centers, no separate criteria with a level I indication exist in the triage protocol.

Figure 2. Factors influencing the destination decision for adult and pediatric patients.



Factors influencing undertriage

The training of the EMS providers was reported as most contributory to prevent undertriage (Figure 3A). In *Central-Netherlands*, it was reported that EMS provider experience could frequently prevent cases of potential undertriage (Figure 3B), however, EMS provider judgment could also increase undertriage. The triage protocol itself was reported as occasionally capable to prevent undertriage. In *Brabant*, EMS provider experience was thought to be occasionally capable to prevent undertriage. The long distance to the level I trauma centres was mentioned as cause of undertriage in *Brabant*.

Table 4. Factors influencing the destination decision from most to least important

	1	2	3	4	5
Mechanism of injury					
Pediatric patients	12.6%	20.7%	55.2%	8.0%	3.4%
Adult patients	7.5%	21.5%	59.1%	9.7%	2.2%
Vital signs					
Pediatric patients	26.4%	32.2%	21.8%	19.5%	0%
Adult patients	24.7%	43.0%	25.8%	5.4%	1.1%
Injury characteristics					
Pediatric patients	55.2%	36.8%	12.6%	1.1%	5.7%
Adult patients	55.9%	29.0%	6.5%	3.2%	5.4%
Age					
Pediatric patients	5.7%	10.3%	10.3%	67.8%	5.7%
Adult patients	1.1%	5.4%	6.5%	76.3%	15.9%
Other*					
Pediatric patients	11.5%	0%	0%	3.4%	85.1%
Adult patients	15.9%	1.1%	2.2%	5.4%	80.6%

Pediatric patients: 87 responders, adult patients: 93 responders
* EMS providers reported the wish of the patients of family as other influencing factors for both adult and pediatric patients.

Factors influencing overtriage

Experience and training of the EMS provider, familiarity with the triage protocol and the protocol itself were all scored as factors that were reported as occasionally of influence to prevent overtriage (Figure 4A). The EMS providers suggest that the fear of undertriage in less experienced EMS providers results in an increased amount of overtriage (Figure 4B).

Consequences of undertriage and overtriage

In both regions, undertriage and overtriage were considered mostly as a learning opportunity. However, 30% of the responders reported that they felt a mistake was made in cases of undertriage. Cases of undertriage are sometimes discussed, whereas cases of overtriage are rarely discussed.

Need for adjustment of protocol

According to approximately 90% of the respondents, the current triage protocol does not lack criteria and 95% reported none of the criteria should be removed. Suggestions for adjustment of the triage protocol were: addition of criteria specific for elderly patients and removal of the Revised Trauma Score.

Figure 3. Factors of influence on undertriage and factors lowering undertriage.

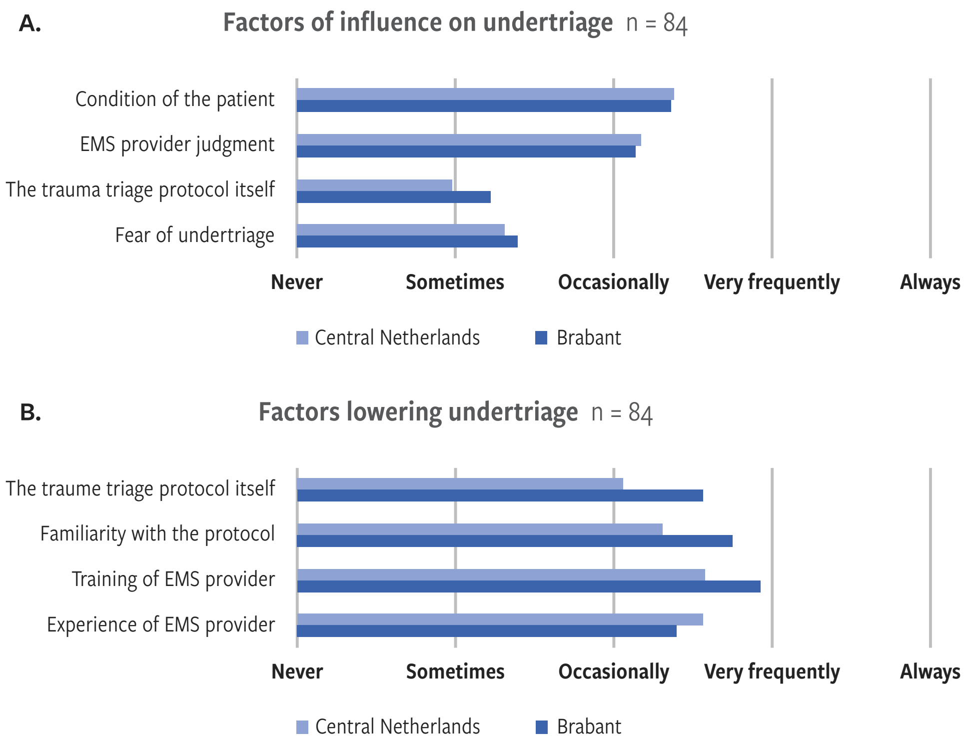
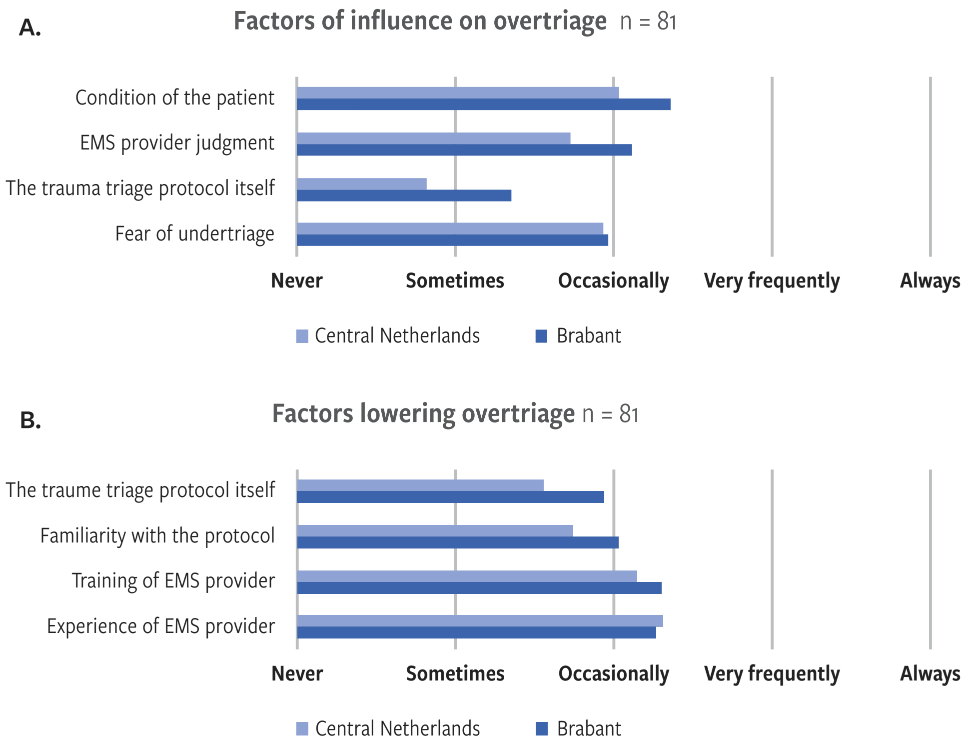


Figure 4. Factors of influence on overtriage and factors lowering overtriage.



Discussion

In this study, the compliance to the triage protocol was analysed and EMS providers were surveyed, to gain more insight in the role of EMS provider judgement in the decision-making process of prehospital trauma triage. The compliance rate for adult patients to the level I criteria of the triage protocol was 72% in *Central-Netherlands* and 42% in *Brabant*. The compliance rate to the level I triage criteria for the paediatric patients was 63% in *Central-Netherlands* and 38% in *Brabant*. The triage protocol only identified 36% of the severely injured adult patients (ISS > 15). Still, 68% and 63% of the severely injured adult patients were transported to a level I trauma centre in *Central-Netherlands* and *Brabant*, respectively.

Previously, compliance rates between 40% and 88% have been reported for different triage protocols in different countries and regions.[21-24] In this study, the compliance to the level I triage criteria for adults differed about 30% between the two regions. The EMS providers were surveyed to explore reasons for non-compliance. The questionnaire showed that geographical distance in Brabant can play an important role in the decision-making process. In this region, the nearest hospital is often a level II or III trauma centre; transport of severely injured patients to these trauma centres results in an increase in undertriage. Previous studies reported a lowered likelihood of transport to a higher-level trauma centre with increased geographical distance.[25-27] Unfortunately, in the current study, information on distance was not available, so the association between distance and the compliance rate could not objectively be analysed.

EMS providers can choose to deviate from the triage protocol for multiple reasons: EMS provider expertise, experience and familiarity with the triage protocol.[17;28-32] Compliance and triage quality might improve with feedback to EMS providers on decision making. In most countries, the EMS providers cannot obtain information from the hospital on specific patients when the EMS medical care is finished due to privacy regulations. Consequently, the EMS providers do not get the feedback they need to learn from possible mistakes. Additionally, involvement of EMS providers in the development of a triage protocol might increase compliance to the triage protocol.[17] When EMS providers believe the triage protocol functions well, they are more inclined to comply with the triage protocol.

Previous studies show that field triage and compliance varies among age groups.[22;33-35] Triage criteria are less sensitive for paediatric patients, however, the EMS are more easily inclined to transport a paediatric patient to a level I trauma centre, compared to adult patients.[24] The elderly patients, on the other hand, are notoriously undertriaged.[13;34;36;37;19] Injuries in elderly patients are increasing in frequency, are difficult to recognize -due to a difference in mechanism of injury and masked physiologic derangement- and carry a higher mortality rate compared to the young.[22] Additionally, previous studies report a lower compliance rate for elderly patients.[22;33;34] Reported reasons for the transport of elderly trauma patients to lower-level trauma centres according to EMS providers were: lack of training, unfamiliarity with the protocol and a feeling that it is not worth to spend expensive trauma centre recourses on elderly patients.[29;30;34] Unfortunately, our questionnaire did not focus on elderly trauma patients as a separate group.

According to the EMS providers, the injury type criteria of the triage protocol had the most influence on the decision between a level I or lower-level trauma centre. Among the categories of the triage protocol, the compliance rate was highest for injury type criteria and lowest for vital signs criteria, in both regions. The injury type category represents criteria with obvious injuries, easily recognized and clearly indicating transport to a higher-level trauma centre.[23;29;34] Vital signs, on the other hand, are less apparent: these differ between age groups and might improve during transport, altering the decision for destination facility. The EMS providers reported that the vital signs criteria did influence the destination decision, but to a lesser extent. Previous studies have shown a lower compliance rate to the vital signs criteria.[23;34;38] This could be because the majority of the trauma patients have normal or near normal vital signs.[39-41]

Most EMS providers reported that additional criteria or removal of criteria would not be necessary. However, the objective analysis of the compliance rates showed that EMS providers often do not adhere to the triage protocol, especially not to the level I criteria. In this study, only a minority of the severely injured patients were identified by the triage protocol. A recent literature review showed that on a worldwide scale, the different triage protocols are not capable to accurately discriminate between patients with and without severe injuries.[14] Thus, efforts to improve the triage protocol are necessary. The current triage protocols used worldwide are outdated and static flow-charts; prediction model with prehospital variables could predict the chance that the patient is severely injured. This prediction model could be integrated in a mobile app, so the EMS provider can calculate the risk of a severe injury quickly and more accurately on-scene. Triage tools integrated in a mobile app are increasingly being developed and used in the prehospital process.[42;43] The prediction model would include predictors of a severe injury such as age, vital signs, mechanism of injury and injured body regions. As elderly patients are more often undertriaged and all are predictors of severe injury.[13;33;34;36;37;44-49]

This study has several limitations. First, the response rate to the questionnaire was relatively low; 29%. Previous questionnaire studies showed similar response rates among EMS providers.[50-52] As shown by the range in years of experience among the responders, the results are expected to be representative for all EMS providers of both regions. Additionally, as with all questionnaire studies, an information bias could be introduced; the EMS providers could have given politically correct answers, feeling as if these were expected of them. The response to the questions of the questionnaire was anonymous to minimize this bias as much as possible. Second, for both regions, missing data was present in some variables of the triage protocol. For *Central-Netherlands*, all missing variables could be multiply imputed, limiting the effect on compliance rates. For *Brabant*, most could be multiply imputed, except for the paediatric trauma score, as it was missing in all paediatric patients. This variable could not be incorporated in the calculation of the compliance rate for paediatric patients. Also, the ISS was only available for the patients who were admitted or who deceased before admission, in the *Brabant* region. A previous study showed all the severely injured patients (ISS > 15) were admitted or deceased before admission.[19] Accordingly, for Brabant, it was assumed that all the patients discharged from the ED had an ISS < 15. Another limitation is that the compliance rate could be an underestimation because some patients might have been transported to the nearest trauma centre due to life-threatening haemorrhage or acute deterioration. Unfortunately, the data on this was not available. However, a previous study executed in the Netherlands reported only 0.1% of the patients were transported to the nearest trauma centre due to acute deterioration.[11] Additionally, the triage protocol was retrospectively applied based on vital signs and description of the injury and mechanism of injury. The investigators were blinded for destination hospital and the ISS. Lastly, no data was available to assess the influence of the Helicopter Emergency Medical Services (HEMS) on the choice of hospital.

Quality of prehospital trauma triage is dependent on the accuracy of and compliance to the protocol. The triage protocol functioned poorly; even flipping a coin would provide a better chance of correctly identifying a severely injured patient. Therefore, improvement of the triage protocol should be of first concern. With an accurate protocol, that the EMS providers can trust, the compliance rate may increase. Future studies should additionally focus on quantifying EMS provider judgment to give more insight in reasons for deviating from the triage protocol. Including EMS provider judgment might improve the quality of the triage protocol and compliance rates even more. This might be the solution to get the right patient to the right hospital and improve chances of survival and avert life-long disabilities.

Conclusion

The compliance rate to the level I criteria varied between 38%-72% for paediatric and adult patient in the two regions. Despite the fact that only a minority of the severely injured patients were identified by the triage protocol, a large part was transported to a level I trauma centre. Still, the undertriage rate was up to 27%, so improvement is necessary. The triage protocol and triage quality desperately need improvement. A newly developed triage protocol, including EMS provider judgment, serves as an important first step on the read ahead to optimize prehospital trauma triage.

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Appendix 1. Survey

General information

1. What is your gender?
   - ☐ Male
   - ☐ Female
2. What is your age?
3. How many years of experience do you have as an EMS provider?
4. Are you familiar with the prehospital trauma triage protocol?
   - ☐ Yes
   - ☐ No
5. What is the level of the following hospitals?

Factors influencing the decision of level of trauma center

6. Does the way you, as a professional, are received in a hospital influence your decision?
   - ☐ No
   - ☐ Yes, sometimes
   - ☐ Yes, often
   - ☐ Yes, always
7. Does the way your patient is received in a hospital influence your decision?
   - ☐ No
   - ☐ Yes, sometimes
   - ☐ Yes, often
   - ☐ Yes, always
8. Room for comments or remarks on question 6 or 7
9. Which of the following factors influence the decision where to transport an adult patient the most? Range from most to least important.
   - ☐ Mechanism of injury (for example: fall from height, car accident, or collision of pedestrian by a car)
   - ☐ Vital signs (for example: blood pressure, GCS, or respiratory rate)
   - ☐ Injury criteria (for example: flail chest, amputation, or multiple fractures)
   - ☐ (Estimated biological) age of the patient
   - ☐ Other (fill out reason in free text section)

Factors influencing the decision for adult patients

10. Do the following factors influence the decision where to transport an adult patient?

	No, never	**Yes, sometimes**	**Yes, occasionally**	**Yes, very frequently**	**Yes, always**
Intuition	○	○	○	○	○
Experience	○	○	○	○	○
Expected drive time	○	○	○	○	○
Request of the patient of family	○	○	○	○	○

11. Are there other factors that influence your decision on where to transport an adult patient?
    - ☐ No
    - ☐ Yes (please explain in free text section)
12. What is the moment when you make the decision on where to transport an adult patient?
    - ☐ Immediately after the notification of the dispatch center
    - ☐ Immediately upon arrival on-scene
    - ☐ After the primary survey of the patient
    - ☐ After the secondary survey of the patient
    - ☐ When the patient is in the ambulance
    - ☐ Other (please explain in free text section)

Factors influencing the decision for pediatric patients

13. Which of the following factors influence the decision where to transport a pediatric patient the most? Range from most to least important.
    - ☐ Mechanism of injury (for example: fall from height, car accident, or collision of pedestrian by a car)
    - ☐ Vital signs (for example: blood pressure, GCS, or respiratory rate)
    - ☐ Injury criteria (for example: flail chest, amputation, or multiple fractures)
    - ☐ (Estimated biological) age of the patient
    - ☐ Other (fill out reason in free text section)
14. Do the following factors influence the decision where to transport a pediatric patient?

	No, never	Yes, sometimes	Yes, occasionally	Yes, very frequently	Yes, always
Intuition	○	○	○	○	○
Experience	○	○	○	○	○
Expected drive time	○	○	○	○	○
Request of the patient of family	○	○	○	○	○

15. Are there other factors that influence your decision on where to transport a pediatric patient?
    - ☐ No
    - ☐ Yes (please explain in free text section)
16. What is the moment when you make the decision on where to transport a pediatric patient?
    - ☐ Immediately after the notification of the dispatch center
    - ☐ Immediately upon arrival on-scene
    - ☐ After the primary survey of the patient
    - ☐ After the secondary survey of the patient
    - ☐ When the patient is in the ambulance
    - ☐ Other (please explain in free text section)

Factors of influence on undertriage

17. In what amount do the following factors prevent undertriage?

	Not important	Slightly important	Moderately important	Important	Very important
Experience	○	○	○	○	○
Training	○	○	○	○	○
Familiarity with the triage protocol	○	○	○	○	○
The triage protocol itself	○	○	○	○	○

18. In the Netherlands, part of the severely injured patients, that belong in a level I trauma center, are transported to a level 2/3 trauma center. What are factors of influence on undertriage, according to you?

