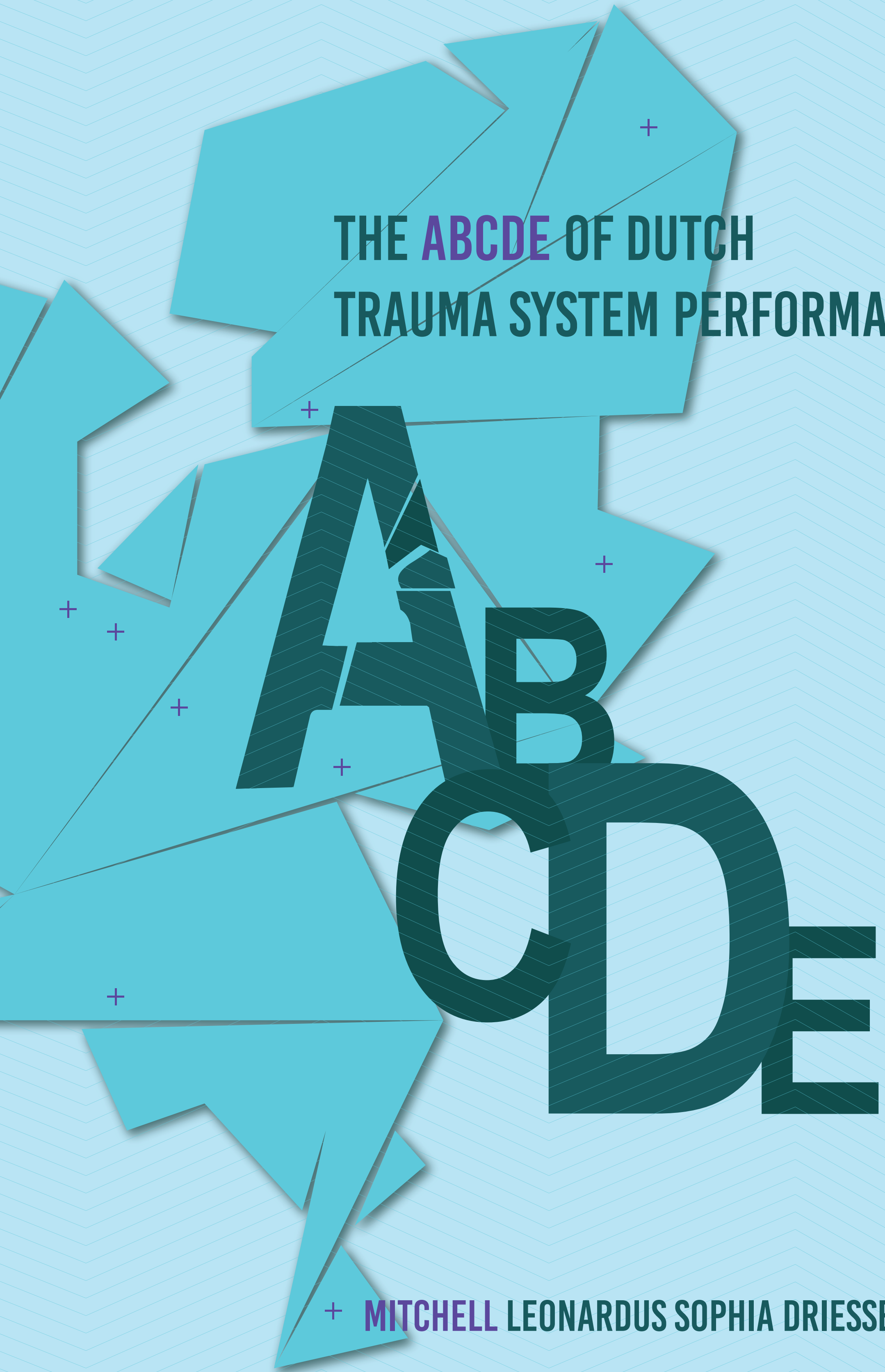
THE ABCDE OF DUTCH TRAUMA SYSTEM PERFORMANCE



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The ABCDE of Dutch trauma system performance

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The ABCDE of Dutch trauma system performance

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(met een samenvatting in het Nederlands)

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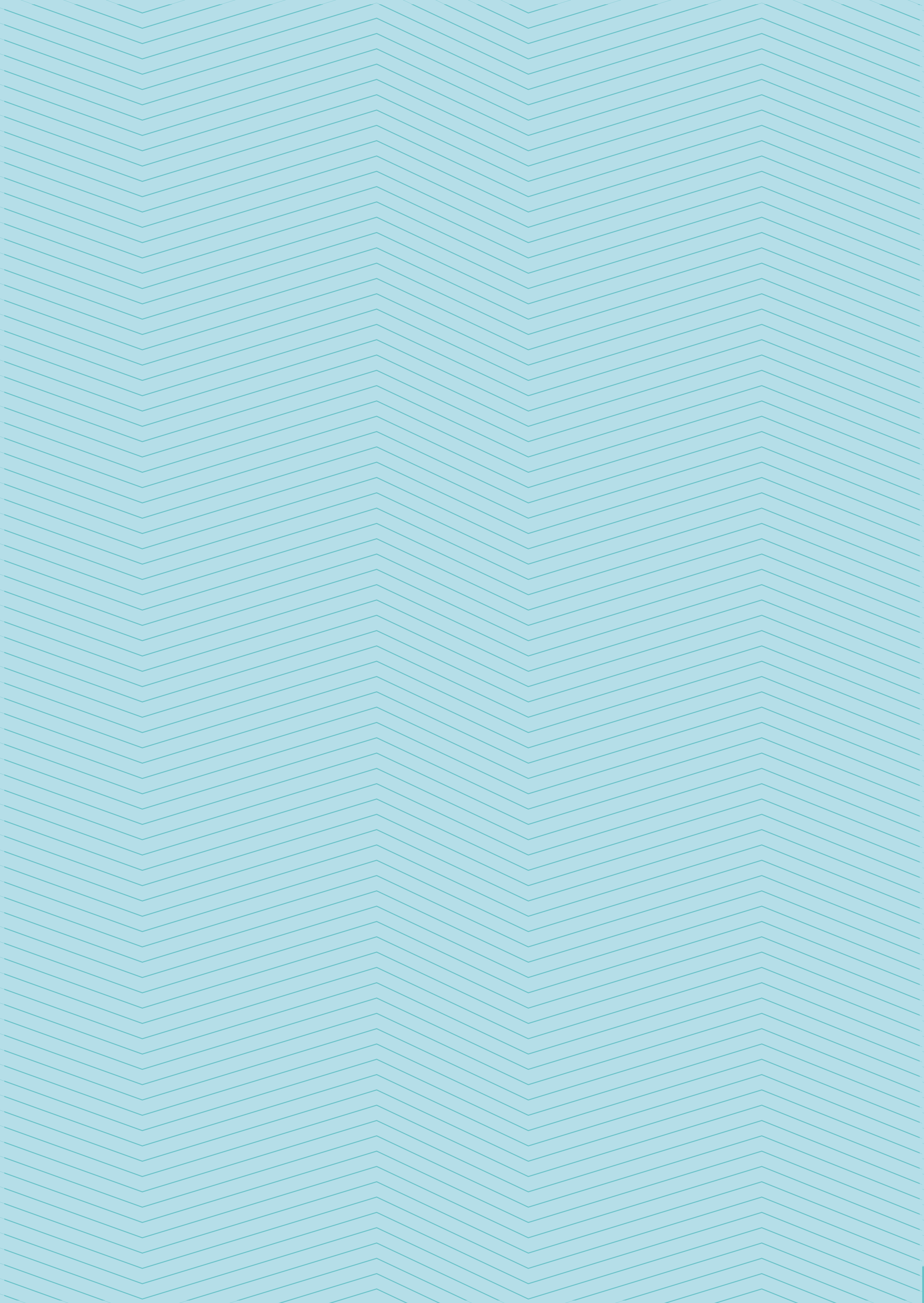

CHAPTER I

General introduction

GENERAL INTRODUCTION

Trauma

The global burden of trauma consists of approximately 5 million deaths annually and accounts for an estimated 10% of the disability adjusted life years.[1] Because trauma is a leading cause of death among young healthy people, trauma has a major impact in the disease burden and health economic aspects such as direct healthcare costs and the productivity loss caused by work absenteeism.[2,3]

Evolution of trauma care in the Netherlands

In 1987, a thesis on trauma care evaluation in the Netherlands concluded that trauma care in the Netherlands was neither integrated nor organized.[4] Trauma patients were, in general, transported to the nearest hospital rather than to the most appropriate hospital. Moreover, it advocated for regionalized trauma care, designation of major trauma centres and the use of field triage protocols, in line with the recommendation of the American College of Surgeons Committee on Trauma (ASCOT). The Dutch trauma system was reformed in 1999, following the ASCOT guidebook entitled *Optimal Resources for Care of the seriously Injured,*[5] a total of eleven level-I or Major Trauma Centres (MTCs) were designated.

At present, these eleven level-I trauma centres form geographically defined inclusive trauma regions. In each region these centres fulfil a coordinating role that encompasses multiple level-II and III trauma centres. The level-I trauma centres are fully equipped to deliver the highest level of emergency and surgical care for the most severely injured with 24/7 coverage of all specialities including thoracic and neurosurgery. Additionally, four of these centres are equipped with 24/7 Helicopter Emergency Medical Service (HEMS) and a Mobile Medical Team (MMT) which are able to dispatch by helicopter or ground vehicle.[6] Within the regional trauma systems all trauma-receiving hospitals have a direct linkage to an MTC, to facilitate expeditious transfer of injured patients within the network, to the hospital with the medical expertise and functional/instrumental capacity that matches their alleged resource needs. Lower-level trauma centres (i.e., level-II and level-III), on the other hand were established to provide optimal care for moderately and mildly injured patients in a cost-effective manner. This organizational change had a major impact on trauma care, as it did in most countries that implemented inclusive trauma systems.[7–13]

The Dutch National Trauma Registry

Trauma registries have been established to collect comprehensive data for quality assessment, improvement and research purposes. Trauma registries document a range of information on injured patients such as demographics, injury details, pre-hospital care, hospital presentation, interventions, and outcomes. A registry can reveal trends in performance and outcomes in individual trauma centres and allows benchmarking and comparison across trauma networks and countries.

By 2012, eleven national trauma registries were identified of which five were established in Europe.[14] The Dutch National Trauma Registry (DNTR) (in Dutch: *Landelijke Traumaregistratie*) includes prospectively collected data from all hospitals with a trauma-receiving emergency department in the Netherlands. This concerns over 70.000 patients annually. Yet, the DNTR differs distinctively in terms of inclusion criteria from other European registries. Namely, it captures all acute trauma related hospital admissions regardless of their age, injury type or severity, resource use or length of stay.

Several publications have stated that excluding trauma patients based on their age, injury type or mechanism is expected to result in an underestimation of resource utilisation, a restricted insight in the quality of trauma care and trauma epidemiology.[15–17] Yet, a comparison study that illustrates the impact of registering all acute hospital admissions is lacking.

Trauma Scoring

The ancient Egyptians were the first to document ways to estimate the severity of an injury. Moreover, they defined when to treat and when to abstain, based on the medical capabilities at that time.[18] Now thousands of years later, trauma scoring is used to distribute patients based on their expected medical needs (i.e., which patients are in need of specialist care in dedicated institutions and which should receive treatment at a level-II or III hospitals).

Originating from 1974 the Injury Severity Score (ISS) is the oldest and still most widely used scoring system in literature.[19] The ISS is based on the Abbreviated Injury Scale (AIS).[20] The AIS score is an anatomically based, consensus derived global severity scoring system that classifies each injury by body region according to its relative importance. The body then is divided into six anatomic regions. The highest AIS score for each of the three most seriously injured regions are squared, and these values are added to produce the final ISS total. Although the ISS has proven to be a useful tool for assessing injury data and trauma systems,[21] it has been criticized for failing to distinguish between poor outcomes related to severe injury or inadequate care,[22] and for having wide interobserver variations.[23] Furthermore, an ISS cut-off of ≥16 points is generally chosen to define the severely injured.[24] In the 1980's these patients had an expected mortality rate of more than 20%.[24] However, since the introduction of trauma systems [8,10,12,13,25] and improvements in medical care, mortality is currently considerably lower.[26]

In 2014, the Berlin polytrauma definition (BPD) was introduced.[27] This definition combines the anatomical classification of injury, the AIS, with the physiological response. For the development of the BPD, the mortality cut-off value was set at a minimum of 30%. The Berlin definition was developed based on a database of severely injured ICU admitted patients, a validation of this new method yet needs to be performed, preferably in a separate data set.

Evaluation of trauma care

Contemporary trauma care performance is mostly based on mortality rates. For example, determining whether a new treatment improves outcome for a specific population. Yet, other, more general determinants can be measured to assess the delivered level of care. Moreover, it is of interest to monitor whether patients were adequately triaged and received appropriate care, and to measure the performance of a single hospital or an entire trauma system.

Another unexpected situation whose effects on trauma care is worth evaluating surfaced in early 2020. A virus named SARS-CoV-2 which was first reported on in the Hubei province of the People's Republic of China, swept across the world.[28] The infected patient suffers from fever, coughing, and dyspnoea in the context of viral pneumonia.[29] The first COVID-19 case in the Netherlands was reported on February 27th, 2020. On March 11th the World Health Organisation recognised the existence of a new pandemic, and on March 12th the Dutch government declared a national lockdown. The SARS-CoV-2 pandemic has had a profound impact on healthcare in general and on the availability of emergency services. More importantly the immediate access to specialised services, including intensive care unit (ICU), was potentially endangered during the pandemic. Severely injured patients highly rely on these resources, shortage may influence their outcome. The silver lining of this undefined pandemic period is that it offers the opportunity to evaluate the functionality of the trauma care system in a time of extreme pressure. The weaknesses and strengths we discover during the pandemic can serve as guidance for similar situations to come.

Accurate prediction of mortality probabilities for individual trauma patients is essential for trauma system evaluation. Various models have been developed for this purpose. One of the first and most well-known models is the Trauma Injury and Severity Score (TRISS). This model was developed based on the United States Major Trauma Outcome Study dataset (MTOS). The MTOS included all trauma admissions and deaths due to trauma, and was first described in 1987.[24,30] The TRISS uses the combination of patient age, the ISS,[31] and the weighted physiological parameters Glasgow Coma Scale (measure to determine the level of consciousness), [32] systolic blood pressure and respiratory rate, included in the Revised Trauma Score (RTS) to predict a patients' likelihood of survival.[33]

Over the past decades several multiple suggestions were reported to overcome shortcomings of the TRISS method, by adding new variables or restructuring existing ones to improve calibration [33–37]. Numerous new models have been developed that claimed to have overcome these alleged shortcomings, or were fitted for specific trauma patient categories such as hip fracture patients, or patients admitted to the ICU.[38–41]

The superlative of comparing the predicted mortality with the observed mortality in a single patient, is doing so for a hospitals' entire trauma population, over an extended period of time. Funnel plots are a graphical tool to present hospital comparisons, without involving ordering or ranking of hospitals.[42] The control limits indicate a range, in which standardized mortality ratio would be expected to fall. If a hospital falls outside of the control limits, it is seen as performing differently than is it to be expected, given the value of the benchmark and prompts an investigation into these hospitals. On the other hand, quality can be improved by learning from good performing hospitals (i.e., adopt best practice) and initiated improvement strategies.

Thesis Outline

The introduction of regional trauma systems has led to a significant improvement in the distribution of patients, the efficiency and quality of trauma care in the Netherlands. The commitment to evaluate outcomes has become an essential part of modern medicine and is most often based on patient-centred outcomes. However, the evaluation of trauma system performance is not that straightforward. In this thesis we evaluate several indicators and methodological components, adjust them if needed, aiming to facilitate the next leap forward in trauma care.

This thesis was build following the ABCDE methodology, which is a well-known method used in trauma resuscitation. However, the letters normally used for Airway, Breathing, Circulation, Disabilities and Environment have been given a different meaning. The first part of this thesis presents the current Accuracy in which the Dutch trauma system succeeds in centralizing the treatment of severely injured patients at the designated level-I trauma centres and non-severely injured patients at level-II or -III centres. Then, we Benchmark the DNTRs' all-inclusive regime with two other European trauma registries. Finally, we assess the epidemiological changes and evaluate the secondary effects on trauma care induced by a socio-economic and medical Catastrophe.

The second part evaluates proposed Definitions to describe severely injured trauma patients, and presents improved preconditions and new methodologies for monitoring and Evaluating trauma system performance. The research questions covered by each chapter are outlined in the following table.

Table 1. The study questions addressed per chapter in this thesis

CHAPTER	Research question
2	To what degree do Dutch trauma system succeed in centralising the treatment of severely injured patients (ISS > 15) at level-I trauma centres and non-severely injured (ISS 1-15) patients at level-II or III trauma centres?
2	Which patient characteristics are associated with emergency medical services undertriage of severely injured patients to a major trauma centre?
3	What is the added value of registering all acute trauma admissions?
4	Did the SARS-CoV-2 pandemic change the epidemiology of the Dutch trauma population?
4	How have the periods of social lockdown affected the mechanisms of injury?
5	Could access and specialized care for severely injured trauma patients be guaranteed to the same level of trauma care during the pandemic as in the pre-COVID-19 era?
5	To what extend did the COVID-19 induced intensive care pressure affect trauma patient outcomes?
6	How well does the Berlin polytrauma definition (BPD) perform in identifying patients with a high risk of resource use and mortality?
6	How well does the Berlin polytrauma definition (BPD) perform in identifying patients with a high risk of resource use and mortality?
7	Are severe isolated injuries entities to be reconned with?
7	Are physiological risk factors present during emergency department resuscitation indicative of resource use or mortality for patients with severe isolated injuries?
8	Can we develop a prediction model that accurately predicts the mortality of all acutely admitted trauma patients using only widely available variables?
9	Can funnel plots be used to evaluate and regulate quality trauma care?

PART I: EVALUATION OF THE DUTCH TRAUMA SYSTEM

A

The Accuracy in which trauma patients are triaged and distributed in the Dutch trauma system is assessed in *Chapter I.* Previous studies indicated that the Dutch triage scheme correctly identifies approximately two-third of the severely injured (ISS ≥16) patients. Mistriage can be detrimental in mature trauma systems with a high degree of resource centralization. Undertriage (i.e., transporting patients requiring specialized trauma care to level-II or III trauma centres) is associated with increased number of readmissions, mortality and life-long disabilities.[7,43,44] In contrast, overtriage (i.e., transporting patients without the need of specialized care to level-I trauma centres) is associated with excessive cost and overutilization of scarce resources.[44,45] This chapter we aimed to assess whether the distribution of severely injured patients is adequately centralized within the current regional trauma networks, and if any specific characteristics of patients who are being mistriaged can be identified.