	No, never	Yes, sometimes	Yes, occasionally	Yes, very frequently	Yes, always
Fear to transport a patient without severe injuries to a level I trauma center	○	○	○	○	○
The triage protocol itself	○	○	○	○	○
My own judgment as EMS provider	○	○	○	○	○
Condition of the patient	○	○	○	○	○
Other (please explain)	○	○	○	○	○

Factors of influence on overtriage

19. In what amount do the following factors prevent overtriage?

	Not important	Slightly important	Moderately important	Important	Very important
Experience	○	○	○	○	○
Training	○	○	○	○	○
Familiarity with the triage protocol	○	○	○	○	○
The triage protocol itself	○	○	○	○	○

20. What are factors of influence on overtriage, according to you?

	No, never	Yes, sometimes	Yes, occasionally	Yes, very frequently	Yes, always
Fear to transport a patient without severe injuries to a level I trauma center	○	○	○	○	○
The triage protocol itself	○	○	○	○	○
My own judgment as EMS provider	○	○	○	○	○
Condition of the patient	○	○	○	○	○
Other (please explain)	○	○	○	○	○

Consequences of undertriage or overtriage

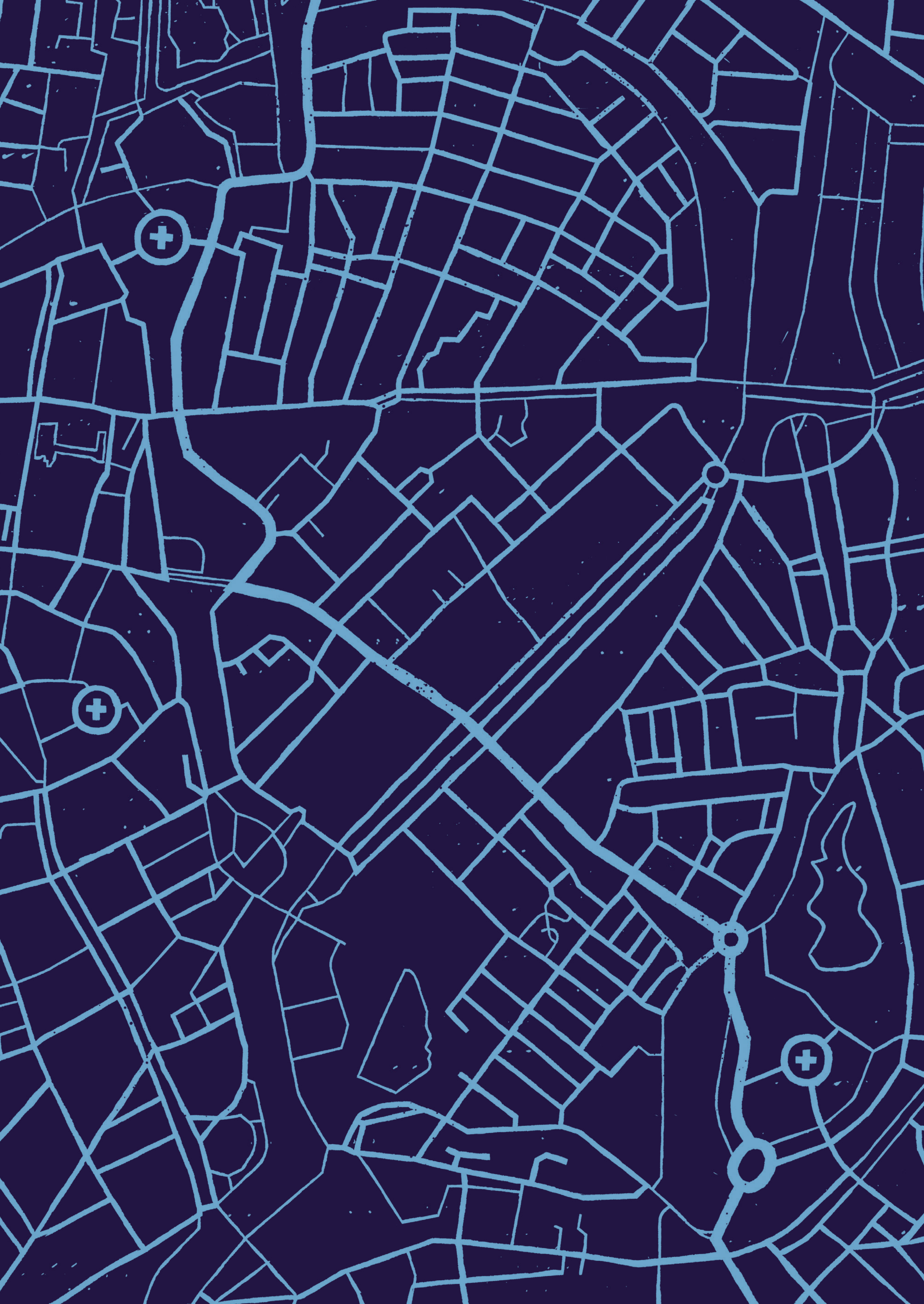
21. Do you receive feedback when you have transported a patient to the right hospital?
    - ☐ No
    - ☐ Yes, sometimes
    - ☐ Yes, often
    - ☐ Yes, always
22. Are there personal consequences of the transport of a severely injured patient to a level 2/3 hospital (undertriage)?
    - ☐ I do not know
    - ☐ No
    - ☐ Yes (please fill out the consequence in the free text)
23. How do you experience (or would you experience) when a severely injured patient, who should have been transported to a level 1 trauma center, was transported to a level 2/3 trauma center?
    - ☐ It does not make a difference to me, I did my best
    - ☐ This is a good learning opportunity for the next time
    - ☐ It feels like I have done something wrong
    - ☐ This makes me insecure for the next, comparable, situations
24. Are there personal consequences of the transport of a mildly injured patient to a level 1 hospital (overtriage)?
    - ☐ I do not know
    - ☐ No
    - ☐ Yes (please fill out the consequence in the free text)
25. How do you experience (or would you experience) when a mildly injured patient, who should have been transported to a level 2/3 trauma center, was transported to a level 1 trauma center?
    - ☐ It does not make a difference to me, I did my best
    - ☐ This is a good learning opportunity for the next time
    - ☐ It feels like I have done something wrong
    - ☐ This makes me insecure for the next, comparable, situations

Alterations for a new protocol for adult patients

26. Are there criteria missing in the current prehospital trauma triage protocol that should be added to a future protocol for adults?
    - ☐ No
    - ☐ Yes (please explain in free text section)
27. Are there criteria in the current prehospital trauma triage protocol that should be removed to a future protocol for adults?
    - ☐ No
    - ☐ Yes (please explain in free text section)

Alterations for a new protocol for adult patients

28. Are there criteria missing in the current prehospital trauma triage protocol that should be added to a future protocol for pediatric patients?
    - ☐ No
    - ☐ Yes (please explain in free text section)
29. Are there criteria in the current prehospital trauma triage protocol that should be removed to a future protocol for adults?
    - ☐ No
    - ☐ Yes (please explain in free text section)
30. Room for comments in general and/or remarks



Development and validation of a prediction model as basis for prehospital triage

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Submitted

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Abstract

Importance

Prehospital trauma triage protocols are used worldwide to get the right patient to the right hospital in order to improve chance of survival and avert life-long disabilities. The American College of Surgeons Committee on Trauma set target levels for undertriage of < 5%. None of the existing triage protocols has been able to achieve this in isolation.

Objective

The aim of the present study is to develop and validate a new prehospital triage protocol that improves current triage rates.

Design, Setting, and Participants

In the multicenter cohort study, all trauma patients aged 16 and over, transported to a trauma center in two different regions of the Netherlands were evaluated.

Main Outcomes and Measures

A new prediction model was developed in one region, based on prehospital predictors of severe injury. Severe injury was defined as an Injury Severity Score > 15. A full model strategy with penalized maximum likelihood estimation was used to construct a prediction model with eight predictors that were chosen based on clinical reasoning. Accuracy of the developed prediction model was assessed in terms of discrimination and calibration. The model was externally validated in a second region.

Results

Eight highly significant predictors were selected for the prediction model. The prediction model showed a c-statistic of 0.823 (95%-CI 0.813-0.832) and good calibration. The cut-off point with a minimum specificity of 50.0%, lead to a sensitivity of 88.8%. External validation showed a c-statistic of 0.831 (95%-CI 0.814 – 0.848) and adequate calibration.

Conclusion and Relevance

The new prehospital trauma triage prediction model is able to lower undertriage to approximately 10% with an overtriage of 50%. The next step should be to implement this prediction model with the use of a mobile app for emergency medical services providers.

Introduction

In first world countries, systems of trauma care substantially reduce mortality associated with injury.[1-3] Recent studies focused on optimizing such trauma systems balancing timely access to expert care, ability of practitioners and teams to attain and sustain the necessary expertise, and the cost effectiveness of the overall trauma system.[2;3] Fundamental to the trauma system is prehospital trauma triage, the goal of which is to identify "at risk" patients and provide early and resuscitative care while transporting the patient to the highest appropriate level of care.[4] Identification of severely injured patients is challenging. Only 0.5% of those injured are severely injured.[4] Other challenges include: assessment of the incident scene and the patient's physiological state and risk of deterioration, identification of obvious injuries, and consideration of adjuvant factors such as age.

Emergency medical services (EMS) providers must differentiate between patients on-scene, often in adverse situations, without advanced diagnostic tools, completed by medical personnel of various expertise acting on incomplete data. The importance of prehospital trauma triage cannot be understated; a structured and reliable process is crucial. Worldwide, protocols are used to help identify severely injured patients. Yet, none of the existing protocols can achieve the recommended triage rates.[5-7] All are simplistic and static tools, whereas patients are dynamic and more advanced methods are available to use on-scene, such as a prediction model in a mobile app.[8;9]

Undertriage occurs when severely injured patients are not transported to a higher-level trauma center and results in delayed case and increased mortality and morbidity.[1;2] Overtriage occurs when patients without severe injuries are taken to a higher-level trauma center, often incurring preventable cost and resource consumption.[3;10] In the Netherlands, level I trauma centers are considered higher-level trauma centers and level II and III are considered lower-level trauma centers. The American College of Surgeons Committee on Trauma (ACS-COT) set target levels of an undertriage below 5% and an overtriage up to 25-35%.[11] The National Health Institute of the Netherlands recommends an undertriage rate below 10%. A target for the overtriage rate was not set, the overtriage rate, however, should be dependent on the regional circumstances, this could be up to 50%.

In the Netherlands, a protocol based on the Field Triage Decision Scheme, is used nationwide (Appendix 1).[12] The average undertriage was 33% in 2015.[13] A recent study by our research group showed an undertriage of 22% and an overtriage of 31% in one inclusive trauma system.[14]

Currently, existing protocols achieve an undertriage of 22%-44%, with an overtriage of 11%-22% on a general trauma population.[6;15;16] The aim of the present study was therefore to develop and validate a new prehospital trauma triage prediction model attempting to lower the undertriage to approximately 10%, with a maximum overtriage of 50%.

Methods

Study design and setting

In the Netherlands, each ambulance service serves a region. In this prospective, multicenter cohort study, all adult trauma patients and all trauma centers in two different regions were included. Data from the Central-Netherlands region was used to develop a diagnostic prediction model which was externally validated using the data of the Brabant region.

Central-Netherlands has one level I trauma center, the University Medical Center Utrecht, and seven level II or III trauma centers. The region covers 535 square miles and has 1.2 million residents. Brabant has one level I trauma center, Elisabeth-TweeSteden Hospital Tilburg, and 10 level II or III trauma centers. The region covers 1,343 square miles and has 1.7 million residents. In both regions the Dutch National Protocol of Ambulance Services is used (Appendix 1).[12]

Patients transported across the borders of these regions were excluded, because data were unavailable. This study was judged by the Medical Ethical Committee of University Medical Center Utrecht as not subject to the Medical Research Involving Human Subjects Act.

Patients

All trauma patients aged 16 and over, determined as highest priority (with flashing lights and siren) by the dispatch center, transported to a trauma center in one of the two regions, were evaluated. In Central-Netherlands, patients were included between January 2012 and June 2014.[14] In Brabant, patients were included between January 2015 and December 2015.

Outcomes and definitions

Independent predictors of severe injury were identified to create a prediction model consisting of a limited number of variables (see below). A severely injured patient was defined as a patient with an Injury Severity Score (ISS) > 15.

Undertriage was defined as the proportion of severely injured patients transported to a level II or III trauma center. Overtriage was defined as the proportion of patients without severe injuries transported to a level I trauma center. The protocol allows for these patients to be transported to a level I trauma center if this happens to be the nearest hospital.

Data sources

Prehospital reports from EMS providers were prospectively collected and included: patient demographics, vital signs, description of the trauma mechanism, scene physical examination data on site (including suspected injured body region), and receiving hospital. The suspected injured body region by EMS providers was divided into six regions: head/neck, face, thorax, abdomen, extremities, or skin and others. These regions were chosen based on the categorization of the Abbreviated Injury Scale (AIS) regions that make up the ISS.

The Dutch National Trauma Database registered injuries for all patients admitted to a hospital. Central-Netherlands patient data were also extracted from the electronic patient documentation for patients discharged directly from the emergency department (ED). The injuries were recorded after discharge or 30 days after admission and coded by trained data managers in both regions. Before 2015, all injuries were coded using the AIS 1990, Update 1998 (AIS98) and from 2015 and on the AIS 2005, update 2008 (AIS08) was used. Therefore, the injuries were coded according to the AIS98 for the Central-Netherlands database and according to the AIS08 for the Brabant database. The ISS was calculated based on AIS scores, to determine injury severity.

Missing data

Missing data were analyzed and considered to be missing at random. Multiple imputation by chained equations was used for both regions separately to account for missing prehospital variables rather than deleting patients who had most data available.[17] Missing values were predicted based on all other predictors, as well as ISS. For both regions respiratory rate, systolic blood pressure, oxygen saturation, and Glasgow Coma Scale were imputed. Pulse was imputed for Central-Netherlands only, as this variable was missing in the Brabant data. For Brabant, ISS was only available for admitted patients. An ISS < 15 was assumed for patients discharged from the ED, as a previous study demonstrated that all severely injured patients (ISS > 15) were either admitted or died in the ED.[14]

Statistical analysis

Frequencies with percentages were used to describe nominal and ordinal variables, mean and standard deviation were used to describe continuous variables. Bivariable binary logistic regression was used to explore potential predictors of a severely injured patient (ISS > 15). Analyzes were performed on five imputed datasets independently and pooled using Rubin's rules, if applicable.[18]

To ensure practical applicability, the maximum number of predictors was limited to eight. A full model strategy with clinically relevant variables was used to develop the prediction model. To improve the accuracy for future patients and other regions, penalized maximum likelihood estimation was used.[19] Penalized maximum likelihood estimation is a rigorous estimation method that potentially results in better generalizability, model reduction, and differential shrinkage of coefficients.[20] The functional forms of all continuous predictors were defined prior to modeling. Restricted cubic splines were used to model non-linear predictors.

The performance of the final prediction model was expressed in terms of discrimination and calibration. Discriminative value was quantified by the c-statistic. The receiver operating characteristic (ROC) curve was plotted and a predefined value for specificity -an overtriage of 50%- was used to determine a cut-off point. Calibration was graphically assessed using a calibration plot.

The final model was externally validated with the Brabant data. Due to heterogeneity between trauma regions (e.g. prevalence of severe injury), the model needed to be recalibrated by updating the intercept for the Brabant region.[21;22] Both calibration and discrimination of the prediction model were assessed in the validation process. Bootstrapped 95% confidence intervals (95%-CI), based on percentiles and 1000 resamples, were calculated for c-statistics and accuracy metrics. All statistical analyses were performed using R v3.2.4.[23]

Results

Central-Netherlands Patients - Design Data Set

A total of 4,950 adult trauma patients were included for the Central-Netherlands region. To account for missing data, multiple imputation was used for pulse in 6.8%, respiratory rate in 6.5%, systolic blood pressure in 7.0%, oxygen saturation in 13.4%, and Glasgow Coma Scale in 4.6% of the patients. Mean patient age was 47 years ± 21.3 years, 2,887 (58%) were male, and

435 (8.8%) had an ISS > 15 (Table 1). In this cohort, the undertriage was 21.6% and overtriage 30.6%.

Brabant Patients – Validation Data Set

In the Brabant region, a total of 6,859 adult trauma patients were included. To account for missing data, multiple imputation was used for respiratory rate in 28.8%, systolic blood pressure in 16.7%, oxygen saturation in 20.9%, and Glasgow Coma Scale in 4.2%. Mean patient age was 51 years ± 22.1 years, 3,583 (52.2%) were male, and 165 (2.4%) had an ISS > 15 (Table 1). The ISS was only available for the admitted patients. In this cohort, the undertriage was 27.3% and overtriage 26.3%.

Table 1. Baseline characteristics of the Central Netherlands region and the Brabant region

Variables	Central Netherlands region n = 4,950	Brabant region n = 6,859
Demographics	**Mean (SD)**	**Mean (SD)**
Age (years)	47 (21.3)	51 (22.1)
	Number (%)	**Number (%)**
Male gender	2887 (58.3)	3583 (52.2)
Pregnancy	32 (0.6)	25 (0.4)
Use of oral anticoagulants	131 (2.6)	234 (3.4)
Alcohol use	531 (10.7)	746 (10.9)
Drug use	43 (0.9)	39 (0.6)
Physiologic characteristics	**Mean (SD)**	**Mean (SD)**
Systolic blood pressure	139 (23.6)	140 (24.3)
Respiratory rate	16 (4.0)	16 (5.1)
Oxygen saturation	96 (4.3)	97 (3.1)
Glasgow Coma Scale	14 (1.9)	15 (1.8)
Revised Trauma Score	12 (0.8)	-
	Number (%)	**Number (%)**
ABC unstable[a]	117 (2.7)	129 (1.9)
Mechanism of injury	**Number (%)**	**Number (%)**
Mechanism criteria[b]	819 (16.5)	475 (6.9)
Fall 2-5 m Fall > 5 m or > 3x body length	314 (6.3) 77 (1.6)	197 (2.9) 24 (0.3)
Fall from stairs, 1-10 steps Fall from stairs, > 10 steps	388 (7.8) 86 (1.7)	288 (4.2) 87 (1.3)

▶ **Table 1** - Continued from previous page

Vehicle rollover	96 (1.9)	129 (1.9)
Injury characteristics	**Number (%)**	**Number (%)**
Penetrating injury to head, thorax, or abdomen	90 (1.8)	30 (0.4)
Expected (unstable) pelvic fracture	26 (0.5)	11 (0.2)
Neurologic deficit (> 1 extremity)	75 (1.5)	60 (0.9)
Symptoms of cerebral contusion or concussion	348 (7.0)	516 (7.5)
Agitation	172 (3.5)	66 (1.0)
Expected injury in AIS region head/neck or trauma to head	2635 (53.2)	2393 (34.9)
Expected injury in AIS region face	955 (19.3)	977 (14.2)
Expected injury in AIS region thorax	719 (14.5)	329 (4.8)
Expected injury in AIS region abdomen	332 (6.7)	74 (1.1)
Expected injury in AIS region extremities	2013 (40.7)	1501 (21.9)
Expected injury in AIS region skin and others	85 (1.7)	85 (1.2)
Expected injury in two or more AIS regions	1230 (24.8)	309 (4.5)
Burning wound with or without inhalation trauma	77 (1.7)	80 (1.2)
Inhalation trauma	29 (0.6)	38 (0.6)
Clinical characteristics	**Mean (SD)**	**Mean (SD)**
ISS	5 (7.1)	-
	Number (%)	**Number (%)**
ISS > 16	435 (8.8)	165 (2.4)
Destination		
Level I trauma center	1724 (34.8)	1882 (27.4)
Level II trauma center	1326 (26.8)	4208 (61.4)
Level III trauma center	1900 (38.4)	769 (11.2)
Admission to hospital	2047 (41.4)	1842 (26.9)
In-hospital death	61 (1.2)	57 (0.8)

SD: standard deviation, ISS: Injury Severity Score, AIS: Abbreviated Injury Score
Central-Netherlands region: respiratory rate missed in 6.5%, systolic blood pressure in 7.0%, oxygen saturation in 13.4%, and Glasgow Coma Scale in 4.6%.
Brabant region: gender missed in 12.5%, respiratory rate in 28.8%, systolic blood pressure in 16.7%, oxygen saturation in 20.9%, Glasgow Coma Scale in 4.2%, and ISS in 73.1% (the patients discharged from the emergency department).
[a] ABC unstable is defined as systolic blood pressure < 90 mmHg and/or respiratory frequency > 29 per minute.
[b] Mechanism criteria are: fall > 2 meters, motor vehicle accident > 32 km/h, or any type of entrapment.

Model development and specification

To develop the prediction model, 43 potential prehospital predictors of the Central-Netherlands database were explored using bivariable analysis (Table 2). Eight predictors were chosen for the final model, based on clinical reasoning. The optimal cut-off point with a minimum specificity of 50.0% (95%-CI: 49.3%-50.7%), lead to a sensitivity of 88.8% (95%-CI: 87.5%-90.0%).

Table 2. Bivariable logistic regression analysis on the Central Netherlands region (n=4,950)

Variables	Beta-coefficient	Standard deviation	P-value	Odds ratio	95% Confidence interval
Patient characteristics					
Age (years)	0.010	0.002	**< 0.001**	1.010	0.005 – 0.014
Female gender	-0.447	0.107	**< 0.001**	0.640	-0.656 – -0.237
Alcohol use	0.205	0.152	**0.177**	1.228	-0.093 – 0.504
Use of oral anticoagulants	0.047	0.307	0.879	1.048	-0.555 – 0.649
Physiologic characteristics					
Systolic blood pressure	0.005	0.002	**0.021**	1.005	1.001 – 1.010
Systolic blood pressure < 90 mmHg	0.818	0.320	**0.011**	2.265	1.209 – 4.244
Pulse	0.009	0.003	**0.001**	1.009	1.004 – 1.014
Respiratory rate	0.042	0.011	**0.001**	1.043	0.020 – 0.066
Respiratory rate < 10 or > 29 /min	1.477	0.238	**< 0.001**	4.381	2.749 – 6.981
Oxygen saturation	-0.096	0.009	**< 0.001**	0.908	0.893 – 0.924
Glasgow Coma Scale	-0.357	0.019	**< 0.001**	0.700	0.674 – 0.727
Revised Trauma Score	-0.846	0.059	**< 0.001**	0.429	0.383 – 0.481
ABC unstablea	2.209	0.300	**< 0.001**	9.110	1.620 – 2.798
Mechanism of injury					
Mechanism criteriab	1.272	0.108	**< 0.001**	3.566	1.061 – 1.482
Fall 2-5 m	0.628	0.168	**0.002**	1.874	0.298 – 0.958
Fall > 5 m or > 3x body length	1.777	0.244	**< 0.001**	5.910	1.298 – 2.256
Car accident > 65 km/h	-0.243	0.200	**0.223**	0.784	-0.634 – -0.148
Motorcycle accident > 32 km/h	1.011	0.150	**< 0.001**	2.749	0.716 – 1.306
Vehicle deformity > 50 cm	0.622	0.488	**0.202**	1.863	-0.335 – 1.579
Vehicle intrusion passenger compartment > 30 cm	1.997	0.495	**< 0.001**	7.368	1.026 – 2.968
Vehicle rollover	0.073	0.354	0.837	1.075	-0.621 – 0.766
Car vs pedestrian impact > 10 km/h	0.599	0.294	**0.042**	1.820	0.023 – 1.175
Car vs bike impact > 10 km/h	0.382	0.185	**0.040**	1.465	0.018 – 0.745

▶ **Table 2** - Continued from previous page

No helmet on motorcycle or horse	1.340	0.243	**< 0.001**	3.819	0.864 – 1.816
No seatbelt in vehicle in high energy trauma	-0.247	0.521	0.636	0.781	-1.268 – 0.775
Deployed airbag in car accident	-0.559	0.314	**0.075**	0572	-1.175 – 0.056
Entrapment in vehicle	1.328	0.272	**< 0.001**	3.773	0.795 – 1.860
Entrapment elsewhere	1.292	0.370	**< 0.001**	3.640	0.566 – 2.018
Trauma to the head	1.206	0.109	**< 0.001**	3.340	0.993 – 1.419
Suicide attempt	0.890	0.324	**0.006**	2.435	0.254 – 1.526
Injury characteristics					
Penetrating injury to head, thorax, or abdomen	1.248	0.251	**< 0.001**	3.484	0.757 – 1.739
Expected (unstable) pelvic fracture	2.683	0.400	**< 0.001**	14.623	1.898 – 3.467
Neurologic deficit (> 1 extremity)	0.590	0.330	**0.074**	1.804	-0.057 – 1.238
Pupil difference	2.569	0.300	**< 0.001**	13.049	1.980 – 3.158
Symptoms of cerebral contusion or concussion	0.897	0.150	**< 0.001**	2.451	1.826 – 3.289
Agitation	1.782	0.170	**< 0.001**	5.939	1.448 – 2.115
Vomiting	0.920	0.274	**0.001**	2.510	0.382 – 1.458
Signs and/or symptoms of head or neck injury	1.157	0.117	**< 0.001**	3.182	0.927 – 1.388
Expected injury in AIS region face	0.412	0.116	**< 0.001**	1.510	0.185 – 0.640
Expected injury in AIS region thorax	0.445	0.127	**< 0.001**	1.561	0.197 – 0.694
Expected injury in AIS region abdomen	0.252	0.184	0.172	1.286	-0.109 – 0.613
Expected injury in AIS region extremities	-0.190	0.104	**0.067**	0.827	-0.394 – 0.014
Expected injury in 2 or more AIS regions	1.110	0.102	**< 0.001**	3.035	0.909 – 1.311
Expected injury to spine	-0.344	0.131	**0.009**	0.709	-0.601 – -0.087

AIS: Abbreviated Injury Scale
Bold indicates significant predictors of ISS > 16 with a p-value < 0.25
Multiple imputation was used to account for the missing prehospital variables. Respiratory rate missed in 6.5%, systolic blood pressure in 7.0%, oxygen saturation in 13.4%, and Glasgow Coma Scale in 4.6%.
[a] ABC unstable is defined as systolic blood pressure < 90 mmHg and/or respiratory frequency > 29 per minute.
[b] Mechanism criteria are: fall > 2 meters, motor vehicle accident > 32 km/h, or any type of entrapment.

Model performance

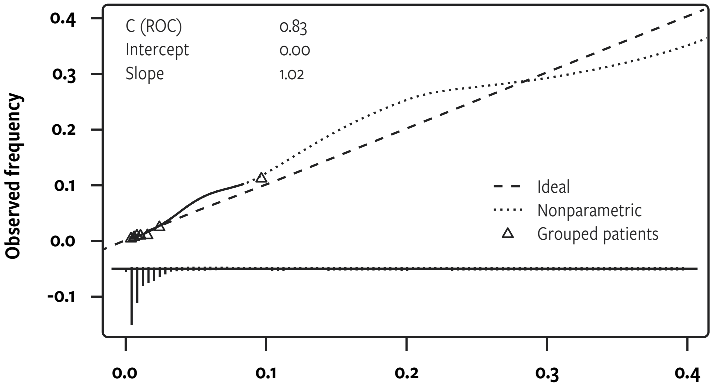
This prediction model resulted in an undertriage of 11.2% (delta difference 10.4%) and an overtriage of 50.0% (delta difference 19.4%) for Central-Netherlands. Robust estimation using penalized maximum likelihood showed that all variables in the model were significant independent predictors (Table 3). The model had a good discrimination with a c-statistic of 0.823 (95%-CI 0.813-0.832). The recalibration method led to an intercept of 0.894 for Brabant. External validation using the Brabant region database showed that the model with the new intercept was well calibrated (Figure 1) and had a good discrimination with a c-statistic of 0.831 (95%-CI: 0.814-0.848).

Table 3. Multivariate analysis of the predictors for ISS > 15 in region Central Netherlands (n = 4,950)

Variables	Beta-coefficient	Standard deviation	P-value	Odds ratio
Patient characteristics				
Age (years), Spline basis function 1	0.011	0.004	0.001	3.24
Age (years), Spline basis function 2	0.001	0.005	0.858	0.18
Physiologic characteristics				
Systolic blood pressure, spline basis function 1	-0.011	0.002	< 0.001	-4.97
Systolic blood pressure, Spline basis function 2	0.020	0.003	< 0.001	7.14
Glasgow Coma Scale	-0.337	0.001	< 0.001	-36.69
Mechanism of injury				
Mechanism criteria[a]	1.314	0.056	< 0.001	23.40
Injury characteristics				
Penetrating injury to head, thorax, or abdomen	1.196	0.131	< 0.001	9.13
Signs and/or symptoms of head or neck injury	0.571	0.056	< 0.001	10.23
Expected injury in AIS region thorax	0.405	0.071	< 0.001	5.72
Expected injury in 2 or more AIS regions	0.713	0.129	< 0.001	12.79
Intercept[b]	2.069	0.315	< 0.001	6.57

AIS: Abbreviated Injury Scale
Multiple imputation was used to account for the missing prehospital variables. Oxygen saturation missed in 13.4% and Glasgow Coma Scale in 4.6%.
[a] Mechanism criteria: fall > 2 meters, motorcycle accident > 32 km/h, or entrapment of a person of body party
[b] Intercept is 0.894 for the Brabant region.

Figure 1. Calibration plot of external validation (Brabant region)



Discussion

In this prospective, multicenter cohort study, we present a ready-to-use prehospital trauma triage prediction model that predicts the presence of severe injury in trauma patients on-scene. The model performed well in both the derivation set and in external validation. To our knowledge, this is the first externally validated protocol showing acceptable triage rates, with potentially an undertriage of 11.2% and an overtriage of 50.0%, depending on the chosen threshold.

Worldwide, triage protocols are based on a simple flowchart including vital signs, injury type, and mechanism of injury criteria.[6;24-27] These triage protocols are simplistic and static: transport to a higher-level trauma center should be considered if just one criterion is present. Whereas, in reality, some factors have a bigger impact on injury severity than others, and it is the combination of factors that indicates the need for higher-level trauma care. In addition, current protocols often use cut-off points for continuous variables, whereas the prediction model uses coefficients for each predictor to represent each variable's distinct impact on injury severity to increase predictive ability.

The prediction model was based on three key elements: (1) inclusion of all adult trauma patients transported by an ambulance to (2) all trauma centers of an entire geographic region, with (3) prehospital parameters measured on-scene by EMS providers. Previous studies have attempted to develop protocols but have not included these three key elements. For example, Dihn and colleagues[26] developed a triage protocol based on patients taken to a higher-level trauma center only, thereby excluding the undertriaged patients. Others included admitted patients only[28;29], thus excluding patients discharged from the ED, or the potentially overtriaged patients. These models would not be reliable in a general trauma population, as they fail to include the patient populations where improvement is of utmost importance: the undertriaged and overtriaged patients.

Eight predictors were included in the prediction model based on clinical reasoning in order to achieve the best accuracy, while keeping it user-friendly without too many factors. Age was included, because previous studies showed a higher undertriage in elderly patients.[6;30-32] Two continuous predictors of the condition of a patient are systolic blood pressure and GCS.[33-35] Penetrating injury is an obvious predictors of potential severe trauma. The brain and thorax are two of the most commonly injured body regions, both associated with a high prevalence of severe injury.[36-38] Also, multiregional injury was previously found as a strong predictor of severe injury.[26] Therefore, these eight predictors were included in the current prediction model. The prediction model resulted in a undertriage of 11.2% and an overtriage of 50.0% in Central-Netherlands.

After penalized estimation, the updated diagnostic prediction model was externally validated with the Brabant region. The prediction model requires an update primarily due to the difference in prevalence of severely injured patients, resulting in a difference in baseline risk.[39] To account for this, the constant value (intercept) in the equation was altered. The constant value can be altered for other regions before applying the prediction model based on prehospital and hospital data of the specific region. External validation –with the altered intercept– showed good discrimination and calibration, indicating that the prediction model would likely be accurate in a region that is heterogeneous with respect to population, prevalence of severe injury, and mechanism of injury. Additionally, the injuries were coded differently in both regions: AIS98 was used in Central-Netherlands and AIS08 in Brabant. When using the AIS08, the overall ISS is lower compared to injuries scored with AIS98.[40] External validation using the AIS08 showed that the prediction model functions well using the most recent AIS.

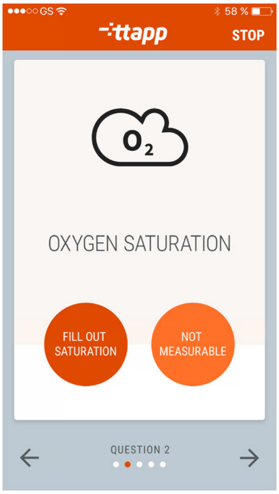
The prediction model did not achieve the goal of an undertriage below 5%, as targeted by the ACS-COT.[41] However, it is a significant improvement compared to the existing protocols.[5;6;15;42] It is unclear whether further improvement of undertriage is achievable by solely improving the protocol. Previous studies have shown that addition of EMS provider judgment can be useful in the identification of severely injured patients.[43-46] In this study, EMS provider judgment could not be quantified, as it was not recorded. Including EMS provider judgment may improve undertriage even more, as well as increase adherence to the protocol. Other factors could have influenced transport decisions as well, such as geographical distance to a higher-level trauma center. Even though distances are relatively small in the Netherlands compared to other countries, distance could have influenced the destination decision, especially in Brabant, as distances are larger in this region. Unfortunately, the effect of distance on the triage quality could not be evaluated in this study, additionally, it remains unclear from what distance it is better to deviate to the nearest hospital.[47]

In practice, it is not feasible to calculate the risk of severe injury based on an equation that must be memorized and applied on-scene. This could be solved by implementing the prediction model in a mobile app; such triage tools are increasingly being developed and used in the prehospital process.[8;9] This mobile app includes every variable, calculates the chance of severe injury, and gives advice on where to transport the patient is much more practical for EMS providers compared to an equation. With a mobile device available on every ambulance, the EMS providers can calculate the risk of severe injury using the prediction model in the app to decide quickly and more accurately where to transport the patient to. EMS provider judgment could be included in the app. A mobile app with the described prediction model is currently being implemented in different regions in the Netherlands. The implementation aims at reducing undertriage specifically.

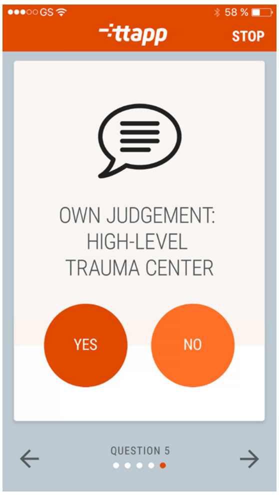
This study has several limitations. In the final prediction model, missing data were present in two variables: systolic blood pressure and GCS. The data was considered to be missing at random and multiple imputation was used to minimize selection bias. Second, for Brabant, the ISS was only available for the patients who were admitted or who died in the ED. In Central-Netherlands –where the ISS was available for all patients– all severely injured patients (ISS > 15) were admitted or died in the ED. Accordingly, an ISS < 15 was assumed for patients discharged from the ED. Lastly, debate remains on most accurate definition of a severely injured patient. Legitimate classification is difficult and dependent on multiple factors, such as: regional circumstances and trauma center level. ISS > 15 might not represent all patients in need of higher-level trauma center resources. However, ISS > 15 is the most used surrogate marker for a severely injured patient when evaluating prehospital trauma triage, therefore we chose this to define a severely injured patient.[5]

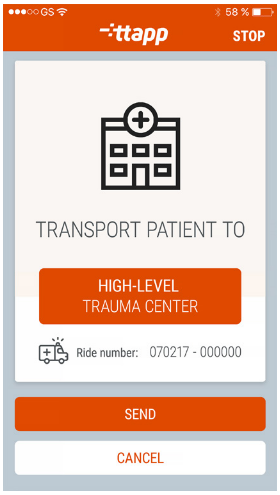
Figure 2. Screen shots of the mobile app

Oxygen saturation, the EMS provider can select 'choose saturation' or 'not assessable'.	The body regions where injury is expected can be selected. In this situation, the body region 'thorax' is selected.



EMS provider judgment: does the patient need to be transported to a level I trauma center?	The advice of TTapp: transport the patient to a level I trauma center.





Future research should focus on the validation of the prediction model in other regions. Differences in incidence of severely injured patients, and consequently baseline risk, can be large, therefore different baseline risks should be determined in other populations. A possible solution is to validate the prediction model in other regions, using our methodology.

The mobile app has been developed and is currently being implemented in the Netherlands (Figure 2). In this mobile app, the equation is integrated in addition to EMS provider judgment. This could be the optimal combination to improve triage rates. Additionally, it could give insight in the value of EMS provider judgment.

Conclusion

This is the first study to develop and validate a prehospital trauma triage protocol based on all adult trauma patients to transported to a trauma center of a region, that can lower the undertriage to approximately 10%, with an overtriage of 50%, from 22% and 31%, respectively. This protocol –based on an equation in which each predictor has its own coefficient– can be implemented with a mobile app for EMS providers. It could be of great help to lower undertriage.

Acknowledgements

None.

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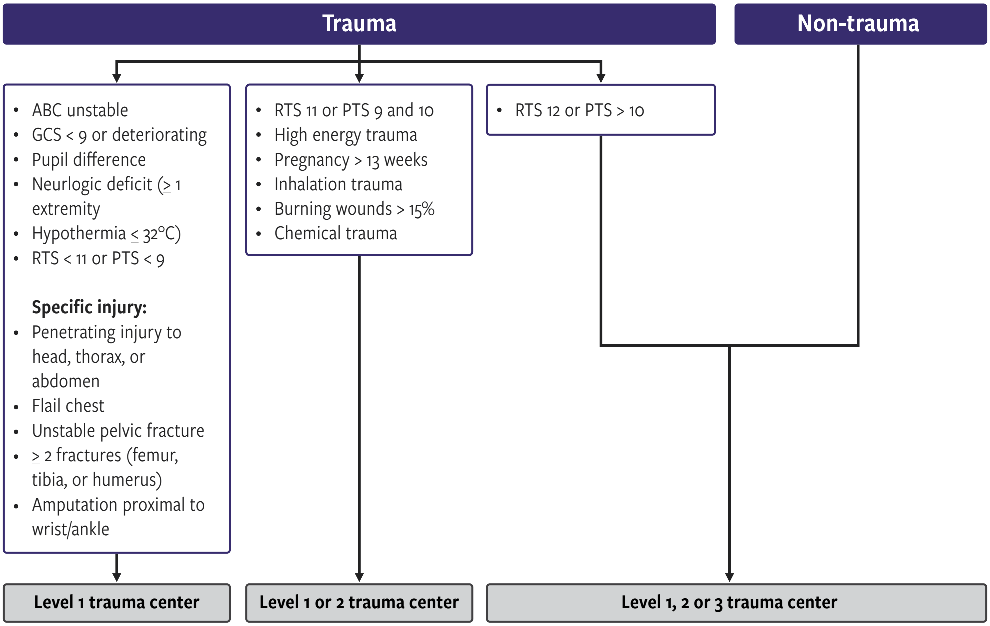
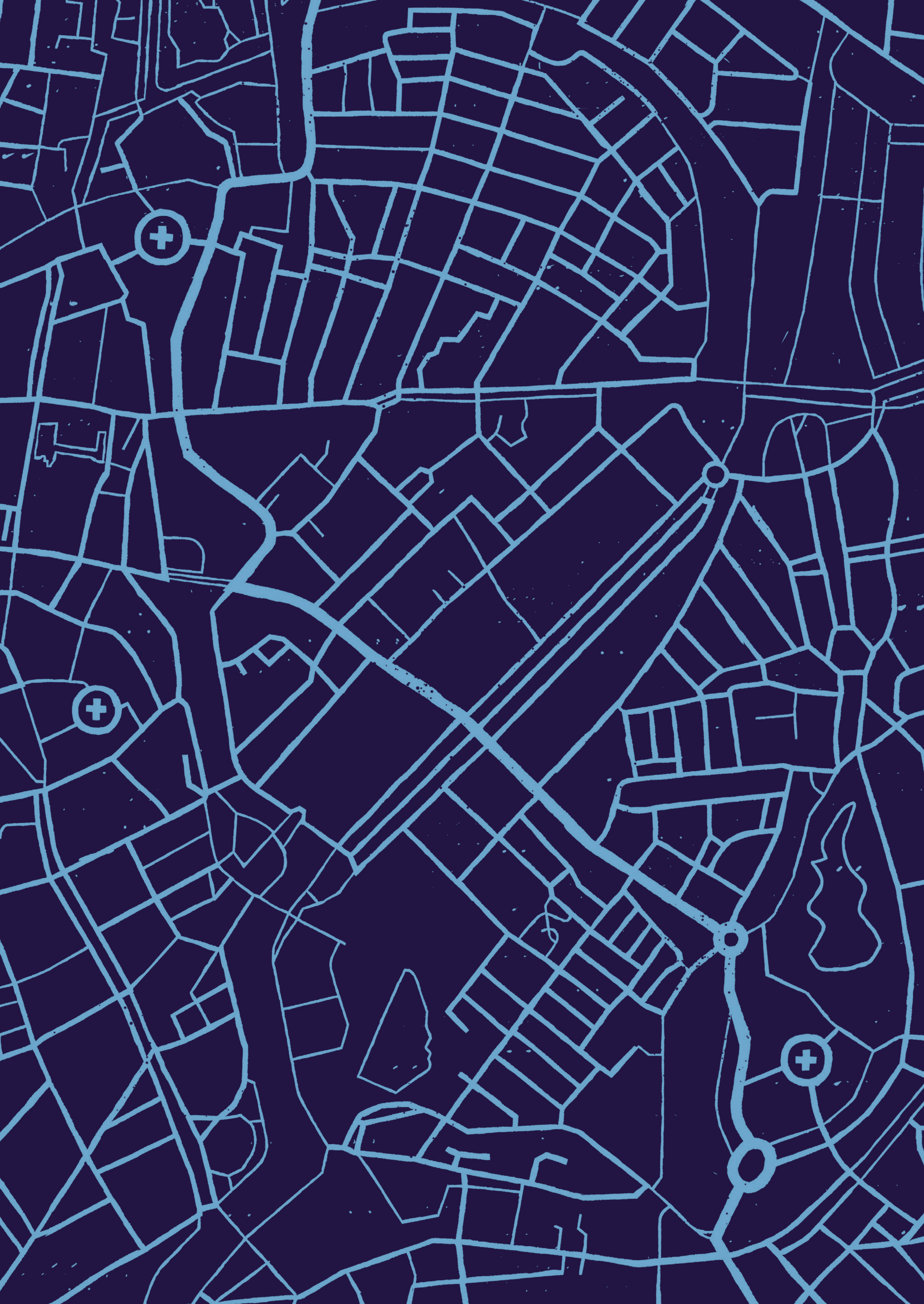
Appendix 1. The National field triage protocol of the Netherlands