B

The in- and exclusion criteria differ extensively between trauma registries.[14,16], which results in significant differences in demographics between international cohorts. After the Finish, the Italian and the Swiss trauma registries, which were instated in 2006 and 2008, the DNTR is one of Europe's youngest trauma registries. Because of the DNTRs' non-discriminative inclusion criteria, it aims to approximate the trauma population in its entirety. *Chapter III* offers a further in-depth description of the maturation of the DNTR and its current status. Moreover, the impact of registering all acute hospital admissions was assessed by Benchmarking the DNTRs' inclusion criteria with those from the national trauma registries in England and Germany.

C

The impact of the SARS-CoV-2 pandemic has been vast and tangible for everyone. Beside its impact on society and the economic situation, the pandemic can be seen as a Catastrophe for the healthcare system in general. However, this unfortunate event created a unique and unexpected opportunity to see if the DNTR can be used to measure secondary on healthcare in general. We hypothesized that two main circumstances might have had an impact on the composition of the trauma population and the delivered trauma care. First, lockdown policies were set to mitigate the propagation of the virus. However, these periods of lockdown could have induced in shifts of epidemiological characteristics of trauma populations. Second, the SARS-CoV-2 pandemic drastically changed the demand on healthcare services resulting in a redistribution of materials and personnel to meet demand. More importantly the immediate access to specialised services, including operating theatres and intensive care units, could not always be guaranteed during the pandemic. In *Chapter IV* we aim to review the effects on trauma epidemiology, aetiology, prehospital times, and primary outcomes during the first two infectious waves and the deceivably tempered period in between. *Chapter V* describes the effects that the unprecedented pressure on the healthcare, and intensive care facilities in particular, had on those trauma patients that rely on it the most, namely those with severe injuries.

PART II: CHANGING THE BOUNDARIES

D

A carefully defined major trauma definition is key in order to facilitate cost-effective and good quality trauma care. Moreover, these definitions can be used to assess trauma system performance based on the level of centralization. Such definition should describe severely injured patients that pose a high risk of medical resource use and mortality. In *Chapter VI* we evaluate the functionality of the Berlin polytrauma Definition on the entire Dutch trauma population. Moreover, the value of adding physiological risk factors to an anatomical injury score is assessed. Subsequently, in *Chapter VII* we try to adjudicated whether patients with severe isolated injuries should be included a Definition for major trauma patients.

E

In order to Evaluate a hospitals' performance within a trauma system it is essential to have a sophisticated mortality prediction model. More importantly, a model should be simple, practical and offering accurate probability of death estimates for all acutely admitted trauma patients. In *Chapter VIII* we describe the development and validation of such a mortality prediction model. Consequently, the performance of this new model is tested on multiple important subgroups of trauma patients. Funnel plots can be used as a graphical tool to assess and compare the clinical performance of hospitals on a quality indicator against a benchmark. In *Chapter IX* we present a national regulatory control scheme on the applicability of this newly developed prediction model using funnel plots for all trauma-receiving hospitals in the Netherlands. Moreover, hospital performance trends are Evaluated with the introduction of comet plots.

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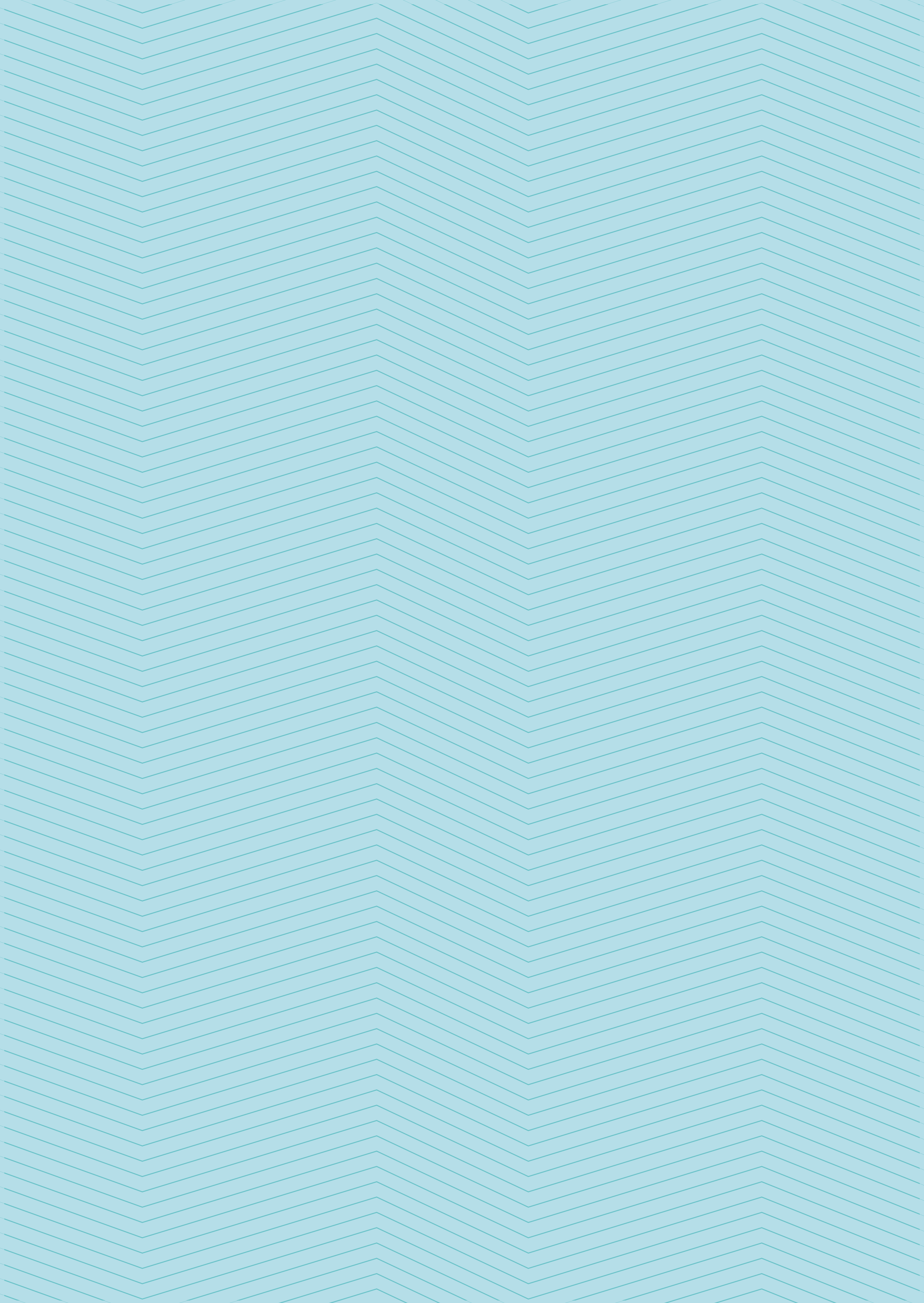

PART I

Evaluation of the Dutch trauma system

A

CHAPTER 2

Dutch trauma system performance: are injured patients treated at the right place?

Injury

L.M. Sturms; M.L.S. Driessen; D. van Klaveren; H.J. ten Duis; G.J. Kommer; F.W. Bloemers; D. den Hartog; M.J.R. Edwards; P.A. Leenhouts; S.W.A.M. van Zutphen; I.B. Schipper; W.R. Spanjersberg; K.W. Wendt; R.J. de Wit; M. Poeze; L.P.H. Leenen; M.A.C. de Jongh

ABSTRACT

Background

The goal of trauma systems is to match patient care needs to the capabilities of the receiving centre. Severely injured patients have shown better outcomes if treated in a major trauma centre (MTC). We aimed to evaluate patient distribution in the Dutch trauma system. Furthermore, we sought to identify factors associated with the undertriage and transport of severely injured patients (Injury Severity Score (ISS) >15) to the MTC by emergency medical services (EMS).

Methods

Data on all acute trauma admissions in the Netherlands (2015-2016) were extracted from the Dutch national trauma registry. An ambulance driving time model was applied to calculate MTC transport times and transport times of ISS >15 patients to the closest MTC and non-MTC. A multivariable logistic regression analysis was performed to identify factors associated with ISS >15 patients' EMS undertriage to an MTC.

Results

Of the annual average of 78,123 acute trauma admissions, 4.9% had an ISS >15. The non-severely injured patients were predominantly treated at non-MTCs (79.2%), and 65.4% of patients with an ISS >15 received primary MTC care. This rate varied across the eleven Dutch trauma networks (36.8%-88.4%) and was correlated with the transport times to an MTC (Pearson correlation -0.753, p=0.007). The trauma networks also differed in the rates of secondary transfers of ISS >15 patients to MTC hospitals (7.8% - 59.3%) and definitive MTC care (43.6% - 93.2%). Factors associated with EMS undertriage of ISS >15 patients to the MTC were female sex, older age, severe thoracic and abdominal injury, and longer additional EMS transport times.

Conclusion

Approximately one-third of all severely injured patients in the Netherlands are not initially treated at an MTC. Special attention needs to be directed to identifying patient groups with a high risk of undertriage. Furthermore, resources to overcome longer transport times to an MTC, including the availability of ambulance and helicopter services, may improve direct MTC care and result in a decrease in the variation of the undertriage of severely injured patients to MTCs among the Dutch trauma networks. Furthermore, attention needs to be directed to improving primary triage guidelines and instituting uniform interfacility transfer agreements.

INTRODUCTION

In the late 1980s, Dutch trauma surgeons expressed their concerns about the quality of care, especially for severely injured patients in the Netherlands.[1] A major issue was that those severely injured patients were often directly transported from the injury scene to the closest hospital regardless of the patients' injuries and the available resources. In 1998, following the United States' example, the Dutch government decided on the implementation of an organised "inclusive" trauma care system composed of regional trauma networks.[2,3] The government designated ten (eleven in 2008) highly specialised, regional, major level one trauma centres (MTCs) and instructed them to care for severely injured individuals, establish regional trauma networks, exchange knowledge and skills, and monitor the quality of trauma care by setting up a trauma registry. The designation of the MTCs was mainly based on available resources in existing hospitals, such as trauma, thoracic and neurosurgical specialties. The number of severely injured patients was unknown at that time. The eleven Dutch trauma networks differ in geography, the number of hospitals, and the population to be served. The geographic layout of the regional trauma networks in the Netherlands and the dispersion of all trauma-receiving hospitals are displayed in Figure 1.

Figure 1. Dutch trauma-receiving hospitals and their distribution within the trauma network

Treatment of severely injured patients in designated MTCs has proven to be associated with a significant survival benefit.[4,5] Moreover, studies have shown that immediate transport of severely injured individuals to an MTC is associated with less morbidity and improved survival than the transport of severely injured individuals to a non-MTC.[6,7] Accordingly, efforts should be made to get the patient to the right place the first time to ensure the best possible outcome for the patient and to make the best use of available resources.[8] In support of this principle, in 2015, the Dutch National Health Care Institute set the norm that within each of the 11 trauma networks, at least 90% of the severely injured patients with an Injury Severity Score (ISS) of >15 should be taken directly to the nearest MTC.[9] Non-MTCs play an essential role in the trauma system by providing effective care for patients with minor and moderate injuries. This helps to preserve MTC resources for the care of severely injured individuals.

The Netherlands includes over 17 million inhabitants living on 33,682 square kilometres of land, with approximately 92% of the entire population living in urban areas, being 13th on the list of the most urbanised countries in the world.[10] The Dutch population has good access to emergency care, and approximately 98% of the inhabitants can be taken to an MTC within 90 minutes. Dutch standards mandate that an ambulance must arrive at the incident scene within 15 minutes. Furthermore, emergency departments (EDs), regardless of their level of trauma care, need to be located in such a manner that an ambulance can deliver a patient to a hospital ED within 45 minutes after the emergency call.[11] Consequently, a relatively large number of EDs, mainly non-MTCs, are dispersed over the Netherlands (Figure 1). To direct the severely injured patient directly to an MTC, it is rather likely that a non-MTC has to be bypassed.

To assist patient triage to the appropriate level of care, the Dutch national protocol of ambulance services has a trauma field triage decision scheme. The triage criteria include vital signs, injury type, and the mechanism of injury and are largely based on the Field Triage Decision Scheme of the American College of Surgeons Committee on Trauma.[8] In severe trauma, one of the four 24/7 Dutch mobile medical teams (MMTs) and two German MMTs (for the border regions) can be dispatched to provide prehospital on-scene medical assistance. The MMT doctor (a specially trained trauma surgeon or anaesthesiologist) decides on hospital triage and often accompanies the patient during transport to the hospital in the ambulance. Air medical transport does not often occur in the Netherlands.

This study evaluates to what degree Dutch trauma networks succeed in centralising the treatment of severely injured patients (ISS >15) at MTCs and non-severely injured (ISS 1-15) patients at non-MTCs. Specifically, we were interested in factors associated with the direct transport of severely injured patients by emergency medical services to an MTC, including MTC transport times as well as patient and trauma characteristics.

METHODS

Patients

For this study, we included all patients reported to the Dutch National Trauma Registry (DNTR) for the hospital admission years 2015-2016. The DNTR inclusion criteria were treatment at the ED within 48 hours after the trauma, followed by direct admission, transfer to another hospital, or death at the ED. Patients without signs of life upon arrival at the ED were excluded.[12]

The DNTR dataset includes the Utstein template items for uniform reporting of data following major trauma.[13] Injuries are coded according to the 2008 update of the Abbreviated Injury Scale (AIS).[14] Severely injured patients were defined as patients with an Injury Severity Score >15.[15]

Primary and MTC definitive care

For the analyses on the primary disposition of injured patients, interfacility transfers were excluded. For the calculations of the percentage of severely injured patients with definitive MTC care, we have added the severely injured patients transferred from another hospital to an MTC to the numerator. We assumed that (the vast majority of) these severely injured patients were transferred from a non-MTC to receive a higher level of trauma care at the MTC.

Trauma network characteristics and prehospital transport times

The population and the amount (square kilometres) of land area (excluding rivers and lakes) within the 11 trauma networks were calculated based on the statistics per four-digit postal code published by Statistics Netherlands (CBS). Moreover, the availability of MTC care within one hour was calculated for Dutch inhabitants based on their home address postal codes and was displayed in time intervals of 10 minutes.

The Dutch National Institute for Public Health and the Environment applied an ambulance driving time model to calculate the population-weighted mean transport time by ground ambulance (GEMS) to the MTC per trauma network. This model is based on measurements of actual driving times of ambulances ‘using lights and sirens’ throughout the Netherlands. This model was also applied to calculate the ground ambulance transport times for ISS >15 patients from the injury location (four-digit postal code) to the closest MTC and non-MTC. The additional transport time to the closest MTC was computed by subtracting the transport time from the injury location to the closest MTC from the transport time to the closest non-MTC; if the difference was positive, the MTC was the closest hospital.

Data analysis

Descriptive statistics were used to summarise the data. Differences between proportions were analysed using $\chi 2$ tests for categorical variables. Pearson's correlations were calculated to determine the relationship between the trauma network's percentage of ISS >15 patients with direct MTC care and the trauma network's mean population-weighted transport time to the MTC and the number of non-MTC hospitals.

A multivariable logistic regression analysis was used to determine which factors are associated with a severely injured patient's direct EMS transport to an MTC. The following patient characteristics were included: age; sex; injury cause; the type of injury; severe (AIS≥4) injury of the head, spine, thorax, abdomen, lower extremity and external body regions; and ISS. Furthermore, we included the additional GEMS transport time to the closest MTC. Missing data were imputed with multiple imputations (5 imputation cohorts). Injury cause, the type of injury, and/or additional transport time were missing for 44.9% of the patients. We compared results without and with the imputation of missing values. The multiple imputations and multivariable regression analyses were conducted in R with the lme4 package.[16,17] A p-value <0.05 was considered statistically significant.

RESULTS

The DNTR consisted of 165,847 patients in 2015 and 2016. A total of 1,843 (1.1%) of these patients were excluded due to missing ISS scores. Furthermore, 7,759 (4.7%) patients who were transferred from another hospital were excluded from the analyses on the primary distribution of the patients as well as for the number of trauma admissions per trauma network and on a national level. This resulted in an annual average of 78,123 acute trauma admissions in the Netherlands, giving an incidence rate of 457 per 100,000.

Figure 1 illustrates the geographical layout of the Netherlands and the distribution of MTCs and non-MTCs within the 11 trauma networks. In the Netherlands, just over half of the Dutch people can reach an MTC within 20 minutes, and 80% can reach an MTC within 30 minutes (Table 1). Approximately 2% of Dutch inhabitants cannot reach a level one trauma centre within 1 hour.

Figure 2 shows the ISS distribution and the percentage of patients with direct MTC care. The more severely injured patients are more often treated at MTCs. Overall, an annual average of 3,842 (4.9% of all acute trauma admissions) patients were severely injured, with an ISS >15. Almost two-thirds of these patients (65.4%) received primary MTC care.

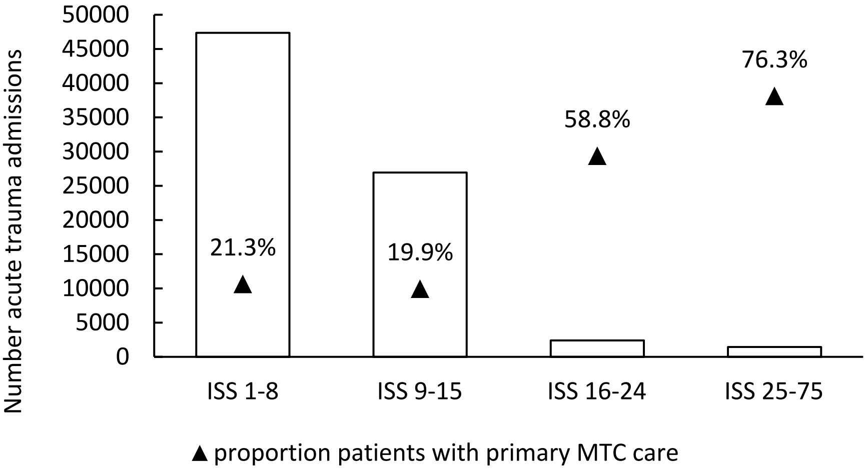

Figure 2. Annual number of acute trauma admissions in the Netherlands and percentage with primary MTC care vs. injury severity

Table 1. Number of Dutch inhabitants and their transport times to the nearest major trauma centre

Transport time (minutes)	Number of inhabitants (x1000)	Cumulative (%)
0 – 10	3532	21.1
10 – 20	5739	55.3
20 – 30	4272	80.7
30 – 40	2044	92.9
40 – 50	670	96.9
50 – 60	166	97.9
> 60	352	100.0

Table 2. Dutch trauma network characteristics and patient distribution

Trauma network	Inhabitants	Land area (km^2)	Non-MTCs	MTCs	Population weighted mean GEMS transport time to MTC (min)	Annual number of trauma admissions						
						Total	ISS 1-15	ISS 1-15 primary MTC-care		ISS >15	ISS >15 primary MTC-care	
						n	n	n	%	n	n	%
TN 1	756,920	2094	3	1	15.2	3649	3435	1590	(46.3)	214	160	(74.8)
TN 2	1,096,795	3674	6	1	20.0	5463	5236	1643	(31.4)	227	128	(56.4)
TN 3	1,117,330	2146	5	1	25.3	6036	5729	1152	(20.1)	307	113	(36.8)
TN 4	1,290,450	2547	5	1	22.7	7030	6619	954	(14.4)	411	291	(70.8)
TN 5	1,364,500	2098	9	1	21.6	6124	5922	774	(13.1)	202	148	(73.3)
TN 6	1,392,305	1640	5	1	14.2	4945	4545	890	(19.6)	400	282	(70.5)
TN 7	1,665,030	8001	10	1	28.7	7713	7356	894	(12.2)	357	198	(55.5)
TN 8	1,852,490	1979	9	1	18.7	8531	8192	1249	(15.2)	340	224	(65.9)
TN 9	1,866,735	1216	6/7[†]	3	9.6	7421	6980	3348[*]	(48.0)	441	390**	(88.4)
TN 10	2,164,815	3383	14	1	23.1	9543	9021	956	(10.6)	522	352	(67.4)
TN 11	2,512,320	4903	11	1	26.0	11670	11247	2017	(17.9)	423	229	(54.1)
NL	17,079,690	33,681	83.5	13	20.9	78,123	74,281	15,464	(20.8)	3842	2,511	(65.4)

Abbreviations: TN, Trauma network; ISS, Injury Severity Score; MTC, Major trauma centre.

[*] Total number of ISS 1-15 patients treated at three MTC hospitals.

[**] Total number of ISS >15 patients treated at three MTC hospitals.

[†] One ED of a non-MTC was closed in 2016.

Table 3. Characteristics of severely injured patients with direct EMS transport to non-MTCs vs. MTCs

		Non-MTC (n=2121)		**MTC (n=4852)**		**Univariate**
		n	**(%)**	**n**	**(%)**	**p-value**
Sex						<0.001
	male	1284	(60.5)	3267	(67.3)	
	female	837	(39.5)	1585	(32.7)	
Age						<0.001
	0-54 y	699	(33.0)	2488	(51.3)	
	55-69 y	499	(23.5)	1107	(22.8)	
	70-84 y	592	(27.9)	955	(19.7)	
	> 84 y	331	(15.6)	302	(6.2)	
Injury mechanism						<0.001
	low-energy fall	606	(28.6)	887	(18.3)	
	motor vehicle accident	126	(5.9)	649	(13.4)	
	other RTA	487	(23.0)	1564	(32.2)	
	high-energy fall	193	(9.1)	831	(17.1)	
	other accident	206	(9.7)	662	(13.6)	
	unknown	503	(23.7)	259	(5.3)	
Type of injury						<0.001
	blunt	1809	(85.3)	4654	(95.9)	
	penetrating	30	(1.4)	170	(3.5)	
	unknown	282	(13.3)	28	(0.6)	
Severity of injury						<0.001
	head AIS≥4	759	(35.8)	2081	(42.9)	
	spine AIS≥4	79	(3.7)	272	(5.6)	
	lower extremity AIS≥4	99	(4.7)	241	(5.0)	
	thorax AIS≥4	325	(15.3)	718	(14.8)	
	abdomen AIS≥4	136	(6.4)	277	(5.7)	
	external AIS≥4	77	(3.6)	220	(4.5)	
ISS						<0.001
	ISS 16-24	1549	(73.0)	2694	(55.5)	
	ISS 25-75	572	(27.0)	2158	(44.5)	
Additional transport time to closest MTC						<0.001
	≥0 min	90	4.2	1174	24.2	
	1-10 min	341	16.1	1049	21.6	
	11-20 min	345	16.3	491	10.1	
	>20 min	455	21.5	229	4.7	
	unknown	890	42.0	1909	39.3	

Abbreviations: RTA, road traffic accident; AIS, Abbreviated Injury Score; ISS, Injury Severity Score; MTC, major trauma centre; non-MTC, non-major trauma centre.

Table 4. Factors associated with direct EMS transport of severely injured patients to MTCs

		Multivariate logistic regression model		
		Adjusted OR (95%CI)		p-value
Sex				
	male		reference	
	female	0.851	(0.746 - 0.971)	0.017
Age				
	0-54 y		reference	
	55-69 y	0.662	(0.563-0.778)	<0.001
	70-84 y	0.422	(0.357-0.500)	<0.001
	> 84 y	0.264	(0.209-0.334)	<0.001
Injury mechanism				
	low-energy fall		reference	
	motor vehicle accident	4.261	(3.333-5.448)	<0.001
	other RTA	2.120	(1.788-2.512)	<0.001
	high-energy fall	2.791	(2.274-3.426)	<0.001
	other accident	1.793	(1.393-2.308)	<0.001
Type of injury				
	blunt		reference	
	penetrating	1.712	(1.089 - 2.693)	0.020
Severity of injury				
	head AIS≥4	1.386	(1.183-1.623)	<0.001
	spine AIS≥4	1.589	(1.160-2.177)	0.004
	lower extremity AIS≥4	1.072	(0.793-1.449)	0.650
	thorax AIS≥4	0.703	(0.583-0.848)	<0.001
	abdomen AIS≥4	0.505	(0.382-0.667)	<0.001
	external AIS≥4	0.779	(0.535-1.133)	0.191
ISS				
	ISS 16-24		reference	
	ISS 25-75	2.642	(2.268 - 3.078)	<0.001
Additional transport time to MTC				
	≤0 min		reference	
	1-10 min	0.247	(0.205-0.297)	<0.001
	11-20 min	0.085	(0.070-0.104)	<0.001
	>20 min	0.029	(0.023-0.036)	<0.001

Abbreviations: RTA, Road traffic accidents; AIS, Abbreviated Injury Score; ISS, Injury Severity Score; MTC, Major trauma centre.

Table 2 describes the trauma network characteristics, including the annual number and primary distribution of injured patients. The 11 Dutch trauma networks differ in terms of land area (range 1,216 - 8,001 sq. km), population to be served (range 756,920 - 2,512,320), the population-weighted mean GEMS transport times to the MTC (range 9.6 - 28.7 minutes), and the number of hospitals (range 4 - 15). Large variations between the networks were observed in the number and distribution of patients to MTC and non-MTC hospitals. The degree to which the trauma network succeeded in providing direct MTC care for severely injured patients ranged between 36.8% and 88.4%.

Shorter population-weighted mean GEMS transport times to the MTC within the trauma network, as a metric of MTC access per trauma network, were significantly correlated with higher percentages of severe injuries with direct MTC care (Figure 3) (Pearson correlation -0.753, p=0.007). The number of non-MTC hospitals per trauma network was not significantly correlated with the percentage of severely injured patients receiving direct MTC care (Pearson correlation -0.100, p=0.770).

Factors associated with direct EMS transport of severely injured patients to an MTC

Most (87.6%) of the severely injured patients were transported by ambulance to the hospital. An additional 3.1% were transported by helicopter. Furthermore, 5.3% of the severely injured patients came by their own transportation means and did not receive EMS treatment at the scene. Finally, for 3.9% of the severely injured patients, the transportation mode was not recorded.

The MMT provided assistance for 25.0% of the ISS >15 patients (ISS 16-24: 16.8%; ISS 25-75: 38.6%). Almost all ISS >15 patients with MMT care were directly triaged to an MTC (93.4%). Only 12.6% of the patients who received MMT care were transported by helicopter.

The incident location (four-digit postal code) was registered in the DNTR for 4,174 (59.9%) ISS >15 patients transported by EMS. Figure 4 shows that longer ground transport times resulted in lower percentages of severely injured patients directly transported to an MTC. Overall, the most severely injured patients with an ISS >24 were more often directly transported to an MTC than severely injured patients with an ISS 16-24; this finding was also true in cases of longer transport times.

An MTC was the closest hospital for 26.8% of the ISS >15 patients with a recorded incident location. Almost all these patients were directly transported to an MTC

(93.6%). If a non-MTC was the closest hospital, EMS decided to bypass this hospital and transport the patients directly to an MTC for 62.1% of the ISS >15 patients.
Table 3 shows that the severely injured patients with direct EMS transport to MTCs differed from their counterparts with direct EMS transport to a non-MTC in all patient and injury characteristics. Multivariable regression analysis (Table 4) demonstrated that females, older patients, patients with severe injuries of the thorax and abdomen, patients injured due to ground-level falls, and patients with longer additional transport times to the closest MTC were less likely to be transported directly to an MTC. Patients injured due to a road traffic accident or a high-level fall were more likely to be directly transported to an MTC. Additionally, higher ISS scores, penetrating injuries, and severe head or spine injuries were associated with a higher proportion of direct EMS transport to an MTC.

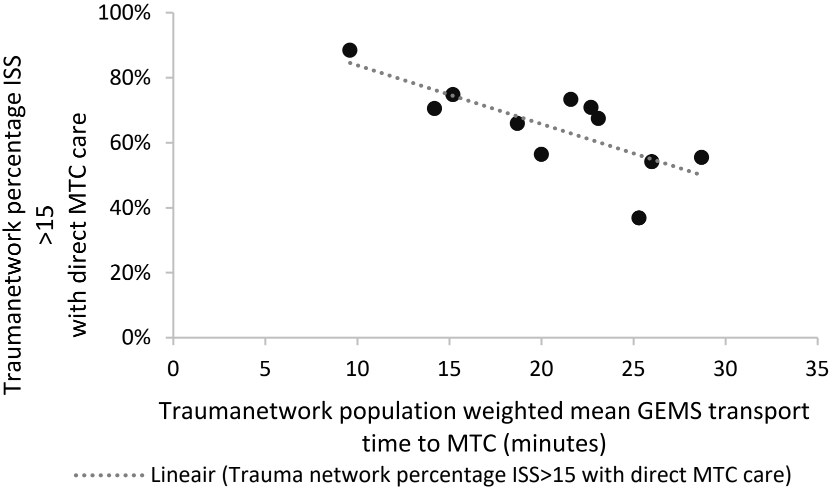

Figure 3. Trauma network percentage of severely injured with primary MTC care vs. MTC access

Definitive MTC care for severely injured patients

The MTCs recorded a total of 840 severely injured patients who were secondarily transferred into the MTC within 48 hours after the incident. Following the assumption that these patients were transferred from non-MTC hospitals, almost one-third (31.6%) of the severely injured patients initially treated at a non-MTC did receive definitive MTC care (trauma network range 7.8%-59.3%). This eventually resulted in 76.3% of all severely injured patients receiving MTC treatment within 48 hours after the incident (trauma network range: 43.6% - 93.2%). The percentage of severely injured patients with secondary triage to the MTC within the trauma network was not correlated with MTC access in terms of the trauma network population-weighted mean transport time (Pearson r=0.369; p=0.264).

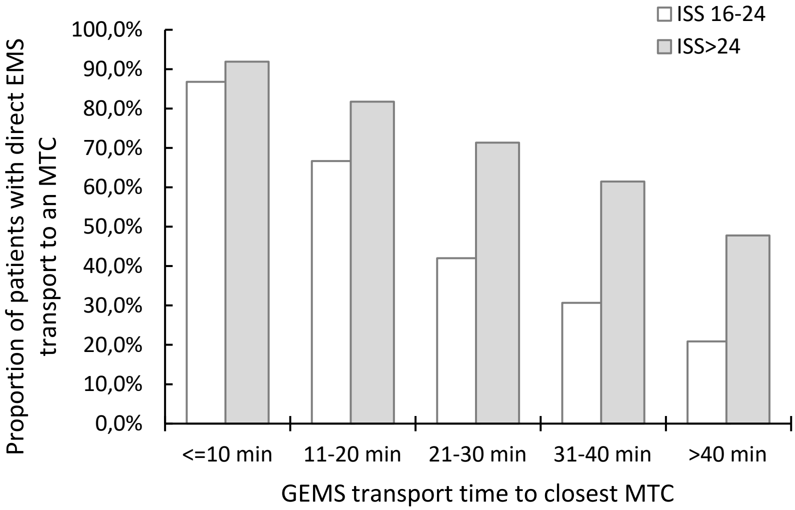

Figure 4. Percentage of severely injured patients directly transported to an MTC versus GEMS transport time to the closest MTC

DISCUSSION

Our study reveals that even in a highly urbanised country such as the Netherlands with good access to emergency care, one-third of all severely injured patients do not receive primary MTC care. This rate is comparable to multiple retrospective studies on the undertriage of severely injured patients in the United States.[18–22] A systematic review of prehospital trauma triage systems reported undertriage percentages for severely injured patients ranging between 1% and 68%.[23] A recent meta-analysis found an evident association between the level of trauma care and in-hospital mortality for major trauma patients. Unfortunately, this meta-analysis included only two European studies, which leaves the levels of undertriage in Europe relatively unattended.[24] Therefore, correct and early identification of severely injured patients in the field is of foremost importance in getting the ISS >15 patients to the MTC the first time.

Compared with other triage protocols, the Dutch triage scheme has shown relatively poor accuracy in identifying severely injured patients.[25–27] Previous studies indicated that the Dutch triage scheme correctly identified approximately one-third of ISS >15 patients.[25,26] Although large differences were observed between trauma networks, a far larger percentage of ISS >15 patients were directly transported to an MTC. Consequently, it seems that the ambulance paramedics outperformed the triage protocols in appraising the potential benefit of trauma centre care for injured patients. This stems from the inaccuracy of field triage tools in predicting post hoc injury severity scoring, such as the ISS, which limits the triage performance metrics.[28] The ISS is widely implemented and therefore of interest for many; however, it should not be used as a system goal but rather as a benchmark to compare networks and performance over time or to calibrate new triage decision tools.

Our results point towards the following injury and patient characteristics associated with prehospital undertriage of ISS >15 patients: female sex, older age, ground-level falls, severe thoracic or abdominal trauma, and lower injury severity scores. These factors have also been mentioned in studies across multiple countries [23]. Improving the identification of high-risk elderly patients has gained interest from the perspective of the ageing population [29]. Older trauma patients differ from younger patients: they can incur life-threatening injuries from low-velocity mechanisms, they have a higher prevalence of comorbid conditions, they take more medications, and they have different physiological responses to injury.[29,30] Innovations are needed to improve triage accuracy and may include novel physiological measurement or diagnostic technologies.[25] Attention needs to be directed towards prehospital health-care providers' education and feedback loops regarding their decision-making.[31,32]

In addition to identifying severely injured patients, other factors, such as the distance to the MTC, may play an important role in triage decision-making. With long travel times to an MTC in remote and rural areas, severely injured patients may be transported first to a non-MTC hospital for initial management and subsequently transferred to an MTC. However, the Netherlands is a small, flat, and densely urbanised country with a very dense road and motorway network.[33,34] Areas within 30 minutes of driving proximity to level one or two trauma centres are generally considered urban.[31,35] The Dutch National Institute for Public Health and the Environment has estimated that, on average, within 30 minutes, 81% of the Dutch population can be transported by ground ambulance to an MTC.[36] Given the good access to MTC care in the Netherlands, it is not to be expected that many severely injured patients will be transported to a non-MTC for initial stabilisation. This assumption is supported by our finding that the most severely injured patients (with a higher risk of deterioration of vital signs and haemodynamic instability) were more often directly transported to an MTC, even in the case of longer transport times. Moreover, the mean population-weighted GEMS transport times to the MTC of the trauma networks were not correlated with higher secondary transfer rates of severely injured patients. Nevertheless, an important factor that needs to be further investigated is the growing demand for ambulance services and shortages of paramedics in the Netherlands. This may affect paramedics' choice for a destination hospital during field triage because a longer travel distance impacts ambulance service availability.

To overcome long travel times due to large distances to the MTC or traffic problems, more frequent MMT support and transport may be considered. Two Dutch studies on the impact of on-scene MMT assistance among severely injured patients showed an odds ratio for survival of approximately two in favour of those aided by MMT.[37,38] This beneficial effect of MMT assistance is likely to originate from the additional expertise and therapeutic options in airway management brought to the scene. Further optimisation of on-scene assistance could simultaneously increase the number of severely injured patients with primary MTC care when MMT physicians decide to transport the patient by helicopter. A study by Mommsen showed a significant decrease in transportation time in cases of multiple trauma, traumatic brain injury and burn injuries; therefore, it was suggested that parallel dispatching of helicopter emergency medical and ambulance services should be considered if the flight distance is more than 35-40 km.[39] However, to date, helicopter transport is not a common practice in the Netherlands. Only the northern Wadden Islands are covered by a routine helicopter ambulance service.

This study shows substantial variability in the percentage of severely injured patients with primary MTC care within the trauma networks. Additionally, we found differences between the trauma networks in the degree to which severely injured patients were secondarily transported to an MTC and the percentage of severely injured patients with definitive care at the MTC. Together, these findings point towards a variation in transfer practices and reveal an important area of improvement. Guidelines for transferring trauma patients between institutions are an essential part of the trauma system.[8] There are no uniform criteria for transfer from a non-MTC to an MTC based on the patients' needs in the Netherlands. These criteria need to be developed, and appropriate training of emergency department physicians at non-MTCs may be essential.

The initial designation of the Dutch MTC was meant to result in the centralisation of care for severely injured patients at the MTCs. However, in the current situation, most Dutch MTCs do not meet the volume requirements of at least 240 yearly trauma admissions with an ISS above 15. Furthermore, depending on the geographical location of an MTC hospital, e.g., centralised in a large city without a non-MTC close by, significant numbers of patients with minor injuries could ultimately be treated at the MTC. Most likely due to insufficient numbers of patients, previous work from the Netherlands has been unsuccessful in showing convincing evidence of a difference in mortality between severely injured patients treated at an MTC and those treated at a non-MTC.[26,40] Moreover, this seemingly inevitable overtriage can have adverse effects on system performance through the overuse of limited resources within the MTC infrastructure and increased costs. One of the priorities in trauma system development has been to minimise the potential delays in definitive care and the risk of morbidity and mortality to individual patients.[41] To secure further concentration of severely injured patients and efficient use of resources, one may think of introducing alternative services for less severely injured patients for whom the MTC is the nearest hospital.