In case of severe ABCD instability and the driving distance is too long, the patient can be transported to the nearest trauma center. GCS: Glasgow Coma Scale, RTS: Revised Trauma Score, PTS: Pediatric Trauma Score



Identification of thoracic injuries by emergency medical services providers among trauma patients

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Submitted

9

Abstract

Introduction

Severe thoracic injuries are time sensitive and adequate triage to a facility with a high-level of trauma care is crucial. The emergency medical services (EMS) providers are required to identify patients with a severe thoracic injury to transport the patient to the right hospital. However, identifying these patients on-scene is difficult. The accuracy of prehospital assessment of potential thoracic injury by EMS providers of the ground ambulances is unknown. Therefore, the aim of this study is to evaluate the diagnostic accuracy of the assessment of the EMS provider in the identification of a thoracic injury and determine predictors of a severe thoracic injury.

Methods

In this multicenter cohort study, all trauma patients aged 16 and over, transported with a ground ambulance to a trauma center, were evaluated. The diagnostic value of EMS provider judgment was determined using the Abbreviated Injury Scale (AIS) of ≥ 1 in the thoracic region as reference standard. Prehospital variables were analyzed using logistic regression to explore prehospital predictors of a severe thoracic injury (AIS ≥ 3).

Results

In total 2,766 patients were included, of which 465 (16.8%) sustained a thoracic injury and 210 (7.6%) a severe thoracic injury. The EMS providers' judgment had a sensitivity of 54.8% and a specificity of 92.6% for the identification of a thoracic injury. Prehospital predictors of a severe thoracic injury were: age, gender, oxygen saturation, respiratory rate, Glasgow Coma Scale, fall > 2 meters, car versus pedestrian with an impact > 10 km/h, entrapment in a vehicle, and suspicion of inhalation trauma or a thoracic injury by the EMS provider.

Conclusion

EMS providers could identify little over half of the patients with a thoracic injury. A supplementary triage protocol to identify patients with a thoracic injury could improve prehospital triage of these patients. In this supplementary protocol, age, vital signs, and mechanism criteria could be included.

Introduction

Trauma and injuries remain a significant global concern and adequate recognition and treatment of these patients is essential.[1] Among severely injured patients, the thoracic body region is the second most commonly injured after an injury to the head.[2-6] Compared to injuries to other body regions, mortality is highest for thoracic injuries.[7] Severe thoracic injuries are time sensitive and adequate triage to a facility with a high-level of trauma care is crucial. In the United States, level I and II trauma centers are capable of providing total care for patients with a severe thoracic injury.[8] In other countries, such as the Netherlands, level I trauma centers are equipped to care for patients with a severe thoracic injury.[9, 10]

Prehospital trauma triage protocols help EMS providers to identify severely injured patients. In the Netherlands, the National Protocol for Ambulance Services –based on the Field Triage Decision Scheme established by the American College of Surgeons Committee on Trauma (ACS-COT)– is used to identify severely injured patients.[11] This triage protocol (as other prehospital trauma triage protocols used worldwide) includes only two criteria to identify a severe thoracic injury: penetrating trauma to the thorax and a flail chest. Prehospital trauma triage protocols are limited to help EMS providers identify patients with a thoracic injury, so the EMS providers must rely on their own judgment and experience. Identifying patients with a severe thoracic injury is difficult, as the majority of severe thoracic injuries do not affect vital signs, such as respiratory rate.[3, 12] Consequently, the undertriage rate among severely injured patients with a thoracic injury is high, one study reported an undertriage rate of 40%.[4, 6, 12]

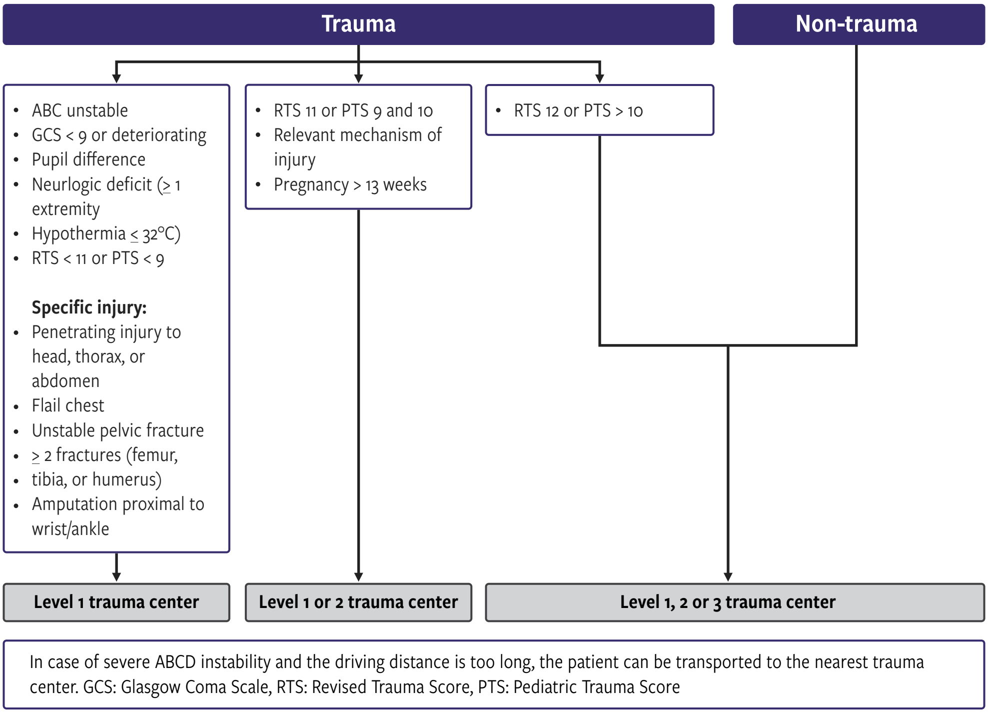
It has previously been shown that emergency physicians of the Helicopter EMS only recognized 45% of the patients with a severe thoracic injury.[13] However, this has not been analyzed among EMS providers of the ground ambulances. Therefore, the aim of this study was to evaluate the diagnostic accuracy of the assessment of the EMS provider in the identification of a thoracic injury among trauma patients and determine prehospital predictors of a severe thoracic injury.

Materials and methods

Study design and setting

This was a multicenter cohort study of prospectively collected data from the ambulance services of *Central-Netherlands* from January 2015 to December 2016. In this region, one level I trauma center (University Medical Center Utrecht) region is equipped to care for patients with severe thoracic injury and the region has nine level II or III trauma centers, all were included in this study. All trauma patients aged 16 and over, transported with highest priority (siren and lights) to a trauma center in region *Central-Netherlands*, were included. The region covers 535 square miles and has 1.2 million residents. EMS providers use the National Protocol for Ambulance Services to identify severely injured patients (Figure 1).[11]

Figure 1. The National field triage protocol of the Netherlands



Patients transported outside of the studied region were excluded. This study was judged by the Medical Ethical Committee of University Medical Center Utrecht as not subject to the Medical Research Involving Human Subjects Act.

Data

Prehospital data were collected from the ambulance services' electronic records, these included: patient demographics, vital parameters, description of the trauma mechanism, and reports on physical examination on site, including the suspicion of thoracic injury by EMS providers. Hospital data were collected from the institutional trauma registry and electronic medical records. The Dutch National Trauma Database registered the receiving hospital, Abbreviated Injury Scale (AIS), and mortality for all patients admitted to a hospital. For patients discharged from the emergency department, data was extracted from the electronic patient documentation. The injuries were coded by trained data managers, using AIS 2005, update 2008.

Outcomes and definitions

To determine the diagnostic value of the identification of a thoracic injury by EMS providers, the prehospital assessment of a thoracic injury, as documented in the ambulance report was used. Thoracic injury, defined as an injury with AIS score of ≥ 1 in the thoracic region, diagnosed at the trauma center, was used as reference standard. A suspected thoracic injury was an injury with AIS score of ≥ 1 in the thoracic region, diagnosed at the hospital, combined with a description of a thoracic injury in the ambulance reports. A thoracic injury with AIS score of ≥ 1 was diagnosed at the hospital, but not described in the ambulance reported was considered an unsuspected thoracic injury. Prehospital variables were analyzed to explore potential prehospital predictors of a severe thoracic injury. A severe thoracic injury was defined as an injury with an AIS score of ≥ 3 in the thoracic region.[21, 22]

Missing data

Missing data were analyzed and appeared to be missing at random. Multiple imputation was used to account for the missing prehospital variables and was performed with SPSS v24 (IBM Corp, Chicago). Missing values were predicted based on all other predictors, as well as the outcome (AIS). The variables with missing data were: pulse (13.5%), respiratory rate (6.3%), systolic blood pressure (5.9%), diastolic blood pressure (6.1%), oxygen saturation (9.9%), and Glasgow Coma Scale (GCS, 6.5%). No patients missed the dependent variable; AIS.

Statistical analysis

Mean and standard deviation were used to describe continuous variables. Frequencies with percentages were used to describe nominal variables, ordinal variables. To compare baseline characteristics between patients with and without a (severe) thoracic injury, the Mann–Whitney U test was performed for continuous variables. For nominal variables, the Chi-squared test was used, the Fisher's exact test was used for nominal variables that occurred in ≤ 5 cases. All tests were performed after multiple imputation and p-value < 0.05 was considered statistically significant. Frequencies and percentages were used to describe EMS provider judgment in the identification of a thoracic injury, stratified by AIS score. The diagnostic value of EMS provider judgment in the identification of a thoracic injury was determined using sensitivity and specificity. To determine potential prehospital predictors of a severe thoracic injury, univariable binary logistic regression was used. All predictors with a p-value < 0.05 were considered predictors of a severe thoracic injury. All statistical analyses were performed using SPSS v24 (IBM Corp, Chicago).

Results

Participants

In total, 3,658 trauma patients were transported by the ambulance services of *Central-Netherlands*. Among these patients, 551 were transported outside of the region and 430 were aged < 16 years old, Consequently, these patients were excluded. A total of 2,766 patients were included in this study.

The mean patient age was 49 years ± 22, 1,695 (58.0%) were male, and 1,115 (40.3%) were admitted to a trauma center (Table 1).

Characteristics patients with thoracic injury

In total, 465 (16.8%) patients had a thoracic injury (AIS ≥ 1 in the thoracic region). In this group, 71.6% of the patients had an additional injury (AIS ≥ 1) to one or more body regions, most had an injury to the extremities (46.9%) or head (35.3%).

One hundred and seventy (36.6%) patients had a severe thoracic injury (AIS ≥ 3 in the thoracic region). In this group, 119 (70.0%) patients were transported to a level I trauma center; the patients aged 65 years or older, with a severe thoracic injury, were less often transported to a level I trauma center (67.2%), compared to patients aged 16-64 years old (71.6%).

Table 1. Baseline characteristics

Variables	All patients n = 2,766	Thorax AIS ≥ 1 n = 465	Thorax AIS ≥ 1 not suspected n = 210	Thorax AIS ≥ 3 n = 170
Demographics	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Age (years)	49.0 (22.0)	52.1 (19.8)†	51.1 (21.1)	55.2 (20.2)●
	Number (%)	**Number (%)**	**Number (%)**	**Number (%)**
Male gender	1,605 (58.0)	306 (65.8)†	136 (64.8) ‡	117 (68.8)
Use of oral anticoagulants	132 (4.8)	18 (3.9)	10 (4.8)	6 (3.5)
Alcohol use	341 (12.3)	40 (8.6)†	27 (12.9)	19 (11.2)
Drug use	22 (0.8)	2 (0.4)	1 (0.5)	0 (0)
Vital signs*	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Systolic blood pressure	141 (26.2)	141.8 (27.5)	139.9 (28.6)	142.2 (29.8)
Diastolic blood pressure	85 (17.9)	86.4 (18.4)	83.8 (19.2)	86.4 (19.8)
Pulse	84 (21.2)	82.9 (23.0)	83.4 (23.2)	84.0 (22.5)
Respiratory rate	16 (4.2)	17.3 (5.2)†	16.3 (4.3)	18.1 (6.2)●
Oxygen saturation	97 (3.7)	96.0 (4.1)†	96.2 (3.9)‡	94.5 (4.8)●
Glasgow Coma Scale Eyes Motor Verbal	14 (1.8) 4 (0.6) 6 (0.7) 5 (0.8)	14.0 (2.6)† 3.7 (0.7)† 5.7 (0.9)† 4.6 (1.0)†	13.5 (2.9)‡ 3.6 (0.8)‡ 5.6 (1.1)‡ 4.3 (1.2)‡	13.3 (3.4)● 3.5 (0.97)● 5.5 (1.3)● 4.3 (1.3)●
	Number (%)	**Number (%)**	**Number (%)**	**Number (%)**
Systolic blood pressure < 90 mmHg	53 (1.9)	7 (1.5)	3 (1.4)	3 (1.8)
Respiratory rate < 10 or > 29 /min	65 (2.4)	27 (5.8)	8 (3.8)	17(10.0)●
Mechanism of injury	**Number (%)**	**Number (%)**	**Number (%)**	**Number (%)**
Fall > 2 m Fall 2-5 m Fall > 5 m or > 3x body length	157 (5.7) 133 (84.7) 24 (15.3)	45 (9.7)† 32 (71.1)† 13 (28.9)†	25 (11.9) ‡ 18 (72.0) ‡ 7 (28.0)	20 (11.8) 12 (60.0) 8 (40.0)
Fall from stairs Fall from stairs, 1-10 steps Fall from stairs, > 10 steps	243 (8.8) 146 (60.1) 97 (39.9)	48 (10.3) 30 (62.5) 18 (37.5)	25 (11.9) 14 (56.0) 11 (44.0)	21 (12.4)● 14 (66.7) 7 (33.3)●
Motor vehicle accident > 65 km/h	154 (5.6)	43 (9.2)†	12 (5.7)	9 (5.3)
Motorcycle accident > 32 km/h	93 (3.4)	17 (3.7)	4 (1.9)	8 (4.7)
Car vs pedestrian impact > 10 km/h	47 (1.7)	12 (2.6)	7 (3.3)	7 (4.1)
Car vs bike impact > 10 km/h	156 (5.6)	30 (6.5)	19 (9.0)	15 (8.8)
Accident with e-bike	24 (0.9)	7 (1.5)	22 (10.3)	2 (1.2)●
Airbag deployment	135 (4.9/0	37 (8.0)†	13 (6.2)	8 (4.7)●
Injury characteristics	**Number (%)**	**Number (%)**	**Number (%)**	**Number (%)**
Penetrating injury to thorax	12 (0.4)	11 (2.4)†	0 (0)	4 (2.4)
Flail chest	3 (0.1)	3 (0.6)†	0 (0)	3 (1.8)

▶ **Table 1** - Continued from previous page

Seatbelt sign	7 (0.3)	4 (0.9)†	0 (0)	3 (1.8)●
Complaint of thoracic pain	229 (8.3)	132 (28.4)†	1 (0.5)	44 (25.9)●
Burning wound or inhalation trauma	31 (1.1)	3 (0.6)	1 (0.5)	3 (1.8)
Suspicion of thoracic injury	411 (14.9)	255 (54.8)†	0 (0)‡	110 (64.7)
Clinical characteristics	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
ISS	4.7 (6.4)	10.1 (9.6)†	11.4 (9.8)‡	18.2 (8.8)●
	Number (%)	**Number (%)**	**Number (%)**	**Number (%)**
Destination				
Level I trauma center	879 (31.8)	227 (48.8)†	123 (58.6)‡	119 (70.0)●
Level II/III trauma center	1,887 (68.2)	238 (51.2)	87 (41.4)	51 (30.0)
Admission to hospital	1,115 (40.3)	294 (63.2)†	145 (69.0)‡	155 (91.2)●
In-hospital death	45 (1.6)	18 (3.9)†	8 (3.8)‡	15 (8.4)●

AIS: Abbreviated Injury Score, SD: standard deviation, m: meters, ISS: Injury Severity Score
* The first vital signs assessed on-scene by the emergency medical services provider
† Indicates a significant difference ($p < 0.05$) as compared to patients without a thoracic injury
‡ Indicates a significant difference ($p < 0.05$) as compared to patients with a suspected thoracic injury
● Indicates a significant difference ($p < 0.05$) as compared to patients without a severe thoracic injury
Systolic blood pressure missed in 5.9%, diastolic blood pressure in 6.1%, pulse in 13.5%, respiratory rate in 6.3%, oxygen saturation in 9.9%, and Glasgow Coma Scale in 6.5%.