An important strength of our study is that the Dutch trauma registry has national coverage, records all acute trauma admissions, and includes prehospital data. Because all hospitals participate in the Dutch trauma registry and it has broad inclusion criteria, we were able to evaluate patient distribution on a national level and benchmark trauma networks.

Our analysis also has several limitations, including the retrospective design and missing data. Retrospective evaluations of system triage performance should always be interpreted with caution. Because actual triage decisions are governed by clinical guidelines and limited information, triage performance is evaluated using definitions with complete information. For example, an ISS >15 was used as a criterion to define severe injury, but it cannot be measured on the scene. We attempted to mitigate the missing data for the regression analysis by using multiple imputations. Another limitation is that for the transferred patients, the referring hospital was unknown. We made the assumption that severely injured patients transferred to an MTC were referred from a non-MTC. Some of these transfers may have been between MTCs, but we expected this to be only a very small proportion. However, this may have resulted in a slight overestimation of definitive MTC care for severely injured patients. To follow a patient closely through the care chain, a personal pseudonymised identification number and Dutch legislation record are needed. An additional limitation of our data analyses is that for the calculations of the GEMS transport times to the closest MTC and non-MTC hospitals, we did not include weather conditions or rush-hour conditions (i.e., traffic congestion), which can impact the transport times. Finally, for the evaluation of ‘getting the patient to the right place at the right time’, it is essential to be able to identify severely injured patients in need of MTC care. In this study, we chose to define severely injured patients requiring MTC care as patients with an ISS >15. These patients have been shown to have better outcomes after MTC treatment.[5] Moreover, an ISS >15 is the most common measure applied in trauma triage evaluation studies to identify patients in need of trauma centre care.[23] However, the ISS >15 criterion may misclassify several injured persons requiring or perhaps not requiring critical trauma resources.[42] It is possible that to define patients who need MTC care and have a high risk of morbidity and a low survival probability, anatomic injury severity (determined with the AIS) should be a criterion, and pathological conditions such as those included in the ‘Berlin polytrauma definition’ should be taken into consideration.[43] This definition includes not only anatomic injury severity (i.e., significant injuries in two or more different anatomic AIS regions) but also pathological conditions (e.g., hypotension, unconsciousness, acidosis, coagulopathy, and age).

CONCLUSION

Despite the facts that the Dutch trauma system was implemented twenty years ago and the Netherlands is a highly urbanised country with good access to MTC care, approximately one-third of severely injured patients are not primarily managed at an MTC. Although a system-wide prehospital triage tool is used, large differences were observed among regional trauma networks in the transportation of severely injured patients directly or secondarily to the MTC.

This study revealed that, in addition to patient and injury characteristics, the distance to the MTCs is of great importance. Health-care providers and policymakers need to prioritise the improvement of the prehospital primary and secondary triage of severely injured patients. Their efforts should focus on improving field triage, the awareness of factors that affect undertriaging, interfacility transfer guidelines, and the provision of resources to overcome longer transport times to an MTC.

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B

CHAPTER 3

The Dutch Nationwide Trauma Registry: the value of capturing all acute trauma admissions

Injury

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ABSTRACT

Introduction

Twenty years ago, the Dutch trauma care system was reformed by the designating 11 level one regional trauma centres (RTCs) to organise trauma care. The RTCs set up the Dutch National Trauma Registry (DNTR) to evaluate epidemiology, patient distribution, resource use and quality of care. In this study we describe the DNTR, the incidence and main characteristics of Dutch acutely admitted trauma patients, and evaluate the value of including all acute trauma admissions compared to more stringent criteria applied by the national trauma registries of the United Kingdom and Germany.

Methods

The DNTR includes all injured patients treated at the ED within 48 hours after trauma and consecutively followed by direct admission, transfers to another hospital or death at the ED. DNTR data on admission years 2007-2018 were extracted to describe the maturation of the registry. Data from 2018 was used to describe the incidence rate and patient characteristics. Inclusion criteria of the Trauma Audit and Research (TARN) and the Deutsche Gesellschaft für Unfallchirurgie (DGU) were applied on 2018 DNTR data.

Results

Since its start in 2007 a total of 865,460 trauma cases have been registered in the DNTR. Hospital participation increased from 64% to 98%. In 2018, a total of 77,529 patients were included, the median age was 64 years, 50% males. Severely injured patients with an ISS≥16, accounted for 6% of all admissions, of which 70% was treated at designated RTCs. Patients with an ISS≤ 15were treated at non-RTCs in 80% of cases.

Application of DGU or TARN inclusion criteria, resulted in inclusion of respectively 5% and 32% of the DNTR patients. Particularly children, elderly and patients admitted at non-RTCs are left out. Moreover, 50% of ISS≥16 and 68% of the fatal cases did not meet DGU inclusion criteria

Conclusion

The DNTR has evolved into a comprehensive well-structured nationwide population-based trauma register. With 80,000 inclusions annually, the DNTR has become one of the largest trauma databases in Europe. The registries strength lies in the broad inclusion criteria which enables studies on the burden of injury and the quality and efficiency of the entire trauma care system, encompassing all trauma-receiving hospitals.

INTRODUCTION

Trauma registries have been established to collect comprehensive data for quality assessment, quality improvement and research purposes. These registries document a range of information on injured patients such as demographics, injury details, pre-hospital care, hospital presentation, interventions, and outcomes. Tohira et al, identified 11 national trauma registries in 2011.[1] Five of these National registries are in Europe of which the England and Wales, Trauma Audit and Research (TARN) registry and the German, Deutsche Gesellschaft für Unfallchirurgie (DGU) Trauma Register, are the most cited in European literature.

In- and exclusion criteria differ extensively between trauma registries. This results in significant differences in demographics between the selected cohorts.[1,2] Exclusion of trauma patients based on their age, injury type or mechanism from trauma registries result in an underestimation of resource utilisation and give limited view on the quality of trauma care and the epidemiology.[3] In 1999, the Dutch government decided to reform the trauma care system on behalf of the Dutch Trauma Society and designated ten level one regional trauma centres (RTCs). These RTCs (eleven since 2008), in collaboration with ambulance services and regional hospitals, have managed to set up regionalized inclusive trauma systems.[4] The RTCs are fully equipped to deliver the highest level of emergency and surgical care for the most severely injured with 24/7 coverage of all specialities including thoracic and neurosurgery. Four RTCs are equipped with 24/7 Helicopter Emergency Medical Service (HEMS) and a Mobile Medical Team which is able to dispatch by helicopter or car.[4] Within the regional trauma systems all trauma-receiving hospitals have a direct linkage to a RTC, to facilitate expeditious transfer of injured patients within the network, to the hospital with the medical expertise and functional/instrumental capacity that matches their alleged resources.

The RTCs succeeded in implementing the Dutch National Trauma Registry (DNTR) in 2007. In this resource all acute trauma related hospital admissions are included, to evaluate the adequacy of the total system, and for quality benchmarking at national, regional and hospital level. Furthermore, injury epidemiology for targeted prevention and to monitor patient distribution, and patient flow to definitive care were evaluated. The Dutch registry differs from other European national registries by capturing all acute trauma related hospital admissions regardless of their age, injury type or severity, resource use or length of stay. The primary aim of this study was to describe the Dutch National Trauma Registry, to illustrate its current status and to assess the impact of registering all acute hospital admissions of trauma victims in comparison to selected populations from national trauma registries in England, Wales and Germany.

METHODS

Patients and dataset

The DNTR includes all injured patients directly admitted to the hospital through the Emergency Department (ED), transferred to another hospital, deceased during ER treatment, within 48 hours after trauma. Patients declared dead before hospital arrival or without vital signs upon arrival at the ED are excluded.

The DNTR dataset includes the items of the Major Trauma Outcome study (MTOS) as well as prehospital items.[5] In 2014 the dataset was extended to correspond to the Utstein template for uniform reporting of data following major trauma.[6] Up to 2014 injuries were coded according to the Abbreviated Injury Scale 1990, update 1998.[7] As from 2015 the injuries are coded according to the Abbreviated Injury Scale 2005, update 2008 [8]

Data collection

The Netherlands encloses about 41.500 km^2 and counted 17.2 million inhabitants in 2018. The number of inhabitants varies between 750.000 and 2.5 million for the 11 trauma regions. The DNTR is composed by the data collected in the 11 trauma regions. The RTCs coordinate these regional trauma registries. For the data collection the RTC's collaborate closely with the regional ambulance services, HEMS and non-RTC. Data collection is done by hired trained personnel or trained medical professionals, that work according to a strict protocol. The DNTR is embedded in a web based relational database (SQL). A trusted third party secures privacy sensitive information and encrypts personal data. Data can be entered through an online data-entry application with plausibility checks or by import of an electronic file.

DNTR organization

For the DNTR a board, a scientific advisory committee, a data manager platform and a program manager have been appointed. Furthermore, the Dutch Trauma Centre Council, composed of leading trauma surgeons from the 11 RTCs, provide their advice for the trauma registry. One data manager per trauma centre, responsible for the coordination of the regional trauma registry, participates in the national data manager platform. Quarterly the platform discusses cases and definitions of data items to ensure consistency across the regional trauma registries. Furthermore, operational aspects of the data management system are discussed.

An online reporting tool is available for the participants including hospital, regional and national benchmark data. Furthermore, annual national and regional reports are published and handed out at a national conference about the trauma registry results. Finally, the RTCs have agreed on terms and conditions for scientific analyses on the national trauma registry database. The RTCs receive annual governmental funding to cover expenditures of DNTR infrastructure and wages, providing continuity in sustaining and developing the registry system.

Analyses

To describe the DNTR maturation we included all cases registered between 2007-2018. Annual hospital participation rate, i.e., percentage of hospitals contributing data to the DNTR, was calculated.

Data of the most recent admission year 2018 were selected for the description of the main patient characteristics, to examine the distribution of trauma patients to RTCs and non RTCs and to look at the value of including all acute hospital trauma admissions.

To describe and classify the sustained injury, the Revised Trauma Score and the Abbreviated Injury Score (AIS) were noted and the injury Severity Score (ISS) was calculated for each patient.[8–10] Severely injured patients were defined as patients with an ISS ≥16. A subgroup of isolated hip fractures was defined as patients with an ISS 9-15 and a femoral neck fracture (853161.3; 853162.3) or an intertrochanteric femur fracture (853151.3;853152.3).

In the DNTR patients transferred within 48 hours after the incident to another hospital are likely to be registered twice. For the distribution and incidence of patients admitted and treated in RTCs and non-RTCs, the patients who were secondarily transferred into hospital after ED treatment at another hospital were excluded.

To assess the value of registering all acute admissions, the inclusion criteria of the TARN and DGU Trauma Register were applied. The TARN inclusion criteria are described in detail in their procedures manual and are, in short, a significant injury, admission for >72 hours, admission to a high-dependency area, or death following arrival at hospital. Isolated fractures of the hip in patients ≥65 years are not registered within TARN.[11] To apply the selection criteria of a significant injury we consulted the TARN to select AIS2008 injury codes that were to be excluded if occurred in isolation (or with an accompanying skin injury). The official inclusion criteria for documenting a patient in the Trauma Register DGU (DGU) are admission via the shock room and in need for intensive care treatment or death before ICU admission.[12] We applied the DGU criteria by selecting the DNTR patients who were presented at the ED and were either directly admitted to the ICU or directly to the operating room and also had ICU treatment or died at the ED.

Statistical analysis was performed using IBM SPSS statistics 24. The Chi-square and the Mann-Whitney-U test were performed to analyse significant differences in patients' characteristics. A p-value of <0.05 was considered as significant. Data are presented as mean, as interquartile range (IQR) and as absolute numbers and percentages.

Missing variable values were considered as not available for analysis. No method for imputation of missing data was performed. Percentages presented within the tables were calculated without missing values. Percentage of missing values for the respective variables are presented in the footnotes of the tables.

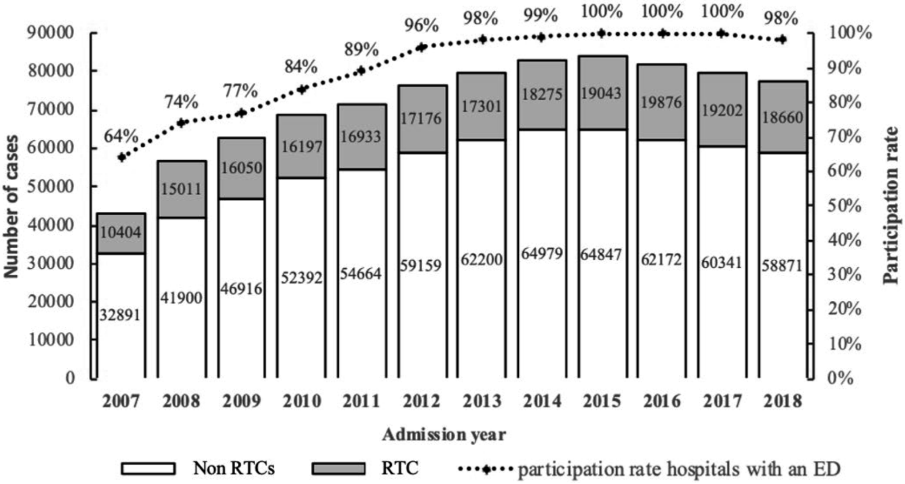

Figure 1. Number of acute trauma admissions registered by the RTCs and non RTCs and participation rate EDs in the Dutch Trauma Registry, 2007-2018

RESULTS

From 2007 to 2018 a total of 865,460 trauma cases were registered in the DNTR. In 2007 64% of all Dutch hospitals with an ED participated. As from 2008 all 11 RTCs centres provide data for the registry. The participation rate increased to 100% in 2015 as shown in Figure 1. In 2018 two non RTCs did not participate due to closure and issues with data-extraction from the electronic patients' files.

In 2018 a total of 77,531 acute trauma admissions were registered of which 3,850 patients (5%) were transferred from another hospital and are likely to have been registered twice. Excluding these patients resulted in an incidence rate of 429 acute trauma admissions per 100,000 inhabitants in 2018.

Table 1 shows the main characteristics for all cases and the subgroups of patients treated in the RTCs and non RTCs in 2018. Half of the injured patients (50%) concerned males. Males had a median age of 48 years (IQR, 22-73) versus a median age of 63 years (IQR, 50-85) for females. The overall median age was 56 years (IQR, 29-81). In 2018, 43% of the patients concerned elderly ≥ 70 years of age of whom 57% were females.

Overall, non-RTC's treated 80% of all cases. In comparison to regional hospitals the patients treated in the RTCs were averagely younger (49 vs 58, $p<0.001$) and more often males (58% vs 47%, $p<0.001$) Furthermore RTC patients were more often, transported by ambulance (74% vs 68%, $p=.013$), more severely injured with an ISS ≥16 (2,4% vs 17,5%, $p<0.001$), more often admitted to ICU (18% vs 5%, $p<0.001$), and had a higher in-hospital mortality (4% vs 2%, $p<0.001$) than the trauma patients treated in the non RTCs.

In 2018, there were 1,867 trauma related in-hospital deaths in the Netherlands. Overall incidence of in-hospital deaths after trauma was 11 per 100,000 population. Overall, in-hospital mortality rate of acute trauma admission was 3% and respectively 2% and 4% in non-RTCs and RTCs. Patients with an ISS≥16 had an overall in-hospital mortality rate of almost 17%. Severely injured patients with an ISS≥16, most frequently sustained an extremity injury (69.0%) followed by head and thorax injuries with respectively 16.3% and 16.1%. Almost one out of every four patients (22.5%) concerned a patient with an isolated hip fracture, of which in 66.0% were females. Of the patients with an isolated hip fracture 79.0% were ≥ 70 years of age, and 88.0% of these cases were treated in a non-RTC.
Figure 2 shows the distribution of patients to RTCs and non RTCs by injury severity after exclusion of the transfers in. The proportion treated at a RTC increases with increasing injury severity. Approximately, 70.0% of patients with an ISS≥16 received primary treatment at designated RTCs.

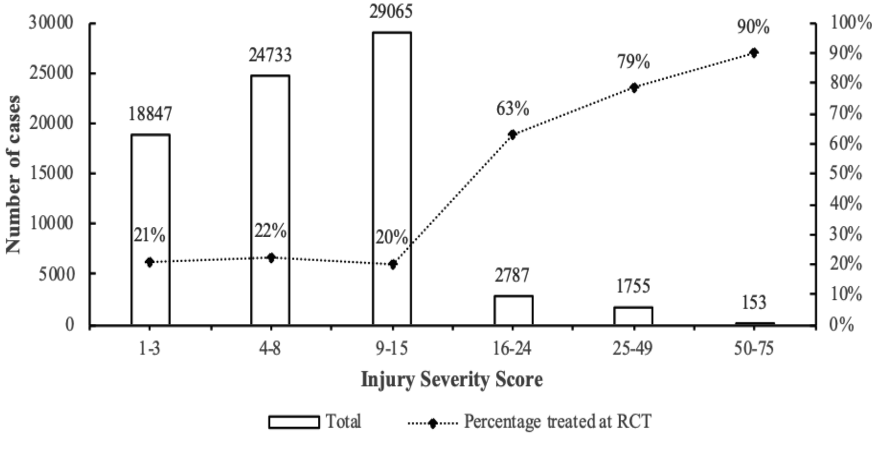

Figure 2. ISS distribution and percentage treated at RTC (DNTR 2018)

Table 1. Main characteristics acute trauma admissions in the Netherlands (n=77.531, DNTR 2018)

		All cases	**Non RTC**	**RTC**
Total 2018		77531	58871	18660
Age	Age median (IQR)	56 (29-81)	58 (33-83)	49 (23-74)
	Children (≤15 years)	16.5%	16.2%	17.5%
	Elderly (≥ 70 years)	43.2%	47.2%	30.8%
Gender (%)	Male	49.8%	47.2%	58%
Injury cause (%)	Home and leisure	60.5%	68.6%	53.2%
	Traffic	20.4%	17.6%	29.1%
	Sport	6.1%	6%	6.2%
	Work	3.2%	2.7%	4.7%
	Assault	2%	1.5%	3.5%
Transportation (%)	Ambulance	70.8%	68%	74%
Referrer (%)	Ambulance	54.0%	51.1%	63%
	GP	28.5%	32.8%	15.2%
	Self-referrer	8.5%	7.5%	12.1%
Mechanism of injury (%)	Blunt	91.2%	90%	94.8%
ISS	ISS median (IQR)	6.9 (4-9)	6 (3-9)	9.5 (4-10)
	ISS ≥16	6.0%	2.4%	17.5%
AIS	Head ≥3	6.8%	4%	15.6%
	Thorax ≥3	6.7%	4.5%	13.9%
	Extremities ≥3	28.8%	31.6%	20%
Hip fracture (%)	Hip fracture ISS 9-15	22.5%	25.9%	19.7%
Hospital stay (days)	LOS median (IQR)	6 (2-8)	5.8 (2-7)	7.2 (2-8)
ICU-stay (%)		7.8%	4.6%	17.9%
Length of ICU stay	Days median (IQR)	4.7 (1-4)	3.2 (1-3)	6 (2-6)
Hospital mortality (%)		2.5%	1.9%	4.4%

Abbreviations: RTC, regional trauma centre; GP, General Practitioner; ISS, Injury Severity Score; AIS, Abbreviated Injury Scale; LOS, length of stay; ICU, Intensive Care Unit.
Missing values: ICU stay (3.4%); referrer (4.1%); transportation (5.7%); mechanism injury (5.8%), injury cause (6.4%).

Table 2. Number DNTR cases for specific subgroups included after application TARN and DGU inclusion criteria

	DNTR	**Number (%) DNTR cases included by DGU inclusion criteria**	**Number (%) DNTR cases included by TARN inclusion criteria**
Total	77531	4167(5%)	24795 (32%)
RTS ED ≤ 10	1239 (16%)	750 (60%)	922 (74%)
ICU admission	6019 (8%)	4082(68%)	4827 (80%)
ISS ≥ 16	4695 (6%)	2331 (50%)	4448 (95%)
Fatal cases	1955 (2.5%)	628 (32%)	1258 (64%)
GOS discharge <5	36976 (47%)	2864 (77%)	14595 (39%)
Age ≤ 19	15046 (19%)	612 (4%)	1807 (12%)
Age 20-49	13103 (17%)	1281 (10%)	4736 (36%)
Age 50-69	15793 (20%)	1183 (8%)	7298 (46%)
Age ≥70	33521 (43%)	1090 (3%)	10926 (32%)

Abbreviations: RTS, Revised Trauma Score; ED, Emergency Department; ICU, Intensive Care Unit; ISS, Injury Severity Score; GOS, Glasgow Outcome Scale.

Value of including all admissions

Overall, respectively, 5% and 32% of the DNTR patients met DGU or TARN inclusion criteria. Table 2 displays the number of DNTR patients for specific items as; ISS- and RTS-score, age, IC admission, hospital mortality, and Glasgow outcome scale at discharge. Furthermore, it shows which percentage of these patients would have been included after application of the DGU and TARN inclusion criteria. The table shows that, next to less severely injured patients, relatively large proportions of especially children, adolescents and elderly are not registered if DGU and TARN inclusion criteria are applied. Regarding mortality, respectively 32% and 64% of fatal cases recorded in the DNTR, would have been included when DGU/TARN inclusion criteria would have been applied. Of these otherwise left out casualties, respectively 92% and 81% were ≥70 years old of whom 55% and 30% had a diagnosis other than an isolated hip fracture.

Figure 3 shows that with increasing ISS, the degree of patients included in the TR-DGU and TARN increases.

Missing data

The quantity of missing data differed between variables and hospitals. The overall missing values per variable are displayed below the associated table. Missing values used in this study, that were missing in more than five percent of patients were; transportation (5.7%); mechanism injury (5.8%), injury cause (6.4%), RTS ED (49%)

DISCUSSION

In this paper we present the Dutch Trauma Registry, which is a comprehensive trauma database encompassing all acutely admitted trauma patients in all hospitals with an ED, in the Netherlands. One of the key elements of the successful implementation of the DNTR is the fact that it was initiated and is supported by the trauma surgeons at the RTCs. The bureaus at the RTCs play an essential role in reaching full participation of the regional hospitals and in the quality assurance of the data.

Our study demonstrates the value of capturing all acute trauma admissions. Application of more stringent inclusion criteria, such as those of the TARN and DGU, result in a very restricted view on the magnitude and impact of injury. For instance, large percentages of children and elderly would be left out, when solely focussed on severely injured patients. Moreover, fatalities, functional outcomes (i.e., Glasgow Coma Scale in our study) and resource use would be largely underestimated and outcome evaluations is incomplete. Also, including all acute trauma admissions (in all hospitals) is a prerequisite to evaluate trauma system performance in terms of getting the patient at the right place at the right time. This is an essential part of inclusive trauma systems. Finally, data collected when broad inclusion criteria are applied, which among others things enables policy-makers to make weighted decisions on injury prevention and control, workforce and financial resource allocation.

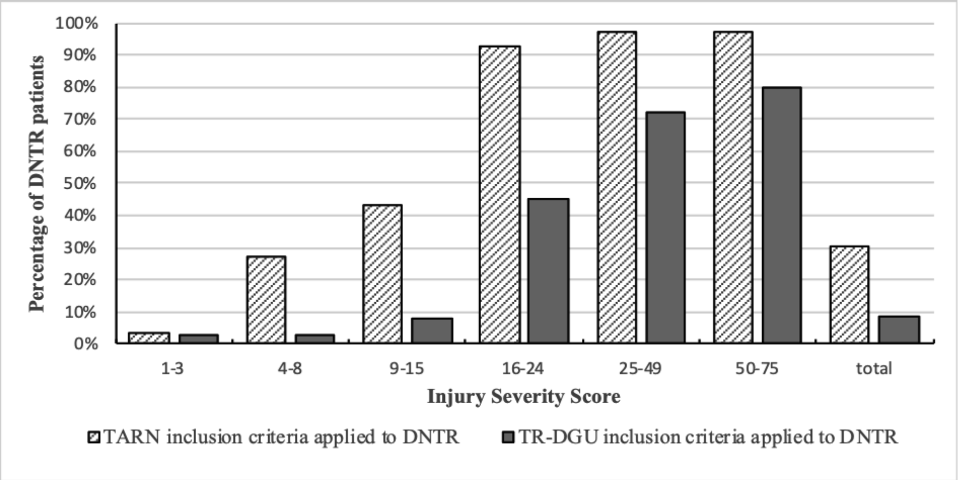

Figure 3. Percentage of DNTR included patients per ISS subgroup, after application of TR-DGU and TARN inclusion criteria

We specifically want to derive attention to the importance of including elderly (≥70) in view of an ageing population and the frailty of this group. Over the last twenty years, an increase has been observed in the incidence of major trauma in elderly.[13,14] Elderly patients represent an increasingly larger proportion of hospital trauma admissions. [15,16] The physiological response to trauma in older adults is different from that in the young.[17,18] Furthermore, prehospital triage tools are relatively insensitive for identifying high-risk elderly trauma patients, which leads to a high under triage rate in elderly trauma patients.[19,20] All leading to a relatively high mortality in this group, and association with worse non-fatal outcomes after traumatic injury regardless of injury severity.[14,18,21]

In this study we applied the inclusion criteria of two well-known national registries in Europe, i.e., the German (TR-DGU) and UK (TARN). Outside Europe, large and well-known trauma registries are the US National Trauma Data Bank (NTDB) and the Australian New Zealand Trauma Register (ATR). The NTDB is the largest trauma data repository in the world, it contains prehospital and in-hospital data on 7,5 million trauma patients. In general, the DNTR inclusion criteria are in line with the NTDB criteria including trauma hospital admissions, patient transfers and deaths resulting from traumatic injury.[22] The DNTR differs from the NTDB by an additional criterion treatment at the ED previous to hospitalization, a defined maximum of 48 hours between the incident and ED presentation and the Dead on arrival are not registered in the DNTR. International comparison is restricted due to the fact that the NTDB partly consists of voluntarily submitted data, as only trauma centres verified by the American college of Surgeons are obliged to submit data.[19,22] Moreover, a significant variability of in- and exclusion criteria between participating hospitals in the NTDB, results in selection bias, making comparison of outcome impossible and not nationally representative.[20,22–25]

The ATR is a bi-national register with over 8,000 records annually. Only including patients presenting to one of the 24 level one designated or equivalent trauma centres across Australia who subsequently died after injury, or patients who sustained major trauma, defined as trauma patients with an ISS ≥12 (using the AIS08).[26] They exclude patients with a delayed admission (>7days), poisoning, drugs or foreign body ingestion that did not cause injury, isolated femoral neck fractures and older adults (>64 years of age) who died with superficial injuries only.[21]

Although nicely set-up, the most obvious limitation is that the data only applies to level one trauma centres, and is restricted to major trauma patients. Moreover, it is not linked to non-trauma centre data, prehospital/scene data and post discharge data. Furthermore, they lack data on elderly trauma patients which is of significant importance as advocated earlier.[27]

The DNTR also has limitations. Whenever in- and exclusion criteria are applied, there are patients being left out. For the DNTR it was a conscious choice to focus only on the acutely admitted patients. One can argue if patients that receive primary treatment in the ED and will undergo semi-elective wrist, elbow or ankle surgery a few days later should be included. Compared to acute trauma admissions, these patients require a different approach of trauma care and outcome evaluation, thus they are not registered in the DNTR. The quantity of these patients and their impact on medical resource use, remains unclear.
Secondly, by registering all trauma patients admitted within 48 hours after trauma, the demand on data managers is high. At the moment, more extensive datasets, such as for instance the DGU and TARN datasets, including comorbidities, consulted practitioners and laboratory findings would pose to larger workload.
Thirdly, outcome should be more elaborate than mortality. Starting with measuring the impact of trauma on the 97% non-fatal trauma patients. Recent studies on patients reported outcome measures after injury, have shown that trauma patients are significant impaired on mobility, self-care and pain up to one year after trauma.[28,29]
Lastly, DNTR numbers on missing data show that there is room for improvement on completeness and consistency of registration in the Netherlands and registries in general.[30]

To address these issues in the future, the DNTR and other Trauma registries should move away from labour-intensive and inefficient data entry and strive for more automated techniques based on electronic health record data and other existing platforms.[20,31] Hereby reducing the number of missing values, lowering the workload and expanding datasets.
To compare the burden of injury we need to compare it as if it were a disease and focus on functional outcomes, quality of life and disability adjusted life years.[28] Ideally a standardized international data script should be implemented, enabling data comparison across countries and even continents. All reflecting a desire to address, understand, and optimize care for trauma patients across the world.[20,31–33]
Finally, we find it important to demonstrate that injuries are a major health problem. The DNTR reports over 80.000 acute trauma admissions. This exceeds the sum of hospital admissions for important acute illnesses such as stroke (41,203 in 2018) and acute myocardial infarction (33,849 in 2018) in the Netherlands.[34] These figures emphasize the impact of trauma and hopefully draw the attention on prevention and the resources needed for trauma care.

CONCLUSION

The DNTR has evolved into a comprehensive well-structured nationwide population-based trauma register. With an annual number of 80,000 cases being entered in the database the DNTR has grown to be one of the largest trauma databases in Europe. The registries strength lies in the broad inclusion criteria which enables studies on the burden of injury and on the quality and efficiency of the entire trauma care system encompassing all trauma-receiving hospitals.

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CHAPTER 4

Impact of the SARS-CoV-2 pandemic on trauma care: A nationwide observational study

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ABSTRACT

Purpose

The SARS-CoV-2 pandemic severely disrupted society and the health care system. In addition to epidemiological changes, little is known about the pandemic's effects on the trauma care chain. Therefore, in addition to epidemiology and aetiology, this study aims to describe the impact of the SARS-CoV-2 pandemic on prehospital times, resource use and outcome.

Methods

A multicentre observational cohort study based on the Dutch Nationwide Trauma Registry was performed. Characteristics, resource usage, and outcomes of trauma patients treated at all trauma-receiving hospitals during the first (W1, March 12 through May 11) and second waves (W2, May 12 through September 23), as well as the interbellum period in between (INT, September 23 through December 31), were compared with those treated from the same periods in 2018 and 2019.

Results

The trauma caseload was reduced by 20% during the W1 period and 11% during the W2 period. The median length of stay was significantly shortened for hip fracture and major trauma patients (ISS≥16). A 33% and 66% increase in the prevalence of minor self-harm-related injuries was recorded during the W1 and W2 periods, respectively, and a 36% increase in violence-related injuries was recorded during the INT. Mortality was significantly higher in the W1 (2.9% vs. 2.2%) and W2 (3.2% vs. 2.7%) periods.

Conclusion

The imposed restrictions in response to the SARS-CoV-2 pandemic led to diminished numbers of acute trauma admissions in the Netherlands. The long-lasting pressing demand for resources, including ICU services, has negatively affected trauma care. Further caution is warranted regarding the increased incidence of injuries related to violence and self-harm.

INTRODUCTION

The first SARS-CoV-2 case in the Netherlands was reported on February 27, and on March 12, the Dutch government declared a national lockdown. The Dutch National Coordination Center for Patient Distribution (LCPS) was quickly instated to facilitate the transfer of SARS-CoV-2 infected patients across the Netherlands. With the national dispersion of SARS-CoV-2 infected patients, the LCPS sought to avoid a locoregional surge of capacity and minimize the impact on acute and elective non-COVID-19 care in more severely affected regions. Relatively quick virus containment was realized, and most measures were revoked by the second week of May; consequently, LCPS scaled down its operations. However, due to increasing numbers of SARS-CoV-2 infections, reinstatement of (lockdown) restrictions and reactivation of LCPS were required by the end of September, without signs of relief at the end of the year.

During these 2020 outbreak periods, two main circumstances might have impacted the trauma population and provided care. First, the lockdown policies that were set to mitigate the propagation of the virus could have shifted the epidemiological characteristics of hospitalized trauma patients. Previous studies have shown widespread epidemiological and aetiological changes in trauma care,[1] late-onset presentation of common medical conditions,[2,3] and higher surgical morbidity in patients with a concomitant SARS-CoV-2 infection.[4] Second, SARS-CoV-2 drastically changed the demand for health care services, resulting in a redistribution of material and personnel.[5,6] This also impacted (clinical) outcomes of patients. Previous research suggested that due to a shortage of ICU beds, a specific group of patients was less likely to be admitted to the ICU for observation, which has impacted outcomes.[7]

The currently available international literature mostly concerns single centre studies with small sample sizes that cover the first infectious outbreak.[8–16] A comprehensive national study that evaluates the changes in trauma epidemiology and care for the trauma population in its entirety over multiple outbreaks is lacking. Such a study can offer valuable information on how to manage the continuity of trauma care during future pandemics or other extreme conditions.

This study aims to better understand how the SARS-CoV-2 pandemic, with subsequent public health care and other societal constraints, has epidemiologically impacted trauma patient characteristics, prehospital times, resource use, trauma care and outcomes on a national scale.

METHODS

Setting

The study was performed according to STROBE guidelines for observational studies.[17] We performed a nationwide, multicentre, retrospective observational cohort study. Patient characteristics, trauma aetiology, ICU resource use and clinical outcomes of trauma patients were compared.

The Netherlands encloses approximately 41,500 km^2, has approximately 17.4 million inhabitants, and approximately 71,623 people were admitted into the hospital as trauma patients in 2020. All acutely admitted trauma patients registered between weeks 2 and 52 of 2018, 2019 and 2020 were included. LCPS was established on March 12 and scaled down its operations gradually to a surveillance level by May 11. This period marks the first wave of SARS-CoV-2 infections in the Netherlands and will be referred to as Wave 1 (W1). By September 23, the LCPS was reinstated due to a second wave of SARS-CoV-2 infections throughout the Netherlands. This period was marked until December 31 and will be referred to as Wave 2 (W2). The period in which the LCPS acted on a surveillance level is referred to as the interbellum (INT). To account for seasonal influences on trauma patients' characteristics and aetiology, the reference periods for the first wave (RW1), the second wave (RW2) and the interbellum (RINT) were established based on the same period in 2018–2019 combined. The main outcomes were measured as in-hospital mortality and 30-day (30 D) mortality.

Data collection

Data were extracted from the Dutch National Trauma Registry (DNTR).[18] The DNTR prospectively documents all injured patients who were directly admitted to a hospital through the emergency department (ED) within 48 hours after trauma, regardless of their age, injury location, and severity. Patients without vital signs upon arrival at the ED were excluded. Moreover, patients transferred within 48 hours after the incident are likely to be registered twice. Therefore, those transferred to another hospital after ED treatment were excluded.[18] The DNTR dataset includes the Utstein template items for uniform reporting of data following major trauma and covers 100% of the trauma-receiving hospitals in the Netherlands.[18] Injuries are coded by trained data registrars according to the Abbreviated Injury Scale (AIS) 2005 update 2008.[19]

Populations

Subgroup analyses were performed for 1) patients with minor injuries defined as injuries with an injury severity score (ISS) [20] of 8 or less, 2) patients who sustained a hip fracture and had an ISS ≤ 15 and 3) major trauma (MT) patients, which were defined as having an ISS of 16 and higher.

Transport times

Differences in prehospital trauma care were assessed based on median prehospital transport times and the number of actual dispatches of Dutch mobile medical teams (MMTs) to provide prehospital on-scene medical assistance for severely injured patients.[21] Ambulance dispatches were categorized in 4 time intervals: response time (a) was defined as the time required for emergency medical services (EMS) to arrive at the scene of an accident; on-scene time (b) was defined as the time spent on scene by EMS professionals; transport time (c) was defined as the time from departing the scene to arrival at the hospital; total prehospital time (d) was defined as the total time between an emergency call and arrival at the hospital.

Statistical analysis

Categorical data are described as numbers (percentages) and were compared using a chi-squared test. Continuous data are expressed as the mean (standard deviation (SD)) or median (interquartile range, IQR, 25th to 75th percentile) for normally or nonnormally distributed variables, respectively, and were compared using a *t test* or a Wilcoxon-Mann–Whitney test, as appropriate. A p value of <0.05 was considered significant. Valid percentages were used, excluding missing values. The number of missing values per variable is listed in Supplemental Material Table 1.

The number of patients registered each week in 2020 was recorded as the observed (O) volume. The average number of patients registered each week in 2018 and 2019 was recorded as the expected (E) volume. Thereafter, the O was divided by the E computing the O/E ratio. An O/E ratio <1 indicates that the volume in that specific week of 2020 was lower than expected, and an O/E ratio >1 indicates a higher volume than expected. Four-week rolling averages of O/E ratios were used to prevent 1-week-outlier artefacts. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.[22]

Ethics statement

The study is exempted from the need for informed consent because it is not subject to the Medical Research Involving Human Subjects Act. Trauma patient registration is facilitated by Dutch law, for which patient anonymity is warranted. Patients or the public were not involved in the design, conduct, reporting, or dissemination plans of our study.

RESULTS

Acute trauma admissions

In W1, a total of 12,184 acute trauma admissions were recorded in the DNTR (i.e., 1523 admitted trauma patients per week on average). This result resembles a decrease of 20% compared to the 30,430 acute trauma admissions during RW1 (i.e., 1902 admitted weekly on average). The decreased number of acute trauma admissions resolved during INT, with a total of 25,506 acute trauma admissions (i.e., 1342 admissions per week), compared to the 51,196 patients (i.e., 1347 admissions per week on average) during RINT. In W2, the number of acute trauma admissions dropped by 10.8%, to a total of 17,455 patients (i.e., 1247 admissions per week), compared to the 39,165 patients (i.e., 1399 admissions per week on average) during RW2 (Table 1).