Table 2. The number of patients with their AIS score

AIS	Thoracic injury suspected	No thoracic injury suspected	Total
	Number (%)	**Number (%)**	**Number**
0	170 (7.4)	2,131 (92.6)	2,301
1	104 (53.1)	92 (46.9)	196
2	41 (41.4)	58 (58.6)	99
3	100 (65.4)	53 (34.6)	153
4	9 (64.3)	5 (35.7)	14
5	1 (50.0)	1 (50.0)	2
6	0 (0)	1 (100)	1

AIS: Abbreviated Injury Score

Diagnostic value of EMS provider judgment

The EMS providers' judgment had a sensitivity of 54.8% (95%-confidence interval [95%-CI]: 50.3-59.3) and a specificity of 92.6% (95%-CI: 91.5-93.6) for the identification of a thoracic injury. The EMS providers suspected a thoracic injury in 51.8% of the patients with a mild or moderate thoracic injury (AIS 1 or 2 in the thoracic region) and in 64.7% of the patients with a severe thoracic injury (Table 2).

The EMS providers started cardiopulmonary resuscitation (CPR) on three patients with an unsuspected thoracic injury with an AIS of 4 or 5. The thoracic injuries (a tension pneumothorax, a major bilateral lung contusion, and a combined injury to the thoracic aorta and vena cava) might be a result of CPR. In the other patients with an unsuspected thoracic injury with an AIS of 4, the EMS providers did suspect injuries to other body regions, mostly to the extremities. One patient had an AIS of 6, this patient was dead on arrival. Among the patients with an unsuspected severe thoracic injury, 48 (80.0%) were transported to a level I trauma center.

Predictors of a severe thoracic injury

Using univariable logistic analysis, 15 potential prehospital predictors of a severe thoracic injury were analyzed. Significant prehospital predictors were: age, gender, oxygen saturation, respiratory rate, Glasgow Coma Scale, fall > 2 meters, car versus pedestrian with an impact > 10 km/h, entrapment in a vehicle, and suspicion of inhalation trauma or a thoracic injury by the EMS provider (Table 3).

Table 3. Univariable binary logistic regression analysis (n = 2,766)

Variables	Beta-coefficient	Standard error	P-value	Odds ratio	95% Confidence interval
Demographic characteristics					
Age (years)	0.013	0.004	**< 0.001**	1.013	1.006 – 1.021
Male gender	0.497	0.170	**0.004**	1.644	1.177 – 2.295
Vital signs					
Systolic blood pressure < 90 mmHg					
Oxygen saturation	-0.118	0.015	**< 0.001**	0.889	0.862 – 0.916
Respiratory rate < 10 or > 29 /min					
Glasgow Coma Scale	-0.194	0.027	**< 0.001**	0.824	0.782 – 0.868
Mechanism of injury					
Fall > 2 m	0.873	0.254	**0.001**	2.393	1.455 – 3.935
Fall from stairs	0.410	0.243	0.092	1.507	0.935 – 2.429
Car accident > 65 km/h	-0.057	0.353	0.872	0.945	0.473 – 1.888
Motorcycle accident > 32 km/h	0.378	0.379	0.319	1.459	0.695 – 3.064
Car vs pedestrian impact > 10 km/h	1.009	0.418	0.016	2.744	1.210 – 6.221
Car vs bike impact > 10 km/h	0.522	0.284	0.066	1.685	0.966 – 2.940
Entrapment in vehicle	2.571	0.611	**< 0.001**	13.081	3.951 – 43.309
Injury characteristics					
Suspicion of inhalation trauma	3.842	1.157	**0.001**	46.617	4.823 – 450.579
Suspicion of thoracic injury	2.587	0.171	**< 0.001**	13.276	9.488 – 18.575

AIS: Abbreviated Injury Scale, m: meters
Bold indicates significant predictors of AIS ≥ 3 in the thoracic region with a p-value < 0.05
Pulse missed in 13.5%, oxygen saturation in 9.9%, respiratory rate in 6.3%, and Glasgow Coma Scale in 6.5%.

Discussion

This study analyzed the diagnostic value of EMS provider judgment, to gain insight in the accuracy of the prehospital assessment of thoracic injuries. In this study, almost one in five adult trauma patients suffered from a thoracic injury. The EMS providers' prehospital identification of a thoracic injury demonstrated a sensitivity of 55% and a specificity of 93%. Among the patients with a thoracic injury, over a third had a severe thoracic injury, of these the patients 30% was not transported to a level I trauma center. Prehospital predictors of a severe thoracic injury were: age, gender, oxygen saturation, respiratory rate, Glasgow Coma Scale, fall > 2 meters, car versus pedestrian with an impact > 10 km/h, entrapment in a vehicle, and suspicion of inhalation trauma or a thoracic injury by the EMS provider.

In the prehospital trauma triage process, EMS provider judgment is crucial, as they assess the injury severity, start treatment if necessary, and determine the destination facility of the patient.[14-16] In this study, the EMS providers' prehospital assessment demonstrated a high specificity, which could be explained by a low pre-test probability on thoracic injury. However, the low sensitivity is concerning; the EMS providers did not identify 45% of the patients with a thoracic injury. This is the first study to determine the diagnostic value of EMS providers of the ground ambulances in the identification of a thoracic injury. Previous studies assessed the ability of emergency physicians to identify thoracic injuries in a prehospital setting. Even though emergency physicians have had more education and training, the studies showed similar rates: thoracic injuries were unrecognized or underestimated in 20-50% of the cases.[12, 13, 17, 18]

Prehospital identification of injuries by anatomic region has been proven difficult, especially in patients suffering blunt trauma.[19] It has been previously reported that 10-15% of the patients with internal organ injuries of the thorax have no associated thoracic wall injury.[20, 21] Penetrating trauma results in obvious visible injuries, however, it occurs in only a fraction of the whole trauma population in the Netherlands. The incidence of penetrating trauma differs per county and depends on regional circumstances, such as crime rates.[22] In the present study, only 2% of the patients with a thoracic injury suffered from penetrating trauma to the thorax. EMS providers use other findings, such as physical examination and vital signs, to identify all other thoracic injuries. However, previous studies showed that, for example auscultation, had a low sensitivity to identify thoracic injuries in the hospital setting.[3, 12, 23, 24] It might even be of less benefit in prehospital setting, where time is crucial and potential other injuries may need attention. Also, the majority of patients with thoracic injuries have normal to near normal vital signs in the prehospital setting, so EMS providers may need additional criteria to identify these patients.[3, 12] Patients with a thoracic injury often have injuries to other body regions and thoracic injuries are more often overlooked with higher rates of multiple injuries, leading to a delay in diagnosis at the hospital.[25-27]

EMS providers must not only recognize the thoracic injury, but also try to determine if the injury is severe or not, to choose the most appropriate hospital for the patient. Currently, the EMS providers use a triage protocol that is not specific for patients at risk of a severe thoracic injury.[11] In the current study, 30% of the patients with a severe thoracic injury were not transported to a higher-level trauma center. Clearly, improvement in the recognition of a severe thoracic injury is necessary. Extra training, education, and a supplementary or integrated protocol with prehospital predictors of a severe thoracic injury might improve the prehospital triage of these patients. The prehospital predictors of a severe thoracic injury found in this study could be used to develop a supplementary triage protocol. In this supplementary protocol, age and mechanism criteria could be included, in addition to vital signs, as the patients often have normal or near normal vital signs.[3, 12]

In this study, a severe thoracic injury was defined as an injury to the thorax with an AIS ≥ 3. Previous studies have used this as a cut-off point[4, 13, 28, 29], however, whether all patients with a thorax AIS ≥ 3 should be treated at a specialized thoracic trauma center remains unclear. Examples of AIS ≥ 3 thoracic injuries are: a hemothorax, three or more fractured ribs, or a laceration of a major artery or vein.[30] Previous studies have shown that patients with a severe thoracic injury often require Intensive Care Unit admission and are more at risk for adverse outcomes.[28, 31, 32] Therefore, transport to a higher-level trauma center is justifiable -even though this is not mandated by a guideline of protocol- but depends on the trauma system . The identification of a severe thoracic injury especially important in the prehospital setting so the EMS provider can make a calculated destination decision; either a higher-level or a lower-level trauma center. Additionally, the EMS provider could consult the emergency physician before arrival at the trauma center, to discuss if the proposed trauma center is the most appropriate destination.

This study has several limitations. First, all patients who were transported outside the study region were excluded. This could have resulted in sampling bias. Second, the suspicion of a thoracic injury was based on the description of the patients' injuries in the ambulance services electronic records. The EMS providers' descriptions did not elaborate on the injury severity; only if an injury was suspected and to what body region. Because of this, analysis of the EMS provider judgment in the prehospital trauma triage process and on injury severity was not possible. Third, the diagnostic value of EMS provider judgment might vary in other countries, as factors influencing EMS provider judgment, such as mechanism of injury, education, and patient population, could be different.

The identification of a thoracic injury is difficult, as most patients have normal to near normal vital signs and lack obvious injury characteristics for example. The EMS providers recognized little over half of the thoracic injuries. Prehospital trauma triage is especially important for the patients with severe thoracic injury. Future studies should focus on the development of a supplementary protocol for patients at risk for a severe thoracic injury. With data from other trauma regions, a prediction model could be developed and externally validated to help EMS providers identify patients with a severe thoracic injury. Including EMS provider judgment in this supplementary protocol could improve prehospital trauma triage of these patients further.

Conclusion

This study shows that the diagnostic value in the identification of a thoracic injury by EMS providers is insufficient. The EMS providers suspected a thoracic injury in 55% of the patients with a thoracic injury. Additional means to help identify these patients, such as a supplementary triage protocol, are necessary to improve prehospital trauma triage of patients with thoracic injury. This will improve their chances of survival and lower the chance of injury related life-long disabilities.

Acknowledgments

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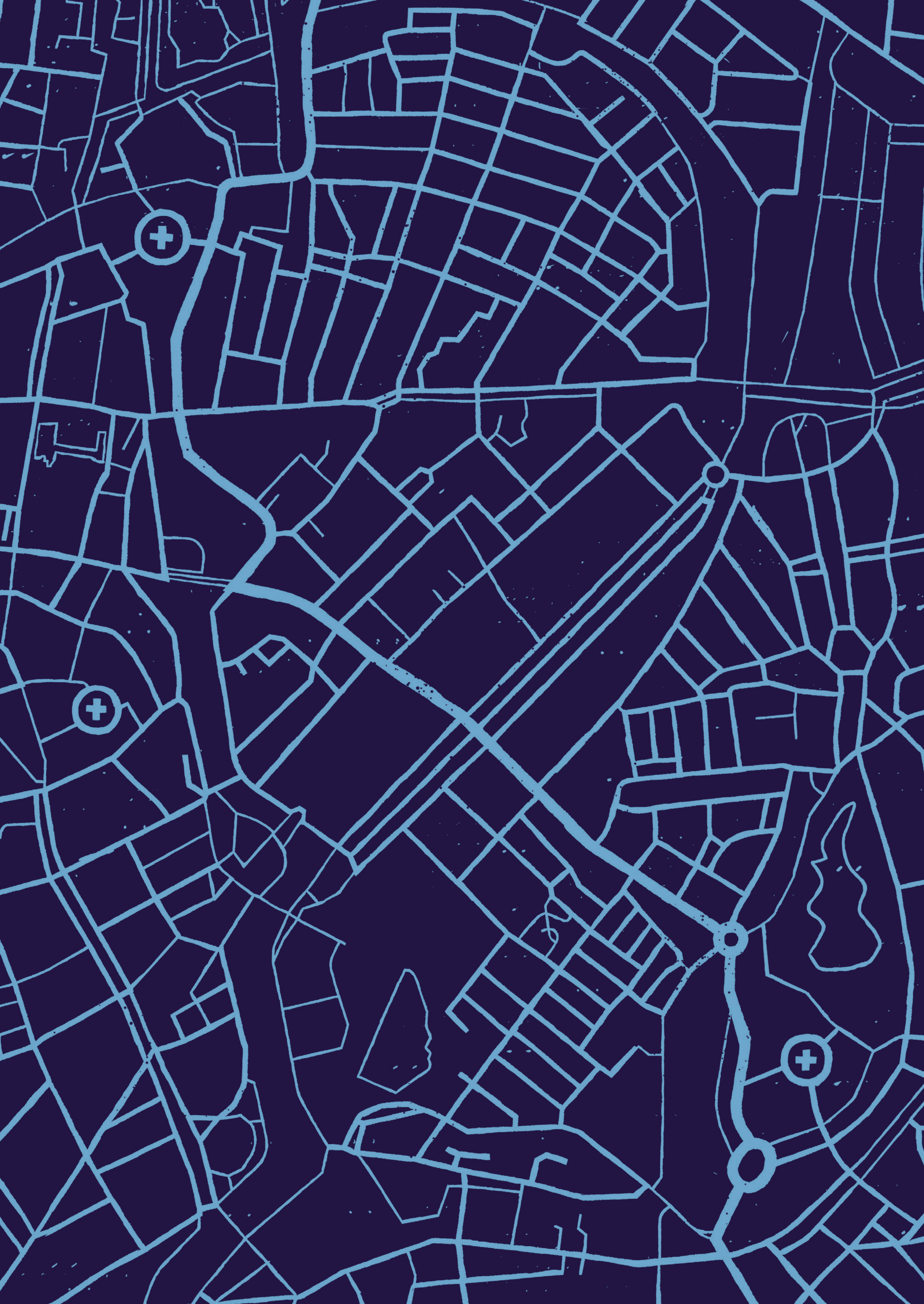

Diagnostic value of emergency medical services provider judgement in the identification of head injuries among trauma patients

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10

Abstract

Introduction

Previous studies reported that many patients with a severe head injury are not transported to a higher-level trauma center, where the necessary round the clock neurosurgical care is available. The aim of this study was to analyze the diagnostic value of emergency medical services (EMS) provider judgment in the identification of a head injury.

Methods

In this multicenter cohort study, all trauma patients aged 16 and over, transported with highest priority to a trauma center, were evaluated. The diagnostic value of EMS provider judgment was determined using the Abbreviated Injury Scale (AIS) of ≥ 1 in the head region as reference standard.

Results

In total, 2,766 patients were included, 980 (35.4%) had a head injury. EMS provider judgment (AIS ≥ 1) had a sensitivity of 67.9% and a specificity of 87.7%. In the cohort, 208 (7.5%) patients had a severe head injury, of these, 68% were transported to a level I trauma center.

Conclusion

Identification of a head injury on-scene is challenging. EMS providers could not identify 32% of the patients with a head injury and 21% with a severe head injury. Additional education, training and a supplementary protocol with predictors of a severe head injury could help EMS providers in the identification of these patients.

Introduction

Traumatic head injury is a leading cause of death and life-long disabilities due to trauma worldwide.[1;2] It can affect the brain in multiple, complex ways, leading to long-term functional, physical, emotional, cognitive and social problems. Prehospital emergency care on-scene and inpatient care at the hospital are crucial to patient outcomes. At the start of the chain of trauma care are the emergency medical services (EMS). The EMS providers start initial care and decide the most appropriate hospital for the patient; a higher-level or a lower-level trauma center. Patients with a severe head injury require immediate evaluation and admission to trauma centers with access to neurosurgical care.[3] Neurosurgical care is available in different types of trauma centers, however, higher-level trauma centers are usually the only facilities that provide around the clock neurosurgical care.[4] These are level I and II trauma centers in the United States[5], whereas in other countries, such as the Netherlands, only level I trauma centers are capable to provide adequate care for patients with a severe head injury.[6] Treatment at higher-level trauma centers is associated with lower mortality and better outcomes in patients with a severe head injury.[7;8]

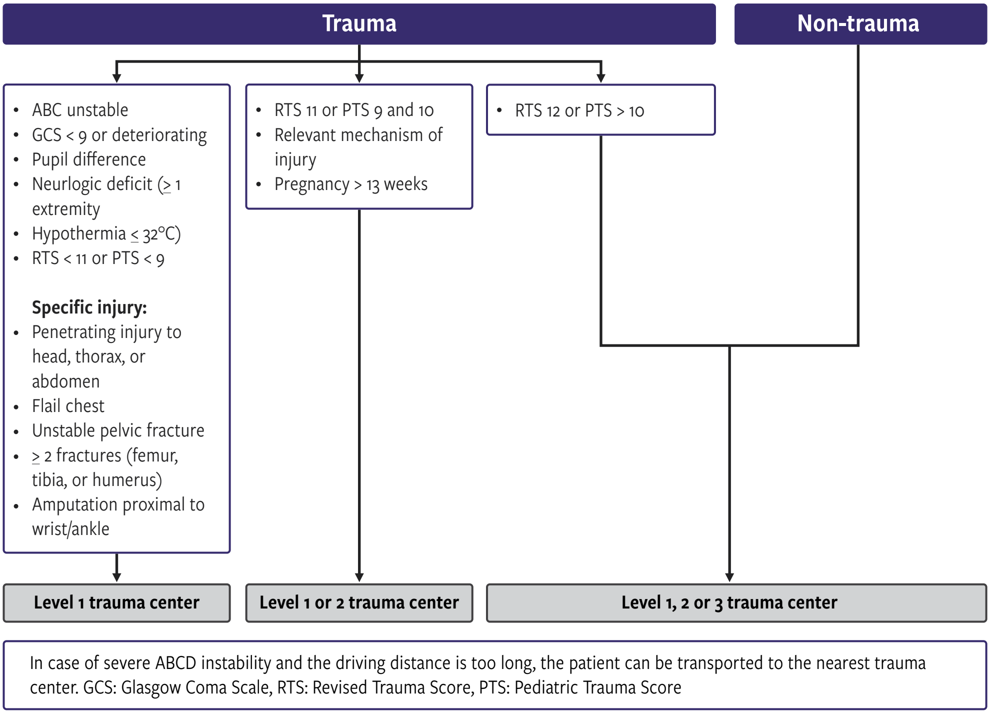
Previous studies show that many patients with severe head trauma are not transported to a higher-level trauma center.[9-13] The ability of EMS providers to accurately identify patients with a head injury is unknown. Therefore, the aim of this study was to analyze the diagnostic value of EMS provider judgment in the identification of a head injury.

Material and methods

Study design and setting

In this multicenter cohort study, data from all trauma patients aged 16 and over, transported to a trauma center in *Central-Netherlands*, were prospectively collected. Patients were included from January 2015 to December 2016. In the *Central-Netherlands* region, one level I trauma center is fully equipped to provide the appropriate level of care 24 hours a day for patients with severe head injury.[6] The region has nine level II or III trauma centers. The region covers 535 square miles and has 1.2 million residents. EMS providers use the National Protocol for Ambulance Services to identify severely injured patients (Figure 1).[14]

Figure 1. The National field triage protocol of the Netherlands



Patients transported to hospitals outside of the region were excluded. The present study protocol was judged by the Medical Ethical Committee of the University Medical Center Utrecht as not subject to the Medical Research Involving Human Subjects Act.

Data sources

Data were collected from the ambulance services electronic records, institutional trauma registry and electronic medical records. Patient consent was not required as this was a retrospective study reviewing medical records, with no more than minimal risk to the participants and in no way affecting their treatment. Prehospital data from the ambulance services included: patient demographics, vital parameters, description of trauma mechanism and physical examination data on site, including if a head injury was suspected. The Dutch National Trauma Database registered injuries for all patients admitted to a trauma center. For patients discharged from the emergency department, data was extracted from the electronic patient documentation. The injuries were coded by trained data managers, using Abbreviated Injury Scale (AIS) 2005, update 2008. Additionally, hospital data included: receiving hospital, admission status and mortality.