Patient's characteristics

During W1 and W2, the median age of trauma patients tended to be higher, with 67 years (IQR, 34-81) and 69 years (IQR, 35-83) compared to 63 years (IQR, 27-81) and 67 years (IQR, 33-82) in RW1 and RW2, respectively (Table 1). The median ISS was significantly lower during W1 and W2, with 3 (IQR, 2-6) during W1 and 3 (IQR, 2-7) during W2 vs. 3 (IQR, 2–8) during both RW1 and RW2 (p <0.001). During W1 and W2, injuries were less frequently of the blunt type (n=10,994 (95.8%)) and (n=15,593 (96.8%) versus (n=27,931 (97.0%)) and (n=35,679 (96.7%)), (p <0.001) (Table 1). Otherwise, there were no notable differences in patient characteristics. The weekly observed/expected ratios for patients with minor injuries, hip fractures and MT are displayed in Figure 1.

Table 1. Patient characteristics of those admitted during the first and second SARS-CoV-2 waves, the interbellum period, and their respective reference periods from 2018 and 2019.

		2020			**2018/2019**		
		Wave 1 (W1) N (%)	**Interbellum (INT)**	**Wave 2 (W2) N (%)**	**Reference Wave 1**	**Reference Interbellum**	**Reference Wave 2 (RW2)**
Total included, n		12184	25506	17455	30430	51196	39165
Weekly admissions, n		1523	1342	1247	1902	1347	1399
Male gender, n (%)		6097 (50.0)	13015 (51.0)	8402 (48.1)	15274 (50.2)	25753 (50.3)	20165 (48.5)
Median age (IQR)	Overall	67 (34 – 81)*	63 (27 – 80)	69 (35 – 83)‡	63 (27 – 81)	63 (27 – 80)	67 (33 – 82)
	Minor injury	50 (10 – 74)	46 (12 – 73)	51 (13 – 76)‡	47 (12 – 73)	47 (12 – 73)	51 (16 – 76)
	Hip fracture	81 (72 – 87)	80 (72 – 87)§	81 (73 – 88)	81 (72 – 87)	81 (72 – 87)	81 (72 – 88)
	ISS ≥16	58 (36 – 74)	57 (34 – 74)	61 (37 – 76)	58 (35 – 75)	58 (34 – 74)	59 (36 – 75)
Median ISS (IQR)		3 (2 - 6)*	3 (2 – 7.75)§	3 (2 – 7)‡	3 (2 – 8)	3 (2 – 7)	3 (2 – 8)
Blunt trauma, n (%)		10994 (95.8)*	23023 (96.1)§	15593 (96.8)	27931 (97.0)	46620 (96.7)	35679 (97.0)
Minor injuries, n (%)		6140 (50.4)*	13856 (54.3)§	8797 (50.4)‡	17396 (57.2)	28875 (56.4)	21384 (54.6)
Hip fracture, n (%)		3183 (26.7)*	5677 (22.6)§	4645 (27.1)‡	6801 (22.4)	11116 (21.8)	9380 (24.1)
ISS ≥16	Number, n (%)	739 (6.1)*	1599 (6.3)§	1037 (5.9)‡	1704 (5.6)	3074 (6.0)	2237 (5.7)
	ICU admission, n (%)	342 (46.3)*	894 (55.9)	513 (49.5)	918 (53.9)	1706 (55.5)	1189 (53.1)
	Median ICU LOS	3 (2 – 6)	3 (2 – 7.75)	3 (2 – 7)‡	3 (2 – 8)	3 (1 – 7)	3 (2 – 8)
	Respiratory support,	175 (58.9)*	413 (52.9)§	255 (56.4)‡	342 (43.4)	662 (45.6)	499 (47.4)
Median hospital LOS	Overall	4 (2 - 7)	3 (2 – 7)§	4 (2 – 8)	3 (2 – 7)	3 (2 – 7)	4 (2 – 8)
	Minor injury	2 (2 – 4)	2 (2 – 4)§	2 (2 – 4)‡	2 (2 – 4)	2 (2 – 4)	2 (2 – 4)
	Hip fracture	6 (5 – 9)*	6 (5 – 9)§	7 (5 – 10)‡	7 (5 – 10)	7 (5 – 10)	7 (5 – 10)
	ISS ≥16	6 (4 – 9)*	7 (3 – 14)§	6 (4 – 9)‡	5 (3 – 9)	7 (3 – 15)	5 (4 – 9)
Mortality, n (%)	Overall	357 (2.9)*	582 (2.3)	560 (3.2)‡	692 (2.2)	1165 (2.3)	1053 (2.7)
	Minor injury	63 (1.0)*	69 (0.5)§	85 (1.0)	119 (0.7)	196 (0.7)	183 (0.8)
	Hip fracture	111 (3.5)	151 (2.7)	171 (3.7)	199 (2.9)	304 (2.7)	313 (3.3)
	ISS ≥16	132 (17.9)	282 (17.6)	215 (20.7)‡	290 (17.0)	488 (15.9)	393 (17.6)
30-Day mortality, n	Overall	574 (4.7)*	929 (3.6)	908 (5.2)‡	1090 (3.6)	1778 (3.5)	1650 (4.2)
	Minor injury	116 (1.9)*	164 (1.2)	173 (2.0)‡	226 (1.3)	344 (1.2)	369 (1.7)
	Hip fracture	216 (6.8)*	330 (5.8)	353 (7.6)‡	402 (5.9)	639 (5.7)	606 (6.4))
	ISS ≥16	154 (20.8)	309 (19.3)	239 (23.0)‡	312 (18.3)	546 (17.8)	428 (19.1)

Abbreviations: ISS: Injury Severity Score; LOS: length of stay;

* 1st Wave (W1) differs significantly (p-value <0.05) from its reference period (RW1) in 2018 and 2019 combined.

§ Interbellum period (INT) differs significantly (p-value <0.05) from its reference period (RINT) in 2018 and 2019 combined.

‡ 2nd Wave (W2) differs significantly (p-value <0.05) from its reference period (RW2) in 2018 and 2019 combined.

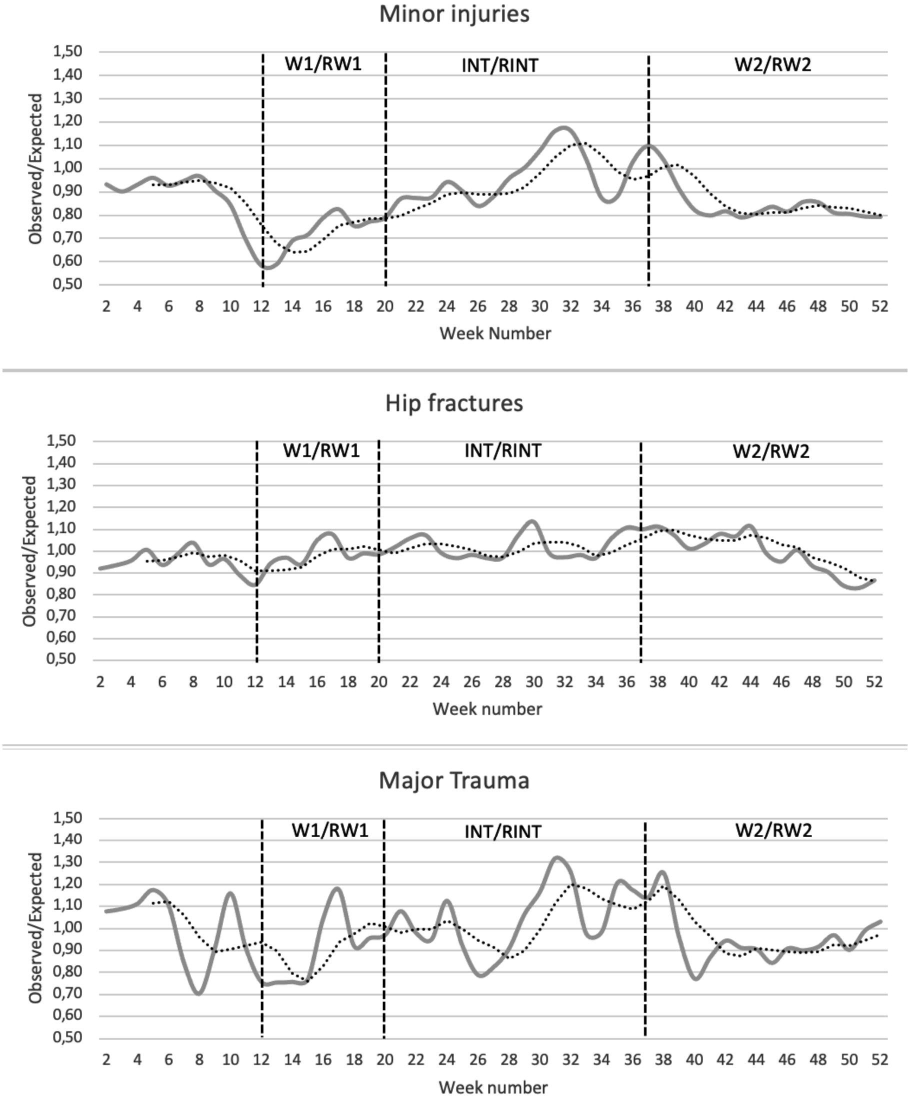

Figure 1. The weekly O/E observed (in 2020) versus expected (average 2018-2019)) trauma patient ratios for those admitted after sustaining a minor injury (ISS ≤8), a hip fracture or a major trauma (ISS ≥16) and the four-week rolling averages of the O/E ratios (dashed line).

Injury cause

Among trauma patients with ISSs of 1-15 and 16-24, the prevalence of sports-related injuries decreased by 45% and 29%, respectively, during the W1 period (Table 2). In contrast, the prevalence of sports-related trauma patients with an ISS >25 increased by 21% and 22% in W1 and W2, respectively, compared to the reference periods. During the W1 and W2 we recorded a decrease in the prevalence of injuries due to road traffic accidents (RTAs) between 27% and 29%, 3% and 22%, and 11% and 23% in respectively the ISS 1-15, 16-24 and ≥25 categories, respectively. Compared to RW1, injuries inflicted by violence decreased during W1 by 30%, 44% and 48% in the ISS 1-15, ISS 16-24 and ≥25 categories, respectively. Compared to the reference period, injuries due to interpersonal violence increased during INT in all injury severity categories, ranging from a 12% increase in the ISS ≥25 category to a 52% increase in the ISS 15-24 category. During W2, injuries resulting from interpersonal violence graded as an ISS between 1-15 and ISS equal to or above 25 decreased by 7% and 32%, respectively, compared to RW2.

The prevalence of injuries due to self-harm increased in all 2020 periods and for every ISS category, ranging from 5% up to 9%. The prevalence of self-harm related in the ISS 16-24 category increased by 6% during the W1 and decreased by 36% and 21% in the INT and W2. In contrast to those decreases the prevalence of severe self-harm related injuries (ISS ≥25) increased by 41% and 26% during the INT and W2 periods, respectively.

Minor injuries

During W1, a 29.4% (6140 vs. 17396) decrease in the total number of trauma patients admitted with minor injuries (ISS ≤8) was recorded. During INT and W2, decreases of 4% (13856 vs. 28875) and 17.7% (8797 vs. 31284), respectively, compared to the reference periods, were recorded (Table 1). Compared to the respective reference periods, the in-hospital mortality of patients with minor injuries significantly increased from 0.7% (n=119) in RW1 to 1.0% (n=63) in W1 (p=0.009) and significantly decreased during INT 0.5% (n=69) vs. 0.7% (n=196) in RINT (p=0.025). Compared to RW1, we recorded a significant decrease (20.8%) in the frequency of patients discharged to nursing homes. Consequently, the number of patients discharged to their homes and rehabilitation centres increased by 5.7% and 3.8%, respectively (Table 3).

Hip fractures

The total number of trauma patients admitted with a hip fracture decreased by 6.4% (3183 vs. 6801) during W1 and 1.0% (4645 vs. 9380) during W2 compared to their respective reference periods RW1 and RW2 (Table 1). A 2% (5677 vs. 11116) increase was recorded during INT. The median length of stay for hip fracture patients was significantly shortened during all periods in 2020, with 6 days (IQR, 5–9) during W1 and INT and 7 days (IQR, 5–10) during W2 (p= <0.001) (Table 1). The in-hospital mortality of patients admitted after sustaining a hip fracture was similar during the W1, INT and W2 compared to the respective reference periods. However, the 30-day mortality increased significantly during both SARS-CoV-2 periods, namely, 6.8% (n=216) vs. 5.9% (n=402) during W1 (p=0.009) and 7.6% (n=353) vs. 6.4% (n=606) during W2 (p= <0.001). Compared to the respective reference periods, hip fracture patients were 11.6%, 12.8% and 6.2% less frequently discharged to nursing homes during W1, INT and W2 (Table 3). Moreover, the number of hip fracture patients discharged to their own homes increased by 26.7% in W1, 4.0% in INT, and 7.1% in W2 compared to the respective reference periods.

Major trauma patients

Compared to the reference periods, a 13.3% (739 vs. 1704) and a 7.3% (1037 vs. 2237) decrease in MT patients was recorded during W1 and W2. In contrast, there was a 4% (1599 vs. 3074) increase in MT patients who were admitted throughout INT (Table 1). Hospital length of stay (LOS) was lengthened during both waves, with a median duration of 6 days (IQR, 4–9) compared to 5 days (IQR, 3–9) and 5 days (IQR, 4–9) in the reference periods. ICU admission decreased for MT patients. During W1, 46.3% (n=342) of MT patients were admitted to the ICU, and 49.5% (n=513) were admitted during W2, compared to 53.9% (n=918) and 53.1% (n=1189) in the respective reference periods. Moreover, ICU length of stay (ICU LOS) was shortened. Compared to a median ICU LOS of 3 days (IQR, 2–8) in all reference periods, we recorded a median ICU LOS of 3 days (IQR, 2–6) and 3 days (IQR, 2–7) during W1 and W2, respectively. Compared to the respective reference periods, the percentage of ICU-admitted MT patients who received respiratory support increased by 15.5% during W1, 7.3% during INT, and 9% during W2. Although MT patient in-hospital mortality was higher for all 2020 periods, a significant difference was only found during W2. In-hospital mortality increased 3.1% (p=0.031), and 30D mortality increased 3.9% (p=0.001) compared to RW2 (Table 1). Compared to the respective reference periods, MT patients were 29.3%, 31.7% and 18.2% less frequently discharged to nursing homes during W1, INT and W2 (Table 3). Moreover, the number of patients discharged to their own homes increased by 4.7% in W1, 10,2% in INT, and 12.8% in W2 compared to the respective reference periods.

Table 2. Trauma causes per injury severity subgroup, for those admitted during the first and second SARS-CoV-2 waves, the interbellum period and during their respective reference periods from 2018 and 2019

	2020			2018/2019		
	Wave 1 (W1) N (%)	**Interbellum (INT) N (%)**	**Wave 2 (W2) N (%)**	**Reference Wave 1 (RW1) N (%)**	**Reference Interbellum (RINT) N (%)**	**Reference Wave 2 (RW2) N (%)**
ISS 1 -15						
Sports	509 (4.7)	1411 (6.3)	852 (5.6)	1835 (6.8%)	2583 (5.8)	1991 (5.8)
RTA	1990 (20.3)	4942 (22.2)	2481 (16.4)	5614 (21.0)	10361 (23.2)	6844 (20.2)
Home and leisure	7594 (70.9)	14620 (65.3)	10958 (72.5)	17787 (66.5)	29140 (65.3)	23292 (68.3)
Work	352 (3.3)	583 (2.6)	483 (3.2)	814 (3.0)	1359 (3.0)	1085 (3.2)
Violence	181 (1.7)	498 (2.2)	235 (1.6)	519 (1.9)	892 (2.0)	693 (2.0)
Self-harm	86 (0.8)	159 (0.7)	109 (1.0)	164 (0.6)	293 (0.7)	206 (0.6)
ISS 16 - 24						
Sports	25 (5.5)	69 (7.6)	32 (5.5)	70 (7.1)	114 (6.6)	65 (5.1)
RTA	194 (42.6)	400 (44.3)	211 (36.5)	401 (40.8)	779 (45.6)	542 (42.5)
Home and leisure	178 (39.1)	334 (37.0)	271 (46.9)	381 (38.8)	636 (37.2)	530 (41.5)
Work	30 (6.6)	41 (4.5)	30 (5.2)	62 (6.3)	71 (4.2)	61 (4.8)
Violence	9 (2.0)	41 (4.5)	21 (3.6)	32 (3.3)	54 (3.2)	45 (3.5)
Self-harm	19 (4.2)	18 (2.0)	13 (2.2)	36 (3.7)	56 (3.3)	33 (2.6)
ISS 25 - 70						
Sports	13 (4.7)	28 (4.1)	20 (4.5)	27 (4.1)	46 (3.8)	30 (3.4)
RTA	105 (38.0)	293 (43.7)	152 (34.6)	271 (41.9)	515 (43.1)	343 (39.2)
Home and leisure	121 (43.8)	228 (34.0)	191 (43.5)	252 (38.9)	445 (37.2)	358 (41.0)
Work	10 (3.6)	40 (6.0)	18 (4.1)	30 (4.6)	65 (5.4)	41 (4.7)
Violence	6 (2.2)	30 (4.5)	15 (3.4)	23 (3.6)	50 (4.2)	34 (3.9)
Self-harm	21 (7.6)	52 (7.7)	43 (9.8)	44 (6.8)	74 (6.2)	68 (7.8)

Abbreviations: ISS: Injury Severity Score; RTA: Road Traffic Accident.

Table 3. Discharge destination for those who endured minor injuries, hip fractures and major trauma and were admitted during the first and second SARS-CoV-2 waves, the interbellum period, and their respective reference periods from 2018 and 2019.

	2020			**2018/2019**		
	Wave 1 (W1) N (%)	**Interbellum (INT) N (%)**	**Wave 2 (W2) N (%)**	**Reference Wave 1 (RW1) N (%)**	**Reference Interbellum (RINT) N (%)**	**Reference Wave 2 (RW2) N (%)**
Minor injury						
Own home	5047 (83.0)	11,246 (81.6)	6876 (78.9)	13,662 (78.5)	22,894 (79.8)	16,396 (76.7)
Nursing home	237 (3.8)	560 (4.1)	440 (5.0)	833 (4.8)	1241 (4.3)	1051 (4.9)
Rehabilitation centre	332 (5.5)	891 (6.5)	653 (7.5)	926 (5.3)	1423 (4.9)	1371 (6.5)
Hip fractures						
Own home	1339 (45.1)	2152 (38.9)	1749 (39.1)	2423 (35.6)	4041 (37.4)	3310 (36.5)
Nursing home	584 (19.7)	1014 (18.3)	888 (19.8)	1473 (22.3)	2272 (21.0)	1915 (21.1)
Rehabilitation centre	910 (30.6)	1816 (32.9)	1412 (31.6)	1762 (26.7)	3018 (27.9)	2632 (29.0)
ISS ≥16						
Own home	319 (52.5)	700 (53.1)	433 (52.7)	709 (50.1)	1246 (48.2)	862 (46.7)
Nursing home	25 (4.1)	57 (4.3)	44 (5.4)	82 (5.8)	162 (6.3)	121 (6.6)
Rehabilitation centre	122 (20.1)	251 (19.1)	156 (19.0)	232 (16.4)	412 (15.9)	333 (18.1)

Abbreviations: ISS: Injury Severity Score.

Transport times

The majority of patients were transported by ambulance, and this proportion significantly increased to 78.3% during both W1 and W2 (Table 4). In comparison to the reference periods, mobile medical teams (MMTs) were significantly less frequently dispatched during all 2020 periods. In contrast, transport by EMS increased during these periods. The response time was significantly different during both INT and W2, with a median of 9 minutes (IQR, 6-13) compared to 9 minutes (IQR, 6-12). Furthermore, the median on-scene time significantly increased during W1 (20 min (IQR, 14-27)) vs. (19 min (IQR, 14-26)), INT (20 min (IQR, 14-26)) vs. (19 min (IQR, 14-25)) and W2 (21 min (IQR, 15-28)) vs. (20 min (IQR, 15-26)). Compared to the historical data, the transport time was only lengthened during W2 (18 min (IQR, 12-25)) vs. (17 min (IQR, 1224)). Consequently, the total prehospital time was significantly longer for all periods in 2020: 54 min (IQR, 44-65) during W1, 53 min (IQR, 43-64) during INT, and 54 min (IQR, 45-66) during W2. The total emergency room treatment time was significantly shorter during W1 (163 min (IQR, 115–220)) vs. (171 min (IQR, 122–232)) and INT (167 min (IQR, 118–225)) vs. (173 min (IQR, 123–234)).

DISCUSSION

We demonstrated that SARS-CoV-2-induced social restrictions have impacted not only the number and epidemiological characteristics of the hospitalized trauma population. The pandemic has led to organizational changes and medical resource shortages that have impacted the entire acute trauma care chain, potentially affecting patient outcomes. In this national study, we made the following observations that should be considered in preparation for future pandemic peaks.

Trauma aetiology

Staying at home is perceived to reduce the risk of becoming injured, as individuals may otherwise be exposed to potentially unsafe traffic and working situations or run the risk of interpersonal violence. Not surprisingly, compared to years prior to the SARS-CoV-2 pandemic, the number of acute trauma admissions was reduced by approximately 20% during the first and 11% during the second infectious wave in the Netherlands. However, this apparent reduction in trauma caseload was counterbalanced by a steady flow of elderly admitted with hip fractures and MT patients.[8,23–25] The restrictions reduced the number of injuries due to sports; however, they did not prevent people from becoming seriously injured or from falling at home.

Table 4. Transport measures and median transport times for those admitted during the first and second SARS-CoV-2 waves, the interbellum period, and their respective reference periods from 2018 and 2019.

	2020			**2018/2019**		
	Wave 1 (W1) N(%)	**Interbellum (INT) N(%)**	**Wave 2 (W2) N(%)**	**Reference Wave 1 (RW1) N(%)**	**Reference Interbellum (RINT) N(%)**	**Reference Wave 2 (RW2) N(%)**
MMT at the scene for major trauma patients (%)	152 (20.8)[*]	332 (20.9)[§]	205 (19.9)[‡]	416 (25.0)	735 (24.5)	510 (23.3)
Major trauma patients directly transported to MTC	509 (68.9)	1106 (69.2)	699 (67.4)	1195 (70.0)	2060 (67.0)	1483 (66.3)
Ambulance transportation (%)	9011 (78.3)[*]	18360 (75.5)	13147 (78.3)[‡]	21427 (73.4)	36607 (74.3)	28668 (76.2)
Median response time (IQR)	9 (6 – 12)	9 (6 – 13)[§]	9 (6 – 13)[‡]	9 (6 – 12)	9 (6 – 12)	9 (6 – 12)
Median transport time (IQR)	18 (12 – 24)	18 (12 – 25)	18 (12 – 25)[‡]	18 (12 – 25)	18 (12 – 25)	17 (12 – 24)
Median on scene time (IQR)	20 (14 – 27)[*]	20 (14 – 26)[§]	21 (15 – 28)[‡]	19 (14 – 26)	19 (14 – 25)	20 (15 – 26)
Median total pre-hospital time (IQR)	54 (44 – 65)[*]	53 (43 – 64)[§]	54 (45 – 66)[‡]	51 (41 – 63)	51 (41 – 63)	52 (42 – 64)
Median total time of ER treatment (IQR)	163 (115 – 220)[*]	167 (118 – 225)[§]	174 (125 – 233)	171 (122 – 232)	173 (123 – 234)	174 (124 – 234)

Abbreviations: MMT: Mobile Medical Team; MTC: major trauma centre; ER: Emergency Room.

[*] Wave 1 (W1) differs significantly (p-value <0.05) from its reference period (RW1) in 2018 and 2019 combined.

[§] Interbellum period (INT) differs significantly (p-value <0.05) from its reference period (RINT) in 2018 and 2019 combined.

[‡] Wave 2 (W2) differs significantly (p-value <0.05) from its reference period (RW2) in 2018 and 2019 combined.

Another development of interest was the increase in the incidence of penetrating trauma. No specific analysis was performed in this study; however, penetrating injuries are most commonly a result of person-to-person violence outside of their own home or related to self-harm.[26] Multiple SARS-CoV-2-related stressors, such as isolation, quarantine, fear and uncertainty, economic fallout, social abuse or violence, might have resulted in increased vulnerability to automutilation and suicidal behaviour.[27] Therefore, the 41% and 26% increase frequency of minor (ISS $\leq$15) self-harm-related injuries during the respective first and second waves and the 37% increase in violence-related severe injuries (ISS $\geq$16) during the interbellum are worrisome. Unfortunately, we are not the first to report this, and increased numbers of injuries resulting from self-harm during the periods of lockdown were found in France,[10,11] the UK,[12,13] Australia [14,15] and the US.[16,28] Preparing for indefinite periods of social restrictions that may lie ahead, policy-makers might want to take precautionary measures to identify and protect those that pose the highest risk of self-harm or domestic abuse and consider additional funding towards mental health services to meet demand.

Trauma care

The unprecedented strain of the SARS-CoV-2 pandemic has impacted the health care system in various ways, with a detrimental impact on trauma care. The number of elderly patients with hip fractures has remained consistent with the pre-SARS-CoV-2 era; however, an increase in mortality was found for the hip fracture population. This increase could be attributed to multiple factors. First, these patients were particularly more vulnerable during the SARS-CoV-2 pandemic. Both older age and comorbidities are triggers for an increased risk of infection or mortality caused by SARS-CoV-2.[29,30] The literature reports an in-hospital mortality rate of approximately 30% for hip fracture patients with a concomitant SARS-CoV-2 infection.[4] Second, there is compelling evidence that early surgery, prompt orthogeriatric care and early postoperative ambulation improve outcomes for patients with hip fractures.[31,32] Our results illustrate that an accelerated care pathway was adopted to shorten the length of hospital stay. However, shortening of hospital length of stay may have led to a suboptimal or unsafe level of recovery before discharge. Third, nursing homes and rehabilitation centres were inadequately prepared to protect their health care workers and patients from infecting each other with SARS-CoV-2. During the first wave, the latter was the case in the Netherlands, as the scarcity of appropriate protective equipment allegedly caused several local outbreaks in nursing homes. The decreased number of patients discharged to nursing homes suggests a response to suboptimal conditions. However, further study is needed to investigate whether these elements have led to unfavourable outcomes for trauma patients admitted after a sustained hip fracture.

Similar to patients with a hip fracture, the number of MT patients has remained substantial, demonstrating the necessity to retain fully functional trauma teams, operating rooms, and especially the availability of ICU beds when planning for future epidemics. Severely injured patients highly rely on the availability of emergency services and immediate access to specialized care, including ICUs. The pressing demand on ICU facilities during the first infectious peak has had a detrimental impact on patients with minor to moderate traumatic brain injuries [ref]. Patients without an obvious ICU indication (e.g., forced by conditions such as prehospital intubation or with a low Glasgow Coma Score) were denied access to the ICU and instead were closely monitored so that any deterioration could be quickly identified, which might have led to more favourable outcomes.

Prehospital care

The SARS-CoV-2 pandemic has affected emergency medical services in different ways. Social distancing and working from home resulted in fewer people on the roads, leading to shortened total EMS prehospital times. However, the increased demand induced by the SARS-CoV-2 pandemic and the subsequent mandatory infection prevention measures could elongate the total EMS prehospital time. A study from the US did not find differences in total prehospital time during the SARS-CoV-2 pandemic compared to 2019, even though transport time was significantly shorter during the pandemic.[33] Among the Dutch trauma population, the prehospital EMS times were significantly longer in all 2020 time periods. An increased on-scene time was the main cause of the elongated total prehospital time. This increase, in turn, could be a potential cause of the recorded increased mortality because there is compelling evidence that a longer on-scene time is associated with increased mortality.[34] More specifically, an on-scene time greater than 20 minutes increases the relative risk of mortality within 24 hours by 1.797 (1.406-2.296) compared to those with an on-scene time of less than 20 minutes.[34] However, the changes in transportation times found in this study are not indisputable. First, the reported association of increased on-scene times with mortality originates from the trauma population with an ISS of 9 and higher. Second, in approximately 40% of the cases included in our study, prehospital transport times were missing.

Strengths and limitations

National coverage is markedly important when evaluating trauma care during a pandemic. In contrast to other regional or single centre studies,[10,12–16,28] this study included all trauma patients admitted to a trauma-receiving hospital in the Netherlands, regardless of the type or severity of the injury. Another major strength is that this study demonstrates trends in trauma care and effects on outcome during multiple phases of the SARS-CoV-2 pandemic and compares it with historical data prior to the SARS-CoV-2 pandemic. This study also has limitations. A coinciding SARS-CoV-2 infection is likely to negatively affect outcomes after trauma. Unfortunately, the cause of death or SARS-CoV-2 infection status of trauma patients is not documented in the DNTR. Another limitation is missing data, as shown in the supplemental materials.

CONCLUSION

Imposed restrictions of individuals' movements and activities in response to the SARS-CoV-2 pandemic led to fewer acute trauma admissions in the Netherlands. We observed that the trauma population was older on average and more frequently concerned with penetrating injuries, and the duration of hospital admission was shortened for vulnerable subgroups. The long-lasting pressing demand for resources, including ICU services, has negatively affected trauma care. Further caution is warranted regarding the increased incidence of injuries related to violence and self-harm.

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CHAPTER 5

The detrimental impact of the COVID-19 pandemic on major trauma outcomes in the Netherlands: a comprehensive nationwide study

Annals of Surgery

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ABSTRACT

Objective*:*

To evaluate the impact of the COVID-19 pandemic on the outcome of major trauma patients in the Netherlands.

Summary Background data:

Major trauma patients highly rely on immediate access to specialised services, including intensive care unit (ICUs), shortages caused by the impact of the COVID-19 pandemic may influence their outcome.

Methods*:*

A multi-center observational cohort study, based on the Dutch National Trauma Registry was performed. Characteristics, resource usage, and outcome of major trauma patients (injury severity score ≥16) treated at all trauma-receiving hospitals during the first COVID-19 peak (March 23 through May 10) were compared with those treated from the same period in 2018 and 2019 (reference period).

Results*:*

During the peak period, 520 major trauma patients were admitted, versus 570 on average in the pre-COVID-19 years. Significantly fewer patients were admitted to ICU facilities during the peak than during the reference period (49.6% versus 55.8%; p=0.016). Patients with less severe traumatic brain injuries in particular were less often admitted to the ICU during the peak (40.5% vs 52 .5%; p=0.005). Moreover, this subgroup showed an increased mortality compared to the reference period (13.5% vs 7.7%; p=0.044). These results were confirmed using multivariable logistic regression analyses. In addition, a significant increase in observed versus predicted mortality was recorded for patients who had a priori predicted mortality of 50% to 75% (p=0.012).

Conclusion*:*

The COVID-19 peak had an adverse effect on trauma care as major trauma patients were less often admitted to ICU and specifically those with minor through moderate brain injury had higher mortality rates.

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic dramatically changed the demand for healthcare services. It is very likely that the reallocation of medical resources to treat the high numbers of COVID-19 patients significantly impacted acute care for critically injured patients. Especially for major trauma patients, the limited capacity of highly specialized trauma centre facilities, including intensive care unit (ICU) capacity, may have had a negative impact on their treatment and outcomes. However, only a few studies have investigated the effects of COVID-19 on the treatment and outcome of trauma patients.[1–7] Moreover, none of these studies, however, solely focused on major trauma patients. Furthermore, these studies were generally based in single centres, with small sample sizes.

In many countries, including the Netherlands, lockdown restrictions were imposed to reduce transmission of the COVID-19 virus and thereby reduce overall pressure on health care. Moreover, to ensure nationwide access to care and effectively distribute the increasing workload, the Dutch government instructed the Dutch Network for Emergency Care to set up a National Centre for Patient Distribution. This became operational in March 2020 during the first peak. Ambulance and helicopter services were used to equally distribute COVID-19 patients across hospitals. The Dutch Network for Emergency Care consists of 11 trauma networks, which in turn consist of a regional level 1 trauma centre designated for the care of the most severely injured patients, surrounded by level 2 and 3 trauma hospitals.[8]

With the COVID-19 pandemic and long-lasting pressing demand for resources, including ICU services, an important question arose: whether access and specialized care for major trauma patients was still guaranteed. Therefore, the aim of this study was to evaluate trauma care during the early 2020 COVID-19 peak with a focus on resource use and outcomes for major trauma patients in the Netherlands, particularly for patients with traumatic brain injury (TBI), as they are frequently admitted to an ICU and are at risk of poor outcomes.[9,10]

METHODS

Study design

We performed a comprehensive, nationwide, multicentre, prospective observational cohort study comparing the patient characteristics, operating room (OR) and ICU resource use and outcomes of major trauma patients treated in all trauma patient-receiving Dutch hospitals during the first COVID-19 peak and a two-year pre-COVID-19 reference period.

The COVID-19 peak in the Netherlands was defined by the period in which the total ICU occupancy exceeded the yearly averaged ICU bed occupancy for 2018 and 2019 (Figure 1). The seven-week COVID-19 peak period in early 2020 lasted from Monday 23 March through Sunday 10 May. The comparison period included patients admitted from Monday 26 March through Sunday 13 May 2018, as well as the period from Monday 25 March through Sunday 12 May 2019.

Data source

Data were extracted from the Dutch National Trauma Registry (DNTR).[8] The DNTR documents all injured patients directly admitted to a hospital through the emergency department (ED) within 48 hours after trauma, regardless of their age, injury location, and severity. Patients without vital signs upon arrival at the ED were excluded.[8] Patients were included based on their hospital admission date and the severity of their sustained injury. This study was exempted from ethics review board approval because the study used coded data from the existing National Trauma Registry, and patient anonymity was warranted. Patients or the public were not involved in the design, conduct, reporting, or dissemination plans of our study. The DNTR dataset includes the Utstein template items for uniform reporting of data following major trauma and covers 100% of the trauma-receiving hospitals in the Netherlands.[11] Injuries are coded according to the Abbreviated Injury Scale (AIS) 2005 update 2008.[12] Major trauma patients were defined as having an injury severity score (ISS) ≥16.[13] We used categories of head AIS ≤3 and AIS ≥4 to distinguish minor to moderate brain injuries from severe TBI. Critical resources are those for which accessibility is potentially endangered during a pandemic. In this study, critical resources included acute access to OP and ICU facilities and overall ICU admission. Outcomes were measured as in-hospital and 30-day (30D) mortality as well as disabilities according to the Glasgow Outcome Scale (GOS)[14] at discharge. To differentiate between disabilities, fatal cases were excluded, and the GOS was dichotomously categorized as either no or mild disabilities versus severe disabilities or vegetative state.

To compare outcomes between the peak and reference period, we compared the predicted mortality and observed mortality for both periods. To calculate mortality probability, we applied the Trauma and Injury Severity Score (TRISS) method with updated coefficients based on the Dutch trauma registry data.[15] The TRISS combines anatomical (ISS), physiological (revised trauma score (RTS)), injury mechanism and age characteristics to quantify the probability of patient mortality.

Comparisons between predicted and observed outcomes were performed for six bands of equal mortality probability: 0-5%, 6-10%, 11-25%, 26-50%, 51-75%, and 76-100%.

Statistical analysis

The study was performed according to the STROBE guidelines for observational studies.[16] Missing values were imputed using multiple imputation in SPSS.[17] Categorical data are described as numbers (percentages) and were compared using a chi-squared test. Continuous data are expressed as the mean (standard deviation, SD) or median (interquartile range, IQR, 25th to 75th percentile) for normally or non-normally distributed measurements, respectively, and were compared using a *t*-test or a Wilcoxon-Mann-Whitney test, as appropriate. A p-value of <0.05 was considered significant. Statistical analysis was performed using IBM SPSS statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.[17]

Two multivariable logistic regression models were developed to assess the odds ratios (OR) for ICU admission and hospital mortality between the peak and reference period. In these models the effects of the periods (peak or reference) as independent predictors. To test for effect modification between time period and brain injury we included the interaction terms between the peak period and patients that either sustained no brain injuries or minor to moderate brain injuries. In this particular case severe brain injuries were used as the reference group. If an interaction term was not significant, it was not included in the final model. Case-mix correction was performed with the inclusion of age, gender, systolic blood pressure (SBP), respiratory rate (RR), Glasgow Coma Scale (GCS), ISS, ICU admission (only for the mortality model) in the models.