Injury severity

The AIS is an anatomical coding system to classify injuries. The AIS describes the body region, type of anatomical structure and severity of the injury. Six levels of injury severity exist; AIS 1 is a minor injury (e.g. a minor concussion) and AIS 6 is the maximum score (an un-survivable injury). Injuries with an AIS ≥ 3 are considered severe injuries (e.g. a skull base fracture, cerebral hematoma or basilar artery laceration).[15]

Outcomes and definitions

The diagnostic value of EMS provider judgment in the identification of a head injury was determined using the ambulance reports as index test. Any description of a head injury was considered a suspicion of a head injury. The reference standard was the head injury diagnosed at the trauma center, defined as any injury with AIS score of ≥ 1 in the head region. Any description of a head injury in the ambulance reports, combined with a head injury with AIS score of ≥ 1 diagnosed at the hospital was considered a correct suspicion of a head injury. The diagnostic value in the identification of a severe head injury (AIS ≥ 3) was determined in a similar fashion; any description of a head injury in the ambulance reports, combined with a head injury with AIS score of ≥ 3 diagnosed at the hospital was considered a correct suspicion of a head injury. When no head injury was described in the ambulance reports, but a head injury with AIS score of ≥ 1 was diagnosed at the hospital, it was considered an unsuspected head injury.

Statistical analysis

To describe continuous variables, means with standard deviation were used. Frequencies with percentages were used for nominal and ordinal variables. To compare baseline characteristics between patients with and without a (severe) head injury, the Mann–Whitney U test was performed for continuous variables, as these variables were all not normally distributed. For nominal variables, the Chi-squared test was used, the Fisher's exact test was used for nominal variables that occurred in ≤ 5 cases. All tests were performed after multiple imputation and p-value < 0.05 was considered statistically significant. Frequencies and percentages were also used to describe the EMS provider judgment in the identification of a head injury, stratified by AIS scores. The diagnostic value of EMS provider judgment in the identification of a head injury was assessed using sensitivity and specificity. All statistical analyses were performed using SPSS v24 (IBM Corp, Chicago).

Results

Study population

In total, 3,658 trauma patients were transported with highest priority by the ambulance services of *Central-Netherlands*. A total of 981 patients were excluded from this study, because they were transported outside of the region and/or under the age of 16. Excluding these patients led to the inclusion of 2,766 patients.

Mean age was 49 years ± 22, 1,605 (58.0%) were male and 1,115 (40.3%) were admitted to a hospital (Table 1).

Table 1. Baseline characteristics

Variables	All patients n = 2,766	Head AIS ≥ 1 n = 980	Head AIS ≥ 1 not suspected n = 315	Head AIS ≥ 3 n = 208
Demographics	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Age (years)	49.0 (22.0)	53.8 (22.0) †	50.2 (23.2)‡	57.7 (21.4)●
	Number (%)	**Number (%)**	**Number (%)**	**Number (%)**
Male gender	1,605 (58.0)	555 (56.6)	189 (60.0)	111 (53.4)
Use of oral anticoagulants	132 (4.8)	79 (8.1) †	22 (7.0)	12 (5.8)
Alcohol use	341 (12.3)	165 (16.8) †	55 (17.5)	26 (12.5)
Drug use	22 (0.8)	7 (0.7)	2 (0.6)	1 (0.5)
Vital signs*	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Systolic blood pressure	140.5 (26.2)	142.6 (27.4)†	138.7 (25.4)‡	144.7 (29.2)●
Diastolic blood pressure	85.3 (17.9)	85.9 (18.3)	84.5 (17.9)	88.4 (19.2)●
Pulse	83.5 (21.2)	84.4 (22.5)	83.5 (20.9)	84.6 (25.0)

▸ **Table 1** - Continued from previous page

Respiratory rate	16.3 (4.2)	16.1 (4.2)	16.1 (4.4)	16.4 (4.7)
Oxygen saturation	96.8 (3.7)	96.3 (4.0)†	96.2 (4.5)	95.4 (4.5)●
Glasgow Coma Scale	14.4 (1.8)	13.7 (2.6)†	14.5 (1.5)‡	11.8 (4.0)●
Eyes	3.8 (0.6)	3.7 (0.8)†	3.8 (0.5)‡	3.1 (1.2)●
Motor	5.9 (0.7)	5.7 (0.9)†	5.9 (0.5)‡	5.1 (1.6)●
Verbal	4.7 (0.8)	4.4 (1.1)†	4.7 (0.7)‡	3.6 (1.6)●
Mechanism of injury	**Number (%)**	**Number (%)**	**Number (%)**	**Number (%)**
Fall > 2 meter	157 (5.7)	73 (7.4)†	25 (7.9)	20 (9.6 ●
Fall 2-5 meter	133 (84.7)	67 (91.8)†	20 (80.0)	16 (80.0)●
Fall > 5 meter or > 3x body length	24 (15.3)	6 (8.2)	5 (20.0)‡	4 (20.0)
Fall from stairs	243 (8.8)	129 (13.2)†	34 (10.8)	26 (12.5)●
1-10 steps	146 (60.1)	78 (60.5)†	18 (52.9)	21 (80.8)●
> 10 steps	97 (39.9)	51 (39.5)†	16 (47.1)	5 (19.2)●
Motor vehicle accident > 65 km/h	154 (5.6)	30 (3.1)†	16 (5.1)‡	5 (2.4)●
Motorcycle accident > 32 km/h	93 (3.4)	17 (1.7)†	10 (3.2)‡	3 (1.4)
Car vs pedestrian impact > 10 km/h	47 (1.7)	25 (2.6)†	6 (1.9)	8 (3.8)●
Car vs bike impact > 10 km/h	156 (5.6)	87 (8.9)†	26 (8.3)	17 (8.2)
Injury characteristics	**Number (%)**	**Number (%)**	**Number (%)**	**Number (%)**
Penetrating injury to head	2 (0.1)	2 (0.2)	0 (0)	1 (0.5)
Neurologic deficit (> 1 extremity)	41 (1.5)	9 (0.9)	4 (1.3)	1 (0.5)
Anisocoria	16 (0.6)	15 (1.5)†	0 (0)‡	10 (4.8)●
Symptoms of cerebral contusion or concussion	396 (14.3)	316 (32.2)†	0 (0)‡	85 (40.9)●
Agitation	105 (3.8)	59 (6.0) †	11 (3.5)‡	29 (13.9)●
Suspected injury in AIS region head	881 (31.9)	665 (67.9)†	0 (0)‡	165 (79.3)●
Clinical characteristics	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
ISS	4.7 (6.4)	7.1 (8.1)†	6.1 (7.4)‡	18.7 (8.3)●
	N (%)	**N (%)**	**N (%)**	**N (%)**
Destination				
Level I trauma center	879 (31.8)	393 (40.1)†	128 (40.6)	141 (67.8)●
Level II/III trauma center	1,887 (68.2)	587 (59.9)	187 (59.4)	67 (32.2)
Admission to hospital	1,115 (40.3)	393 (40.1)†	171 (54.3)	141 (67.8)●
In-hospital death	46 (1.7)	31 (3.2)†	4 (1.3)‡	23 (11.1)●

AIS: Abbreviated Injury Score, SD: standard deviation, m: meters, ISS: Injury Severity Score
* The first vital signs assessed on-scene by the emergency medical services provider
† Indicates a significant difference ($p < 0.05$) as compared to patients without a head injury
‡ Indicates a significant difference ($p < 0.05$) as compared to patients with a suspected head injury
● Indicates a significant difference ($p < 0.05$) as compared to patients without a severe head injury
Systolic blood pressure missed in 5.9%, diastolic blood pressure in 6.1%, pulse in 13.5%, respiratory rate in 6.3%, oxygen saturation in 9.9% and Glasgow Coma Scale in 6.5%.

Characteristics of patients with a head injury

In this cohort, 980 (35.4%) patients had a head injury (AIS ≥ 1 in the head region). Among these patients, 666 (68.0%) had an injury to another body region and 332 (33.9%) had an injury to multiple body regions, in addition to a head injury. A severe head injury (AIS ≥ 3 in the head region) was diagnosed in 208 (21.2%) patients, of these, 177 (85.1%) had in injury to another body region and 116 (55.8%) had an injury to two or more body regions, besides a head injury. One hundred and forty-one (67.8%) patients with a severe head injury were transported to a level I trauma center; patients aged 16-64 years old, were more often transported to a level I trauma center (71.8%), compared to patients aged 65 years or older (62.6%).

Table 2. The number of patients with their AIS score

AIS	Head injury suspected	No head injury suspected	Total
	Number (%)	**Number (%)**	**Number**
0	219 (12.3)	1,567 (87.7)	1,786
1	428 (63.2)	249 (36.8)	677
2	72 (75.8)	23 (24.2)	95
3	91 (76.5)	28 (23.5)	119
4	56 (80.0)	14 (20.0)	70
5	18 (94.7)	1 (5.3)	19

AIS: Abbreviated Injury Score

Diagnostic value of EMS provider judgment

EMS provider judgment in the identification of a head injury (AIS ≥ 1) had a sensitivity of 67.9% (95%-confidence interval [95%-CI]: 64.9-70.7) and a specificity of 87.7% (95%-CI: 86.1-89.2). The patients with an unsuspected head injury had significant differences in vital signs, mechanisms of injury and injury types, compared to patients with a suspected head injury.

Among the patients with an unsuspected head injury, 72.1% had an injury to another body region (AIS ≥ 1). With higher AIS scores, a higher percentage of the head injuries were suspected (Table 2). Still, 20.7% severe head injuries were not suspected by the EMS provider. In 25.6% of these patients, EMS providers suspected an injury to the face and in 20.9% an injury to the extremities. The type of head injuries that were missed the most were: cerebral hematomas, subdural bleedings and epidural bleedings; especially those without any injuries visible from the outside, such as abrasions, lacerations or contusions. In the group of patients with an AIS 5 head injury, a head injury was not suspected in one patient (5.3%). In this case, cardiopulmonary resuscitation was applied and the EMS providers reported that no injuries were seen. Among the patients with an unsuspected severe head injury, 21 (48.8%) were transported to a level I trauma center.

Discussion

This is the first study to evaluate the diagnostic value of the prehospital identification of head injuries by EMS providers of the ground ambulance. In this study, 35% of the included trauma population suffered from a head injury. The EMS providers' prehospital assessment of head injury, as documented in the ambulance reports, had a sensitivity of 68% and a specificity of 88%. Among the patients with a head injury, 21% suffered from a severe head injury. In this group, the EMS providers suspected a head injury in 79% and 68% were transported to a level I trauma center.

EMS provider judgment plays an essential role in the prehospital trauma triage process.[17;18] The EMS providers must assess the injury severity and act accordingly. The EMS providers' prehospital assessment had a high specificity, this might be partly explained by the low pre-test probability on a head injury. However, identifying a head injury is challenging as shown by the relatively low sensitivity. Previous studies showed that the vital signs are often not affected and may change over time; patients suffering a head injury from low-risk mechanisms of injury might present to the EMS providers with minimal symptoms, but develop alarming symptoms hours or days later.[18-22] In this study, most patients with a head injury had a Glasgow Coma Scale (GCS) between 12 and 15. On the other hand, presenting symptoms indicative of a head injury might not be recognized as deviation from the patients' regular behaviour or attributed to intoxication.[23] Also, additional injuries to other body regions could distract the attention from the head injury. Almost 40% of the patients not suspected of having a head injury had injuries to one of the extremities. EMS providers might have had their attention drawn to these more prominent injuries, failing to recognize or report the head injury.

Worldwide, 26% to 67% of the patients with a severe head injury are not transported to a higher-level trauma center.[10;11;19;25;26] The percentage depends greatly on the inclusion criteria; a selection in trauma patients or trauma centers. For example, including only patients admitted to higher-level trauma centers, leads to an underestimation of the undertriage rate, as the undertriaged patients are not included. In this study, one in three patients was not transported to a level I trauma center, this could be due to the currently used triage protocol. Even though the triage protocol of the Netherlands includes criteria that implicate a severe head injury (e.g. GCS < 9 or anisocoria), the suspicion of a severe head injury, specifically, is not an indication to transport a patient to a level I trauma center. The Brain Trauma Foundation recommends transport of patients with a severe head injury to higher-level trauma centers, as this improves chances of survival.[3] Prehospital triage of these patients might improve with additional education, training and a supplementary or integrated protocol.

In the supplementary protocol, prehospital predictors could help in de identification of patients with a severe head injury. Some variables, such as age and GCS, might be indicative of a severe head injury, as these were significantly differed among patients with a severe head injury. However, a more data is necessary for an in-depth analysis to develop and validate prediction model for severe head injuries as a supplementary protocol. Multiple studies show that many severely injured elderly patients are not transported to a higher-level trauma centre, especially those with a severe head injury.[10-13;26] As injuries in elderly patients are increasing in frequency, are more difficult to recognize and carry a higher mortality rate compared to the young, age is an important factor to consider.[28-30] Other factors that are easy to assess in the prehospital setting should be considered as well, for example the AVPU (alert, voice, pain, unresponsive) and GCS. Due to its simplicity, the AVPU has been suggested as a useful measure. However, it has a relatively high inter-rater reliability and it is questioned if the four different states could be easily differentiated by EMS providers.[31;32] Unfortunately, the AVPU was not documented in the ambulance reports, so could not be evaluated in this study and its use in the prehospital setting has not been studied. The GCS is considered a significant and reliable indicator for a severe head injury by the Brain Trauma Foundation.[3] Previous studies found that the motor component of the GCS was just as predictive as the full GCS, when assessing the AIS score[33] and survival.[34;35] So, the motor component of the GCS might be more suitable to incorporate in the supplementary protocol.

The study is limited by the information available in the ambulance reports. It is not mandatory for the EMS providers to report the injury severity or a suspected diagnosis. However, they have to report to what body region they suspect an injury and have the option to describe the injuries or suspected diagnosis. With this information, the diagnostic accuracy in the identification of a head injury could be determined, but the accuracy of EMS provider judgment on injury severity could not. Secondly, factors influencing EMS provider judgment, such as mechanism of injury, education and patient population could be different for other countries. Accordingly, the diagnostic value of EMS provider judgment might vary for other countries. Lastly, outcome data was not available for this study, therefore, the result of the missed head injuries could not be analyzed.

Future studies should be executed to gain further insight in the EMS provider judgment in the prehospital trauma triage process. A supplementary protocol in the form of a prediction model for patients at risk of a severe head injury could be developed to aid EMS providers in the identification of patients with a severe head injury.

Conclusions

The identification of a head injury on-scene is challenging. The EMS providers could not identify 32% of the patients with a head injury and 21% with a severe head injury. To improve patient outcomes, correct and timely identification of these patients is crucial. Extra education and training of EMS providers could improve the recognition of patients with a severe head injury. Additionally, a supplementary protocol with predictors of a severe head injury could help EMS providers in the identification of these patients.

Acknowledgments

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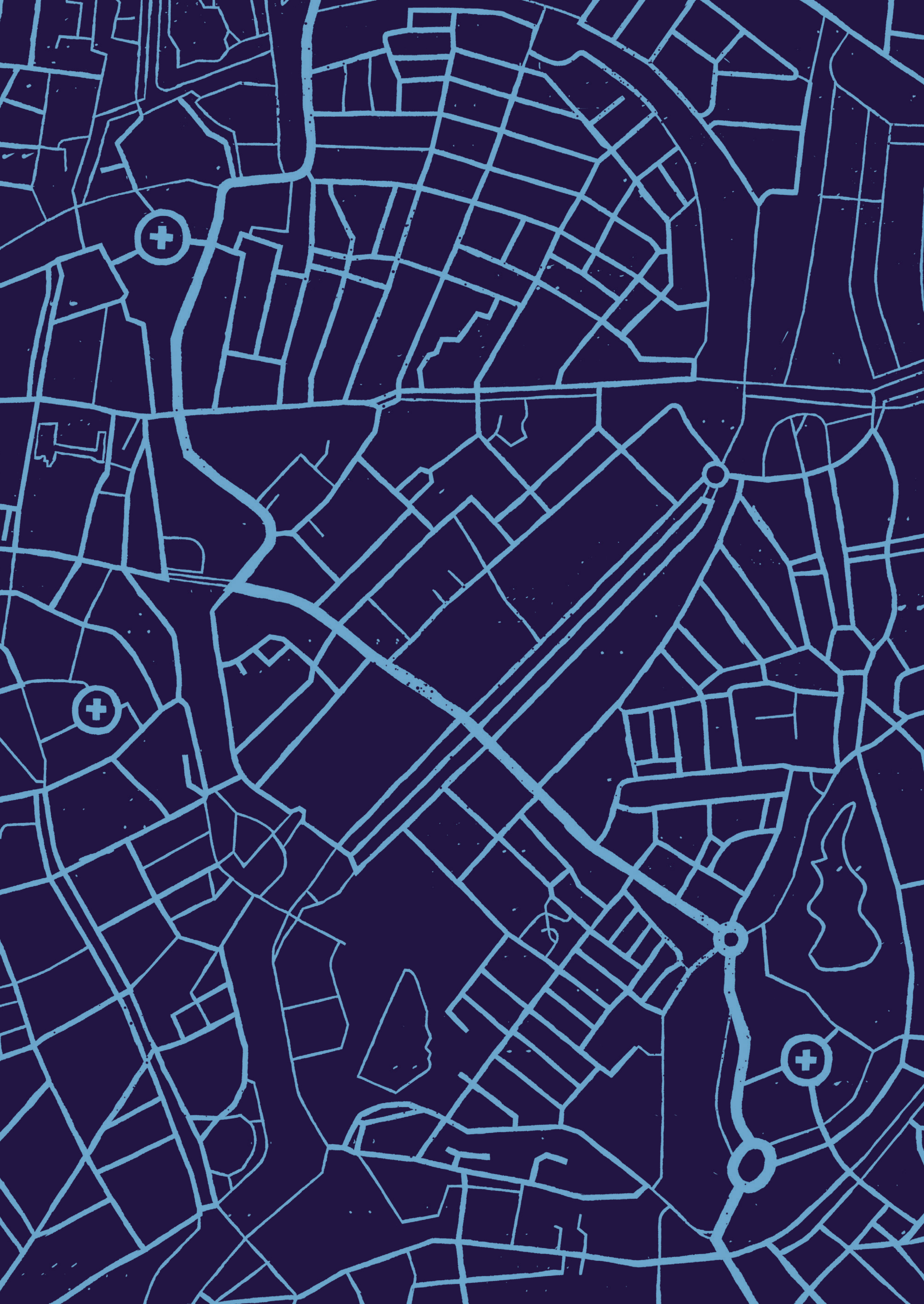

General discussion

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General discussion

Trauma systems have been developed to provide optimal care for trauma patients. Ensuring transport of severely injured patients to higher-level trauma center has a profound impact on these patients' survival.[1, 2] At the same time, transport of patients without severe injuries to lower-level trauma centers should be warranted, to lower the preventable burden on higher-level trauma centers and relatively high costs.

In this thesis, the current effectiveness of different aspects of prehospital trauma triage was evaluated and a new method to improve prehospital trauma triage was developed.

Effectiveness of prehospital trauma triage systems worldwide

The American College of Surgeons Committee on Trauma set a target goal for the transport of 95% of the severely injured patients to a higher-level trauma center (which is equal to an undertriage rate of 5%).[3] To lower the undertriage rate, more patients have to be transported to higher-level trauma centers. The transport of up to 50% patients without severe injuries to higher-level trauma center can be accepted (this is an overtriage rate of 35%-50%), to achieve this.[3]

An accurate prehospital trauma triage protocol forms the base of prehospital trauma triage. However, based on **Chapter 2**, none of the triage protocols used worldwide are accurate enough to achieve an undertriage rate of 5% or lower, combined with an acceptable overtriage rate of 50% or lower. Nonetheless, the EMS providers make the ultimate decision on where to transport the patient; in compliance with the triage protocol or not. **Chapter 3** showed that many severely injured patients were not transported to a higher-level trauma center. **Chapter 4** showed that EMS provider judgment could lower the undertriage rate, especially for severely injured patients meeting none of the criteria.

The first chapters all focused on the triage of adult patients. Triaging pediatric patients is different from adults, due to a great variability in reference ranges of vital signs, mechanism of injury, and injury patterns across childhood. **Chapter 5** reviewed articles evaluating the accuracy of prehospital trauma triage protocols on pediatric patients. None of the investigated triage protocols complied with the quality targets for undertriage and overtriage established by the American College of Surgeons Committee on Trauma.

Most studies analyzing the different aspects of prehospital trauma triage in trauma systems included in the reviews lacked in methodological quality. An accurate assessment of a trauma triage system should include all trauma patients transported to all levels of trauma centers in a specific geographic region, clearly describing the initial destination and mode of transportation. Only with these key elements, the prehospital trauma triage quality can be assessed and ultimately improved.

Trauma system performance in the Netherlands

In the Netherlands, the National Health Institute of the Netherlands set a target goal of an undertriage rate below 10% in 2016.[4] The Dutch Trauma Registry, that collects prehospital and hospital data of all admitted patients showed that the average undertriage rate is 33% in the Netherlands.[5]

To fully evaluate the prehospital trauma triage quality, all adult trauma patients transported with highest priority to a trauma center in one region of the Netherlands were analyzed in **Chapter 6**. This study showed that the Dutch National Protocol of Ambulance Services functioned poorly; even flipping a coin is a better way to identify a severely injured patient compared to using the triage protocol. Fortunately, the EMS providers can use their clinical judgment and experience to assess the patient. Consequently, more severely injured patients are transported to higher-level trauma centers. Still, 22% of the severely injured patients were not transported to a higher-level trauma center (undertriage).

In **Chapter 7**, the compliance to the triage protocol was further analyzed in two regions of the Netherlands over a different time period. Like the study in chapter 6, this study showed that the Dutch national triage protocol could identify only a minority of the severely injured patients in both regions. It failed to support EMS providers to correctly identify severely injured patients in need of higher-level trauma center care. Again, owing to EMS provider judgment, a large portion of the severely injured patients was transported to a higher-level trauma center. Unfortunately, still one out of four severely injured patients was not transported to a higher-level trauma center, so improvement of prehospital trauma triage is imperative.

A new tool for the improvement of prehospital trauma triage

The previous chapters showed that the present prehospital trauma triage quality was insufficient. To start improvement at the base, the first step was to tackle the inadequate triage protocol. Technology is developing at a high pace, whereas the currently used triage protocols are outdated, simplistic, and static flow charts. Today, more innovative methods are available to use on-scene. These could be used to improve prehospital trauma triage quality.

In **Chapter 8**, a prehospital prediction model was developed and validated. This prediction model included ten predictors of a severe injury and is able to identify over 90% of the severely injured patients. It could help EMS providers in the identification of severe injured patients. The prediction model is a complicated formula; not user-friendly for EMS providers to use on-scene when time is crucial. The EMS providers need a user-friendly and quick method the aid them in the decision-making process. A solution is the integration of the new prediction model in a mobile app.

Diagnostic value of EMS provider judgment

The head and thorax are the most commonly severely injured body parts and previous studies show that many of these patients are not transported to a higher-level trauma center.[6-8] **Chapter 9** and **Chapter 10** show that the identification of injuries to the head and thorax is challenging. The EMS providers must not only recognize the injury, but also try to determine if the injury is severe or not, to choose the appropriate hospital for the patients. Prehospital trauma triage might improve with additional education, training, and a supplementary or integrated triage protocol with prehospital predictors for the specific body part. A supplementary protocol could not only help in the identification of these injuries, it could help redirect the patients to trauma centers with the specific resources they need.

Future perspectives

This thesis showed that improvement in prehospital trauma triage quality is a necessity. The newly developed triage prediction model, integrated in a mobile app, can be the first step in the improvement. Currently, a pilot study is running in different regions of the Netherlands to test the mobile app. This might be the endpoint of this thesis, but it is the starting point to improve prehospital trauma triage, as some critical problems still remain to be solved.

Defining higher-level trauma center resource-need

Worldwide, the most used surrogate marker for a severely injured patient in need of higher-level trauma center care is the Injury Severity Score (ISS). The ISS is an anatomic scoring system, based on the injury severity of the injuries to different body regions.[9] This score correlates with chance of hospitalization, injury-related disability, and mortality. However, using this score, patients in need of higher-level trauma center resources can be missed.

Patients with an ISS > 15 are considered severely injured patients, however, some patients with an ISS of 9 might need higher-level trauma center resources as well. For example, patients with a cerebral hematoma, heart laceration, or pelvic fracture (all ISS 9). On the other hand, not all patients with an ISS > 15 need higher-level trauma center resources. An inaccurate definition of a severely injured patient will not only give an inaccurate representation of the triage quality, it is also an inadequate basis to improve the prehospital trauma triage. Formulating a resource-based definition could be the foundation on which the improvement of prehospital trauma triage is based and truly get the right patient to the right hospital.

Distance and prehospital triage

The nearest hospital should be bypassed for a higher-level trauma center in case of a patient in need of higher-level trauma center care.[3, 10] However, it remains unknown when it is better to transport the patient to the nearest hospital, instead of a higher-level trauma center.

Balancing supply and demand

This thesis focused on the transport of severely injured patients to higher-level trauma centers, this is the start to improve prehospital trauma triage. However, in reality, multiple levels among trauma centers and more patient groups that need different resources exist. A more tailor-made prediction model, directing patients to the specific trauma center they need might be the next step to improve prehospital trauma triage for all patients. Additionally, a real-time indication of the trauma centers' capacity could help redirect the patients to the best possible hospital for that individual patient at that moment. With this, smarter tool, the supply and demand could be better balanced.

EMS provider education

Treatment and transport decisions must be made quickly and correctly; therefore, EMS providers must be well trained to make these decisions under adverse circumstances. In the Netherlands, the EMS providers are registered specialized nurses, with a seven-month training on the job. In contrast to the EMS providers in the United States, the EMS providers in the Netherlands have to care for all patients in het prehospital phase, including patients with neurologic and cardiologic complaints. To maintain competencies and qualification, EMS providers attend annual refresher courses. However, one potential aspect in the education is still missing; the EMS providers do not receive feedback on their work. Where all complications are registered and reported to doctors, the EMS providers do not receive regular feedback on their performance and cannot learn from their actions. Timely feedback to the EMS providers on the correctness of their decisions could help in the education and experience.

Current privacy regulations in the Netherlands do not allow for feedback on the patients' injuries to the EMS providers. This is a major missed opportunity and flaw in the care system. With these regulations, the government obstructs the advancement in knowledge and expertise of EMS providers -and consequently, improvement of prehospital trauma triage quality.

The government must seize this opportunity and solve these restrictions, so a routine feedback system can be developed. To make it even more efficient, the feedback system could be incorporated in the mobile app. After the EMS providers has used the app to decide the destination and has transported the patient to the trauma center, the patients' injuries are send back to the app, with information what the best level trauma centers would have been for that patient. With this feedback, the EMS provider judgment can improve a lot.

Joining forces: the optimal trauma triage system

With further centralization it is crucial that the EMS providers can differentiate between the patients in need of higher-level trauma center care. Implementation of the new triage tool in a mobile app should be the next step in the advancement of prehospital trauma triage. In this app the whole trauma system –from dispatch center to the hospital– could be integrated, so the information from every part of the chain could be send ahead to the next. This will improve the whole trauma chain.

Additionally, the new triage tool could also be the basis for triage tools for other specialties, such as Neurology or Cardiology. For example, in the field of Neurology, some patients have to be transported to a Comprehensive Stroke Center, while lower acuity patients should be transported to the nearest stroke center. The next step would be to develop and implement a tool for all patients transported by EMS providers. The lessons learned could be used for the most optimal implementation of these tools in the prehospital field.

General conclusions

Trauma systems have been developed to provide optimal care for patients and increase their chance of survival. At the start of the trauma system chain is prehospital trauma triage, the goal of which is to transport the right patient to the right trauma center. The current system is well designed; however, it can be optimized with accurate prehospital trauma triage. Inadequate prehospital trauma triage quality has a negative impact on the whole trauma system chain, such as a decreased functional outcome for the patient and relatively higher trauma care costs. The currently used prehospital trauma triage protocols and triage quality desperately need improvement. Innovation, education, and regional collaboration are the three pillars on which this improvement is based. A newly developed triage tool serves as an important first step on the road ahead to optimize prehospital trauma triage. This road will lead to an improvement of the entire trauma care chain and provide future patients with the care they deserve.

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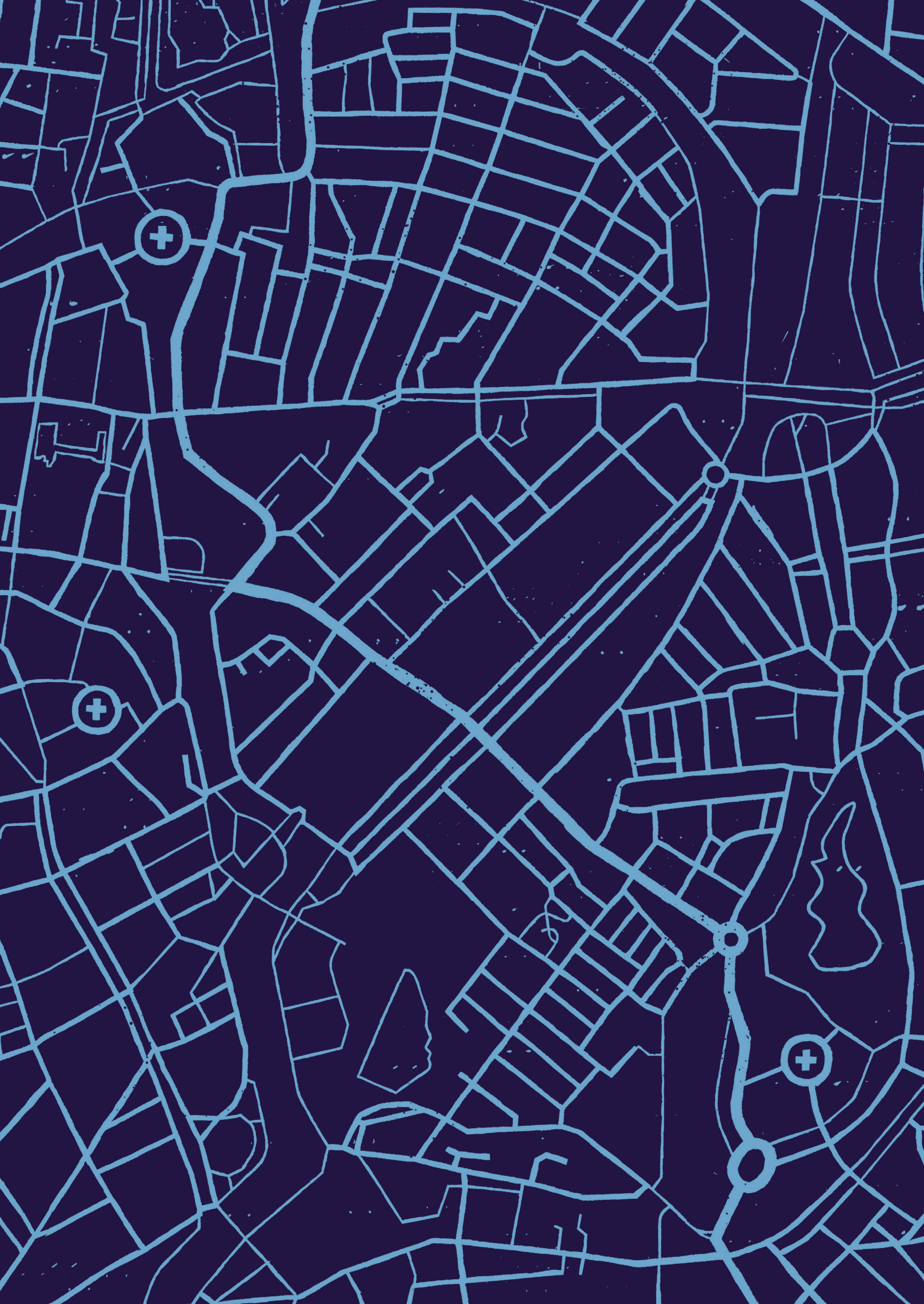

Summary

12

Summary

Worldwide, every five seconds a life is cut short as a result of an injury. Additionally, many more lives are affected by injury-related disabilities.[1] Not only does this include the lives of the patients, but those of their families and communities too, often irrevocably changing them in a devastating way. In first world countries, systems of trauma care have been shown to substantially reduce the mortality associated with injury.[2-4] These systems are an organized effort within a geographical region aiming to provide fitting care for all trauma patients. Over the last decades, studies focused on optimizing such trauma systems in terms of balancing timely access to expert care, ability of practitioners and teams to sustain necessary expertise, and cost effectiveness of the overall system.[3, 4]

Prehospital care is the first link in the chain of the trauma system. When a person is injured, a call is made to the dispatch center and the emergency medical services (EMS) are activated. The EMS providers have to start initial care, decide whether treatment at a trauma center is necessary, and if so, transport the patient to the most appropriate trauma center.[5] The chain of trauma care is a pathway leading from the on-scene emergency care to discharge from the trauma center, passing several decision points along its way. Continuity throughout the trauma chain enables the most efficient and effective care. Any delays or inappropriate decisions at the decision points can reduce quality of care and lead to increased risk of complications, suboptimal recovery, or even death.

In trauma systems, different levels of trauma centers exist. Each level is specifically designed to facilitate the appropriate care for the patients' needs. In general, two levels of trauma centers can be distinguished; higher-level and lower-level trauma centers. The higher-level trauma centers have the facilities to provide total and definitive care for every aspect of injury and all severely injured patients, 24 hours a day, seven days a week. Lower-level trauma centers are, in their turn, designed to treat the patients without severe injuries, so these patients can be cared for promptly.[6]

Severely injured patients have a higher chance of survival when treated at a higher-level trauma center.[2] Furthermore, transport of severely injured patients to lower-level trauma centers can result in: delay in diagnosis, missed injuries, and decreased functional outcome.[2, 3] In other words, accurate prehospital trauma triage can save lives. Concurrently, transport of the

patients without severe injuries to lower-level trauma centers should be warranted, to lower the burden on higher-level trauma centers.[11, 12]

Every single day, EMS providers assess and make decisions for each individual patient. This process of prehospital trauma triage plays a central role in any trauma system. The goal is to identify the at-risk patients and transport them timely to the most appropriate trauma center. However, identification of severely injured patients is a challenging task. Most people involved in traumatic situations are not injured, a minority requires evaluation at the hospital, and only 0.5% qualifies as severely injured.[7] The EMS providers must differentiate between these cases on-scene, often in adverse situations, without advanced diagnostic equipment, forcing them to act on incomplete or unavailable data. With this in mind, the importance of prehospital trauma triage cannot be understated. Bringing structure and clarity is critical for a reliable triage process.

In order to accomplish this, prehospital trauma triage protocols have been developed to help EMS providers identify severely injured patients. In 1986, the American College of Surgeons Committee on Trauma (ACS-COT) established the first prehospital trauma triage protocol, which included the concept of bypassing the nearest hospital for a higher-level trauma center.[8, 9] This has proven to be pivotal in the development of prehospital trauma triage systems. The ACS-COT set a target goal of transporting 95% of the severely injured patients to a higher-level trauma center (which is equal to an undertriage rate of 5%).[10] To lower the undertriage rate, more patients have to be transported to higher-level trauma centers. The transport of up to 35-50% of the patients without severe injuries to a higher-level trauma center can be accepted (this is an overtriage rate of 35%-50%), in achieving this.

Around the globe, different trauma triage protocols are used. Most include an assessment of vital signs, mechanism of injury, and injury type criteria.[6, 11, 12] However, the currently used triage protocols worldwide are not able to adequately identify the severely injured patients (**Chapter 2**) and subsequently achieving the goals set by the ACS-COT. In addition to the triage protocol, other factors play an important role in the transport decisions. These include: EMS provider judgment, geographical distance, and patient characteristics (**Chapter 3**). EMS provider judgment is one of the factors that could substantially lower the undertriage rate, especially for severely injured patients that are missed due to a failing triage protocol. (**Chapter 4**). Triaging pediatric patients is different from adults. This is due to a great variability in normal ranges of vital signs, mechanism of injury, and injury patterns seen across childhood.

Separately evaluating the prehospital trauma triage quality for pediatric patients showed that none of the triage protocols complied with the quality targets for undertriage and overtriage (**Chapter 5**).

Evaluation of the prehospital trauma triage in two regions of the Netherlands showed that the triage protocol in use functioned so poorly; even flipping a coin had a higher chance of correctly identifying a severely injured patient. (**Chapter 6** and **Chapter 7**) Fortunately, the EMS providers also rely on their clinical judgment and experience to assess the patient. Consequently, more severely injured patients are transported to higher-level trauma centers. Still, work remains to be done, since 22%-27% of the severely injured patients were not transported to a higher-level trauma center (undertriage).

As shown in the aforementioned studies, prehospital trauma triage needs improvement. An accurate triage protocol should be of first concern, as it forms the base of adequate prehospital trauma triage. A newly developed and validated prediction model could identify over 90% of the severely injured patients (**Chapter 8**). This triage prediction model could aid EMS providers in their transport decisions. Furthermore, addition of EMS provider judgment could enhance the accuracy even more.

The head and thorax are the most commonly severely injured body parts. On-scene identification of injuries to these body parts often proves to be challenging (**Chapter 9** and **Chapter 10**). Nevertheless, recognition of these injuries is especially important, as these patients need to be transported to a higher-level trauma center. Additional education, training, and a supplementary triage protocol with prehospital predictors could help in the identification of the injuries.

This thesis showed that currently used prehospital trauma triage protocols and triage quality are falling short and desperately need improvement. The current system is well designed; however, it can be optimized with accurate prehospital trauma triage. Inadequate prehospital trauma triage quality has a negative impact on the whole trauma system chain, such as a decreased functional outcome for the patient and relatively higher trauma care costs. Innovation, education, and regional collaboration are the three pillars on which this improvement is based. A newly developed triage tool serves as an important first step on the road ahead to optimize prehospital trauma triage. This road will lead to an improvement of the entire trauma care chain and provide future patients with the care they deserve.

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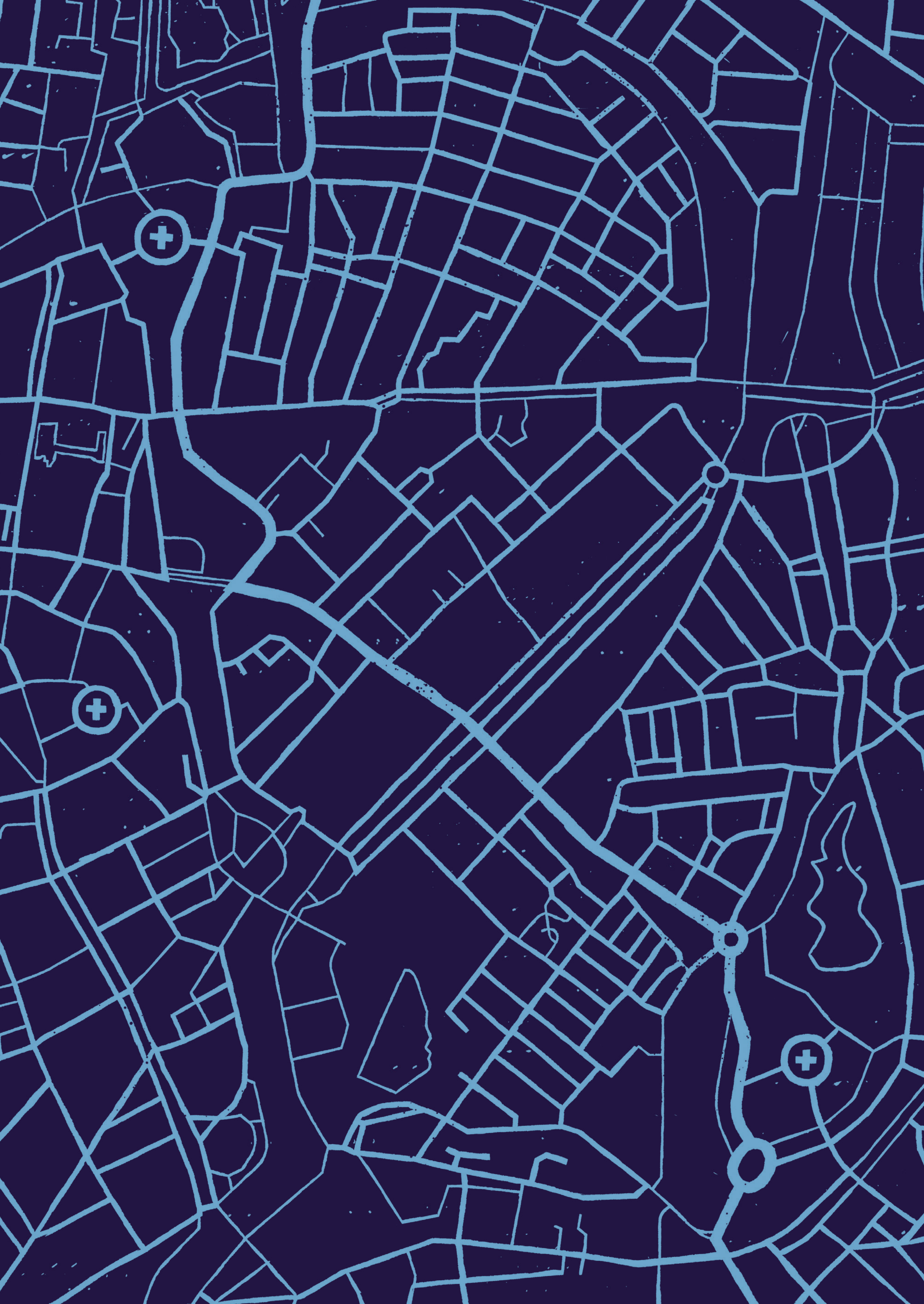

Nederlandse samenvatting

13

Nederlandse samenvatting

Over de gehele wereld overlijdt er elke vijf seconden iemand aan de gevolgen van traumatisch letsel. Naast dit akelige feit, wordt een nog veel groter aantal levens permanent aangetast vanwege door letsel-veroorzaakte handicaps.[1] Deze letsels hebben niet alleen een effect op het leven van de patiënt, maar ook op die van zijn of haar familie en omgeving. In eerste wereldlanden zijn traumasystemen ontwikkeld om de mortaliteit als gevolg van traumatische letsels aanzienlijk te verlagen.[2-4] Deze traumasystemen bieden binnen één regio passende zorg voor alle traumapatiënten. De wetenschap heeft zich gedurende de afgelopen decennia met name gericht op het optimaliseren van dergelijke traumasystemen. Dit doet zij door tijdige toegang tot deskundige zorg te waarborgen, toe te zien op het vermogen van behandelaars en teams om de noodzakelijke expertise te onderhouden en door het bewaken van de kosteneffectiviteit van het totale systeem.[3, 4]

Pre-hospitale zorg is de eerste schakel in de spoedzorgketen. Wanneer een persoon gewond raakt zal er een melding binnenkomen bij de meldkamer en zo nodig de ambulance ingeschakeld worden. De ambulanceverpleegkundigen moeten vervolgens ter plaatse de behandeling starten, beslissen of behandeling in een traumacentrum noodzakelijk is en, zo ja, de patiënt naar het meest geschikte traumacentrum transporteren.[5] De spoedzorgketen is het pad dat leidt van de zorg die ter plaatse geboden wordt tot en met ontslag uit het traumacentrum, waarbij verschillende beslismomenten gepasseerd worden. Continuïteit door de gehele spoedzorgketen zorgt voor de meest efficiënte en effectieve zorg. Vertraging en onjuiste beslissingen op deze cruciale beslispunten kunnen de kwaliteit van de zorg verminderen en leiden tot een verhoogd risico op complicaties, suboptimaal herstel of zelfs tot de dood.

In een traumasysteem zijn de traumacentra in verschillende levels onderverdeeld. Hoofdzakelijk valt er een onderscheid te maken tussen twee levels; de hogere-level traumacentra (in Nederland de level 1-traumacentra) en de lagere-level traumacentra (level 2- en 3-traumacentra in Nederland). De level 1-traumacentra hebben de faciliteiten om elk aspect van een letsel en alle ernstig gewonde traumapatiënten te behandelen, 24 uur per dag, zeven dagen per week. Aan de andere kant zijn de level 2- en 3-traumacentra specifiek gericht op de opvang en behandeling van traumapatiënten zonder ernstige letsels, zodat zij snel behandeld kunnen worden.[6]

Ernstig gewonde patiënten hebben een hogere overlevingskans wanneer zij behandeld worden in een level 1-traumacentrum.[2] Op deze manier kan adequate pre-hospitale trauma triage levens redden. Daarnaast kan behandeling van ernstig gewonde patiënten in een level 2- of 3-traumacentrum leiden tot een vertraging in diagnose, gemiste verwondingen en een verlaagde functionele uitkomst van de patiënt.[2, 3] Aan de andere kant moeten patiënten zonder ernstige letsels juist naar de level 2- en 3-traumacentra getransporteerd worden om onnodige belasting op het level 1-traumacentrum en relatief hoge kosten te voorkomen.[11, 12]

Pre-hospitale trauma triage door ambulanceverpleegkundigen speelt een centrale rol in elk traumasysteem. Dit proces heeft als doel: het herkennen van de ernstig gewonde patiënt en deze tijdig naar het juiste level traumacentrum transporteren. Echter is de herkenning van ernstig gewonde patiënten lastig. Na een ongeval hebben de meeste mensen geen letsel, een klein deel heeft behandeling nodig in een traumacentrum en bij slechts 0,5% is er sprake van ernstig letsel.[7] De ambulanceverpleegkundigen moeten deze patiëntengroepen ter plaatse onderscheiden –vaak in ongunstige situaties, zonder geavanceerde diagnostische apparatuur. Met dit in het achterhoofd, mag de waarde van pre-hospitale trauma triage niet onderschat worden. Een betrouwbaar triageproces op basis van structuur en duidelijkheid zijn hierbij letterlijk en figuurlijk van levensbelang.

Pre-hospitale trauma triage protocollen zijn ontwikkeld om ambulanceverpleegkundigen te ondersteunen in de herkenning van ernstig gewonde patiënten. In 1986 heeft de American College of Surgeons Committee on Trauma (ACS-COT) het eerste pre-hospitale trauma triage protocol ontwikkeld. Hierin was ook het passeren van een level 2- of 3-traumacentrum voor een level 1-traumacentrum opgenomen.[8, 9] Dit heeft een bewezen cruciale rol gespeeld in de ontwikkeling van pre-hospitale trauma triage systemen. De ACS-COT heeft als doelstelling gesteld dat minstens 95% van de ernstig gewonde patiënten naar een level 1-traumacentrum getransporteerd moet worden (dit is gelijk aan een ondertriage van 5% of minder).[10] In nastreving van een zo laag mogelijk ondertriage percentage, moeten meer patiënten naar de level 2- en 3-traumacentrum getransporteerd worden. Om dit te kunnen bereiken kan het transport van 35% tot 50% van de patiënten zonder ernstige verwondingen geaccepteerd worden (overtriage).

Wereldwijd worden verschillende trauma triage protocollen gebruikt. De meeste protocollen omvatten een beoordeling van de vitale parameters, mechanisme van verwonding en verwondingstype.[6, 11, 12] Echter blijken de huidige protocollen niet in staat te zijn om adequaat ernstig gewonde patiënten te herkennen **(Hoofdstuk 2)**, om de gestelde doelstelling van de ACS-COT te behalen. Naast het triage protocol beïnvloeden ook andere factoren zoals de eigen inschatting van de ambulanceverpleegkundige, geografische afstand tot een level 1-traumacentrum en patiëntkarakteristieken de uiteindelijke bestemming **(Hoofdstuk 3)**. De eigen inschatting van de ambulanceverpleegkundigen is een van de factoren die de ondertriage zou kunnen verlagen. De ambulanceverpleegkundigen kunnen, op basis van hun eigen inschatting en ervaring, de ernstig gewonde patiënten herkennen die niet als zodanig werden ingeschat door het triage protocol **(Hoofdstuk 4)**. Pre-hospitale trauma triage van kinderen is anders dan de triage van volwassenen. Gedurende de jeugd is er een grote variabiliteit in de normaalwaarden van de vitale parameters, mechanismen van verwonding en verwondingspatronen. Een aparte evaluatie van de kwaliteit van pre-hospitale trauma triage onder kinderen liet zien dat geen enkel van de huidige triage protocollen voldeed aan de kwaliteitsdoelstellingen voor ondertriage en overtriage **(Hoofdstuk 5)**.

Evaluatie van de pre-hospitale trauma triage in twee regio's in Nederland liet zelfs zien dat het opgooien van een muntje tot betere herkenning van een ernstige gewonde patiënt leidt dan het volgen van het triage protocol **(Hoofdstuk 6 en 7)**. Gelukkig konden de ambulanceverpleegkundigen met hun eigen inschatting en ervaring de ernstig gewonde patiënten aanzienlijk beter herkennen, waardoor ernstig gewonde patiënten alsnog naar het level 1-traumacentrum werden gebracht. Helaas werd nog steeds 22%-27% van de ernstig gewonde patiënten niet naar een level 1-traumacentrum getransporteerd; er is duidelijk noodzaak tot verbetering.

De verbetering van het triage protocol moet de hoogste prioriteit hebben omdat dit de basis vormt van de pre-hospitale trauma triage. Het in deze thesis ontwikkelde en gevalideerde predictiemodel is in staat om meer dan 90% van de ernstig gewonde patiënten te herkennen **(Hoofdstuk 8)**. Dit predictiemodel kan ambulanceverpleegkundigen helpen in de keuze van het juiste traumacentrum. Aangevuld door de eigen inschatting van de ambulanceverpleegkundigen als extra criterium, zou de accuraatheid van het triage protocol in praktijk nog hoger kunnen blijken.

De meest voorkomende ernstig gewonde lichaamsdelen zijn het hoofd en de thorax. Het ter plaatse herkennen van deze letsels is lastig (**Hoofdstuk 9 en 10)**. Desondanks is de herkenning van deze letsels belangrijk omdat patiënten met deze letsels zeer gebaat zijn bij behandeling in een level 1-traumacentrum. Extra educatie, training en een aanvullend triage protocol met pre-hospitale voorspellers zouden kunnen helpen bij de herkenning van deze specifieke letsels. Deze thesis laat zien dat de huidige pre-hospitale trauma triage protocollen en triage kwaliteit tekort schieten en dringend aan verbetering toe zijn. Het huidige systeem is in essentie goed ontworpen; het kan echter sterk verbeterd worden door middel van nauwkeurige pre-hospitale trauma triage. Inadequate pre-hospitale trauma triage heeft een negatieve invloed op de gehele spoedzorgketen, zoals een verminderde functionele uitkomst van de patiënt en relatief hoge zorgkosten. Innovatie, educatie en regionale samenwerking zijn de drie pijlers waarop de verbetering gebaseerd moet zijn. Een nieuw triage middel is de eerste belangrijke stap op weg naar optimale pre-hospitale trauma triage. Deze weg zal leiden naar een verbetering van de gehele spoedzorgketen, die toekomstige patiënten zal verzekeren van de zorg die zij verdienen.

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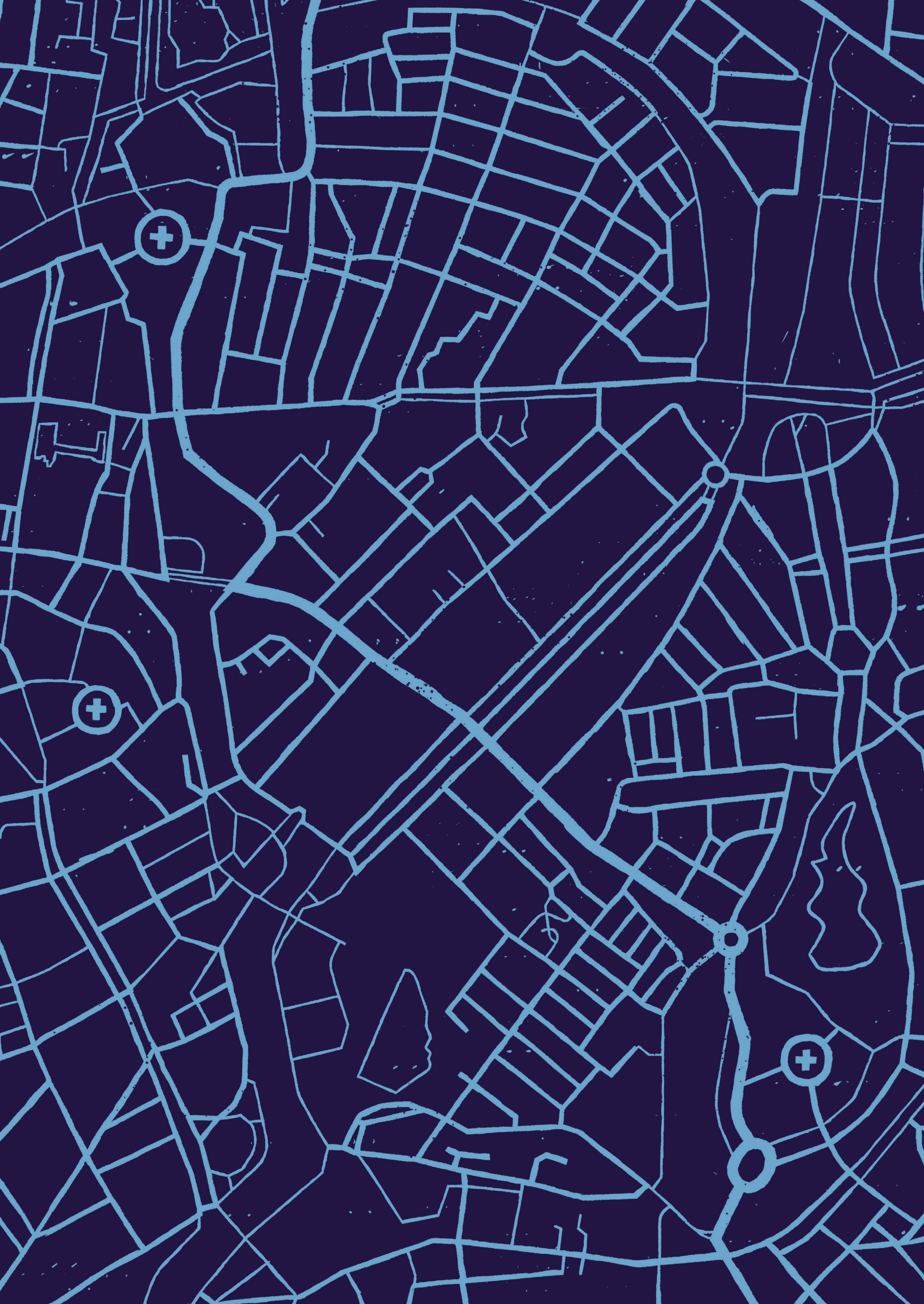

Appendices

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Lieve pap en mam, zonder jullie was het nooit gelukt om altijd al m'n overenthousiaste dromen na te jagen en te bereiken, van onderhandelen over huisdieren tot dit boekje. Het is toch allemaal maar mooi gelukt, nu maar afwachten wat de volgende bevlogen plannen zullen zijn... ;)

Curriculum Vitae

Eva Adriana Jacqueline (Eveline) van Rein was born on May 25th, 1990 in Utrecht, the Netherlands. In 2008, she graduated from bilingual preparatory scientific education at Cals College in Nieuwegein. After completing the first year of Biomedical Sciences at Utrecht University in 2009, she was admitted to medical school and subsequently started her education in Medicine. In 2015, during her Masters, she was a graduate research assistant at the Orthopedic Spine Center, Massachusetts General Hospital in Boston, United States of America, for five months. In the same year, the first research project under the supervision of Dr. M. van Heijl and Prof. dr. L.P.H. Leenen was initiated. This project became the start of this thesis. After graduating on October 4th, 2017, she worked full-time as a PhD candidate to finish her thesis and guide the pilot study of the Trauma Triage App. This position was funded by the Dutch Innovation Fund.

In January 2019, Eveline will start working at the St. Antonius Hospital, as a resident not in training in General Surgery. Next, she hopes to start her surgical residency.

List of abbreviations

ACS-COT	American College of Surgeons Committee on Trauma
ALS	Advanced Life Support
ANA	Anatomic criteria
AIC	Akaike information criterion
AIS	Abbreviated Injury Scale
AIS98	Abbreviated Injury Scale 1990, Update 1998
AIS08	Abbreviated Injury Scale 2005, Update 2008
AUC	Area under the curve
CI	Confidence interval
CNS	Central nervous system
CPR	Cardiopulmonary resuscitation
CRAMS	Circulation, Respiration, Abdomen, Motor, Speech criteria
ED	Emergency department
EMS	Emergency medical services
FN	False negative
FP	False positive
FTDS	Field Triage Decision Scheme
GCS	Glasgow Coma Scale
HTI-ISS	Hospital Trauma Index Injury Severity Score
ICD-9	International Statistical Classification of Diseases and Related Health Problems
ICISS	nternational Classification Injury Severity Score
ICU	Intensive care unit
IQR	Inter Quartile Range
ISS	Injury Severity Score
LPA	National Protocol of Ambulance Services (Landelijk Protocol Ambulancezorg)
MGAP	Mechanism, Glasgow Coma Scale, Age, and Arterial Pressure score
MOI	Mechanism of injury
NISS	New Injury Severity Score
NR	Not reported
PHI	Prehospital Index
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PTS	Pediatric Trauma Score

PTTC	Pediatric Trauma Triage Checklist
STARD	Standards for Reporting Diagnostic Accuracy Studies
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
QUADAS-2	Quality Assessment of Diagnostic Accuracy Studies
ROC	Receiver operating characteristic
RS	Reference standard
RTS	Revised Trauma Score
SBP	Systolic blood pressure
SD	Standard deviation
TC	Trauma center
TN	True negative
TP	True positive
T-RTS	Revised Trauma Score for Triage
TRISS	Trauma Score – Injury Severity Score
TS	Trauma Score
TTR	Trauma Triage Rule
VTC	Vittel triage criteria

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