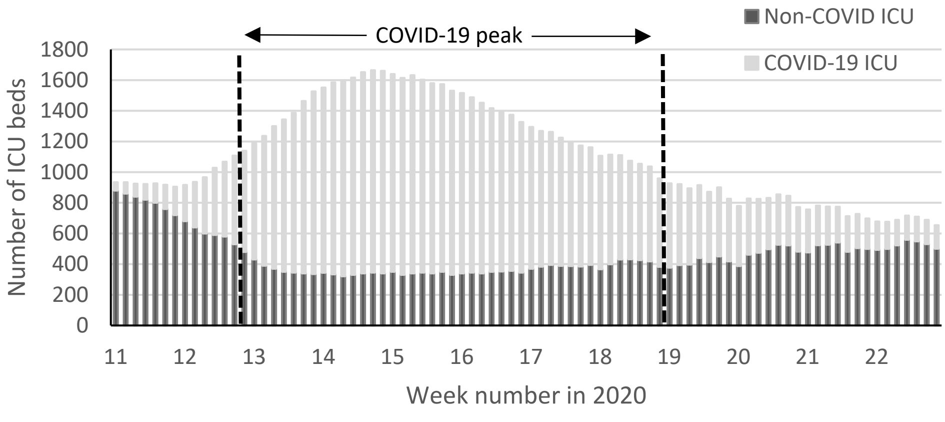

Figure 1. Dutch national intensive care bed occupancy for a seven-week period from March 8^{th} to May 31^{st}, 2020. (The data used in this graph were obtained from the National Centre for Patient Distribution [LCPS] and the Dutch National Intensive Care Evaluation [NICE] register).

RESULTS

Number of major trauma patients

A total of 520 major trauma patients (ISS≥16) were acutely admitted during the first peak period (49 days), which is 8.7% lower than the average of 569 major trauma patients who were admitted during the reference period. The average weekly number of major trauma patients admitted was significantly ($p=0.027$) lower during the COVID-19 peak period (74, SD 20) than during the pre-COVID-19 era (81, SD 14). Figure 2 shows the weekly number of admitted major trauma patients and the weekly number directly admitted to the ICU or OR. In parallel to the lower number of admitted patients, the weekly number of patients needing immediate ICU or OR care was lower than that in the reference period.

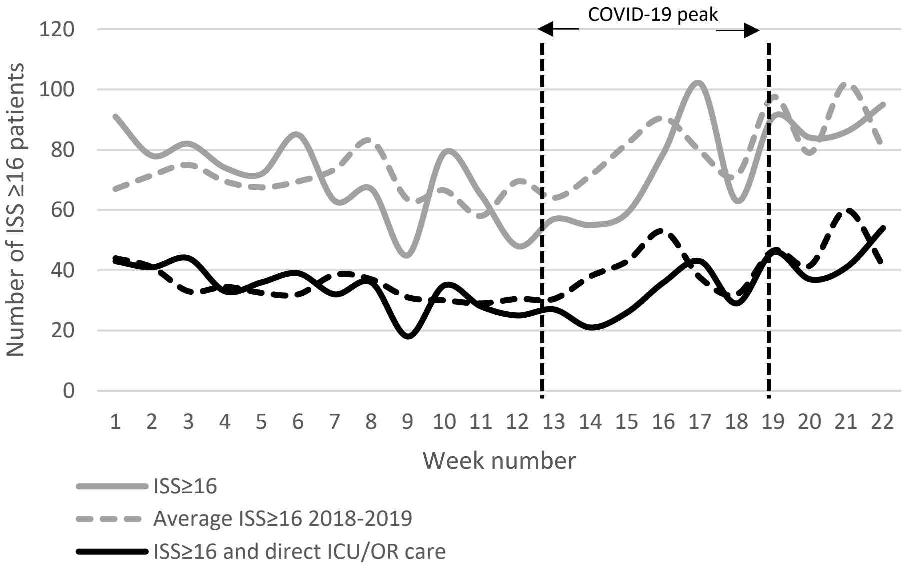

Figure 2. The weekly number of major trauma patients and the number of major trauma patients directly admitted to the ICU or operating room (OR) during the COVID-19 peak and reference periods.

Patient characteristics

The baseline characteristics and the cause of injury of major trauma patients showed no significant differences between the peak and reference periods (Table 1).

Resource use and outcome

Significant differences in resource use were found for median hospital length of stay, the number ICU admissions and respiratory support in the ICU (Supplemental material Table 1). During the peak period the median length of stay was 7 days (IQR, 3 - 13) which is significantly shorter than the 8 days (IQR, 3 - 16) in the reference period (p=0.021). The percentage of ICU-admitted major trauma patients was lower during the peak period (49.6% vs 55.8%, p=0.016). Moreover, the percentage of major trauma patients that received respiratory support during ICU admission increased from 50.2% during the reference period to 62.4% in the peak period (p=0.049).

Regarding the outcome measures, no significant differences between the study periods were recorded in terms of the number of patients who left the hospital with severe disabilities or in a vegetative state (32.5% vs 27.9%, p=0.137), or for the overall hospital mortality (18.5% vs 17.8%, p=0.753) or the 30day mortality (24.4% vs 20.8%, p=0.095). However, for major trauma patients with a predicted mortality between 51% and 75%, a significantly higher observed mortality (74%) was recorded (p=0.026) during the COVID-19 peak compared with the pre-COVID-19 reference period (46%) (Figure 3). The total percentage of ICU-admitted major trauma patients within this predictive mortality band was lower during the peak period than during the reference period (58.3% vs 87.5%, p=0.018).

Table 1. Major trauma patient characteristics and mechanisms of injury of patients treated during the first COVID-19 peak versus the reference periods.

		Peak	Reference		P value
		2020	**2018**	**2019**	
Total included		520	554	585	
Mean inclusions per week (SD)		74 (20)	81 (14)		0.364
Male sex		347 (66.7%)	773 (67.8%)		0.647
Median age (IQR)		59 (37 – 75)	59 (36 -75)		0.891
Median age direct ICU admitted (IQR)		53(32 – 68)	52 (30 – 68)		0.776
Median ICU LOS (IQR)		3 (2 – 6)	3 (2 – 8)		0.013
ISS Median (IQR)		21 (17 – 26.7)	21 (17 – 26)		0.729
	16 – 24	317 (61.5%)	697 (61.2%)		
	25 – 49	185 (35.6%)	407 (35.7%)		
	50 – 75	18 (3.5%)	35 (3.1%)		
Blunt trauma		508 (97.7%)	1100 (96.6%)		0.154
AIS ≥3					
	Head	275 (52.9%)	608 (53.3%)		0.851
	Face	25 (4.8%)	30 (2.6%)		0.026
	Neck	8 (1.5%)	15 (1.3%)		0.082
	Thoracic	209 (40.2%)	496 (43.5%)		0.200
	Spine	74 (14.2%)	141 (12.3%)		0.306
	Abdominal	49 (9.4%)	124 (10.9%)		0.388
	Upper extremities	8 (1.5%)	21 (1.8%)		0.693
	Lower extremities	92 (17.7%)	193 (16.4%)		0.708
	External	22 (4.2%)	45 (3.9%)		0.789
Injury cause					0.070
	Sports	30 (5.8%)	67 (5.9%)		
	RTA	204 (39.2%)	465 (40.8%)		
	Home	216 (41.5%)	425 (37.3%)		
	Work	33 (6.4%)	65 (5.7%)		
	Violence	6 (1.1%)	35 (3.1%)		
	Self– harm	31 (6.0%)	52 (4.6%)		

Abbreviations: LOS, length of stay; ISS, Injury Severity Score; AIS, Abbreviated Injury Score; RTA, road traffic accident.
Peak: the period from March 23 through May 10, 2020.
Reference: the period from March 26 through May 13 for 2018, and the period from March 25 through May 12 for 2019

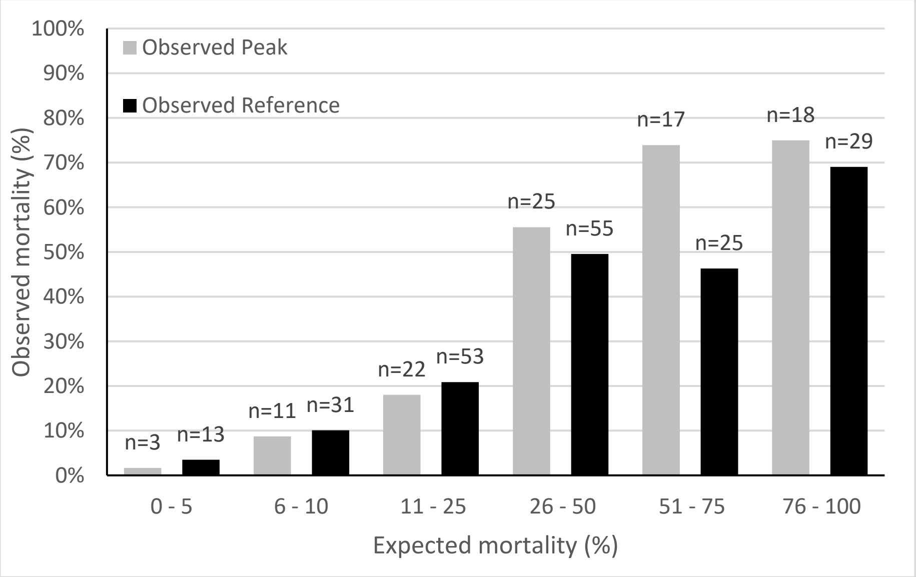

Figure 3. Major trauma patients expected and observed mortality during the first COVID-19 peak in 2020 and the reference periods in 2018 and 2019.

Traumatic brain injuries

The subgroup analysis of patients with TBI is shown in Table 2. There was a significant decrease in the number of ICU admissions for patients with minor to moderate TBI, defined as head AIS ≤3, during the peak vs reference period (40.5% vs 52.5%, p=0.005) (Table 2). The overall mortality rate for this group was significantly higher during the peak period (13.5% vs 7.7%; p=0.044). A further evaluation showed that the mortality rate for those not admitted to the ICU was significantly higher during the peak than during the reference period (10.3% vs 2.3%; p=0.016). This difference in mortality was not observed for those admitted to the ICU (p=0.145). The length of stay (LOS) was shortened among deceased patients with minor to moderate TBI admitted to the ICU, with a median of 3 days (IQR 1.25 - 5.75) at the peak compared to 6 days (IQR 2 - 10) in the reference period (p=0.015). Critical resource use and outcome for severe head injuries (AIS ≥4) did not differ between the peak and reference periods (Table 2).

Multivariable regression models

In the multivariable prediction models the association between period (peak vs reference) and ICU admission and mortality ware tested as shown in Table 3. Patients admitted during the peak had a significantly lower odds ratios (0.740 (0.647 – 0.847)) on being ICU admitted.

The model describing for mortality did not show a significant higher odds ratio for mortality of patients admitted during the peak (0.803 (0.519 – 1.242)). Patients with no TBI (0.606 (0.399 – 0.921) or minor to moderate TBI (0.253 (0.198 – 0.325)), had overall a significantly lower odds ratio on mortality, compared to patients with severe TBI. However, the significant interaction term for peak period and TBIs showed that there is a difference between the two periods. The effect of the COVID peak period is higher for patients with minor to moderate TBI compared to patients with severe TBI. Patients with moderate to severe TBI had a higher risk (OR 2.510 (1.136 – 5.546)) of mortality during the peak in comparison with the reference period.

We also performed an additional multilevel binary logistic regression analysis to assess whether the regional trauma networks significantly affected the independent variables, however, no significant differences in effects were found (results not shown).

Table 2. The incidence, resource use and outcome for less and more severe head injuries during the peak and reference period.

		Peak	**Reference**		**p-value**
		2020 **n=520**	**2018** **n=561**	**2019** **n=578**	
Head AIS ≤3		163 (31.3%))	171 (30.5%)	181 (31.3%)	0.857
Admitted to ICU		66 (40.5%)	185 (52.5%)		0.005
Mortality		22 (13.5%)	27 (7.7%)		0.044
Not admitted to ICU		10 (10.3%)	4 (2.3%)		0.016
Admitted to ICU		12 (18.2%)	23 (12.4%)		0.145
Median LOS deceased (IQR)	Hospital	3 (1.5 – 9)	7 (3 – 14)		<0.001
	ICU	3 (1.25– 5.75)	6 (2 – 10)		0.015
Head AIS ≥4		197 (37.9%)	189 (33.7%)	220 (38.1%)	0.438
Admitted to ICU		107 (54.3%)	230 (54.5%)		0.808
Mortality		51 (25.9%)	122 (29.8%)		0.314
Not admitted to ICU		21 (23.3%)	48 (26.8%)		0.537
Admitted to ICU		30 (28.0%)	72 (31.3%)		0.444
Median LOS deceased (IQR)	Hospital	3 (2 – 6.5)	3 (2 – 6)		0.637
	ICU	7 (3 – 14	3 (2 – 6.5)		0.790

Abbreviations: AIS, Abbreviated Injury Score; ICU, Intensive Care Unit; LOS, length of stay.
Peak: the period from March 23 through May 10, 2020.
Reference: the period from March 26 through May 13 for 2018, and the period from March 25 through May 12 for 2019

Table 3. Multivariable logistic regression models, 95% confidence intervals, and p–values for independent variables and interaction terms to determine their association with ICU admission and mortality.

	ICU admission (OR)	**p-value**	**Mortality (OR)**	**p-value**
Age	0.987 (0.984 – 0.990)	0.000	1.037 (1.029 – 1.045)	0.000
Male vs female	0.941 (0.821 – 1.079)	0.383	1.171 (0.865 – 1.584)	0.307
Systolic blood pressure	0.992 (0.990 – 1.995)	0.000	0.996 (0.991 – 1.001)	0.880
Respiratory rate	1.040 (1.026 – 1.054)	0.000	1.047 (1.018 – 1.078)	0.002
Glasgow Coma Scale	*		*	
Injury Severity Score	1.037 (1.020 – 1.054)	0.000	1.090 (1.073 – 1.108)	0.000
ICU admission vs no ICU admission	-	-	1.396 (1.022 – 1.908)	0.001
Peak vs reference period	0.740 (0.647 – 0.847)	0.015	0.803 (0.519 – 1.242)	0.323
No TBI vs severe TBI	1.017 (0.865 – 1.196)	0.838	0.609 (0.400 – 0.925)	0.020
Minor to moderate TBI vs severe TBI	0.937 (0.799 – 1.099)	0.422	0.253 (0.198 - 0.325)	0.000
Peak*no TBI	**		1.285 (0.621 – 2.657)	0.499
Peak* minor to moderate TBI	**		2.510 (1.136 – 5.546)	0.023

Abbreviations: OR, odds ratio; ICU, Intensive Care Unit; TBI, traumatic brain injury.
Peak: the period from March 23rd through May 10th, 2020.
Reference: the period from March 26th through May 13th for 2018, and the period from March 25th through May 12th for 2019
* Excluded from the model due to strong collinearity with TBI
** Interaction terms without significant result were excluded from the model

DISCUSSION

We demonstrated that during the COVID-19-induced ICU occupancy peak, major trauma patients who would likely benefit from being closely monitored, like patients with minor to moderate TBI, were less often admitted to the ICU and showed worse outcomes. Thus, despite all efforts made to secure access to critical trauma care, the health care crisis due to COVID-19 had an adverse effect on trauma care. Trauma care could not be guaranteed to the same level as in the pre-COVID-19 era.

Number of major trauma patients

We found that during the COVID-19 peak in the Netherlands, major trauma was approximately 9% less common than during similar seasonal periods in the years prior to the COVID-19 pandemic. This reduction was likely caused by lockdown restrictions. However, the number of major trauma patients remained substantial, demonstrating the necessity to take this into account for the modelling of epidemics and forecasts of ICU bed utilization.

Increased mortality and triage of trauma patients

Our most compelling finding is the lower ICU admission rate and increased mortality in major trauma patients with minor to moderate TBI that were not admitted to the ICU during the peak period. We suggest that this group might have benefitted from ICU care, as the comparable group in the pre-COVID-19 period had better outcomes. This demonstrates that crucial decisions were made during the first COVID-19 peak that led to less favorable outcomes.

We speculate that competition for ICU resources led to a negative selection of major trauma patients. In the case of an obvious ICU indication forced by conditions such as prehospital intubation, severe TBI with a low GCS, or high injury severity with prehospital interventions, ICU care is automatically assumed to be needed. In these cases, admission was unavoidable, whereas in those patients with minor to moderate TBI, ICU admission and treatment would have been ‘a choice’. This speculation is supported by our finding that during the COVID-19 peak, a larger proportion of patients in the ICU were ventilated than during the reference period. This indicates that fewer patients were admitted to the ICU for close monitoring so that any deterioration could be quickly identified.

The increased mortality of major trauma patients with a predicted mortality of approximately 51-75% is also worrisome. The average observed mortality within this band was 46% in the reference period, which is in sharp contrast to the 74% mortality during the COVID peak in 2020. Further analyses showed that within this band significantly less patients were admitted to ICU during peak.

In summary, our data suggests that the limited availability of ICU resources led to less favorable triaging for major trauma patients, where the situation, instead of necessity or the basic triage adage, ‘do the most for the most’, was not adhered to. When making this choice between patients, those with a higher survival probability and outlook for a better neurological prognosis should have priority over those with a more dismal prognosis or worse neurological outcome.

Major trauma and COVID-19

The high number of COVID-19 patients requiring respiratory support and often having prolonged ICU stays resulted in a strain on the ICU capacity in the Netherlands. This raises dilemmas about how best to allocate scarce critical resources. In defining guidelines and criteria for the selection of patients for ICU treatment (in the case of absolute scarcity), medical and ethical grounds need to be taken into account.[18] Basic ethical notions including ‘to save as many lives as possible’ and triage criteria for admittance to the ICU should apply equally to COVID-19 and non-COVID-19 patients. In the Netherlands, in the pre-COVID-19 era, we found that major trauma patients admitted to the ICU had a median ICU stay of three days, and one of four died. COVID-19 patients have been reported to have a much longer ICU stay and a higher risk of death. International studies on ICU-admitted COVID-19 patients reported that the median length of ICU stay for critically ill COVID-19 patients was 12 days (IQR, 6 to 21), and the ICU mortality ranged between 30% and 48%.[19–22] These findings need to be taken into account in future resource planning and drafting of triage tools.

An important question that needs to be addressed is how to utilize our findings in planning and ensuring an equipoise distribution of care facing similar challenges going forward. One of the criteria for the Dutch level 1 trauma centres is that, at least one ICU bed is preserved for trauma patients at all times. However, in the case of extreme scarcity of ICU resources it is likely that this bed is used for non-trauma patients when the ICU capacity is stretched.

During the pandemic, ICU resource scarcity in the Netherlands was not solely caused by the relentless demand. Capacity expansion was limited by shortages in workforce, but also in equipment such as mechanical ventilators and protective materials. Furthermore, a nationwide system that enables real-time data on hospitals ICU availability was not in place at the time. Such a system facilitates the coordination between hospitals and helps decision makers to allocate resources. These crucial factors should be addressed to ensure a better response to pandemics in the future.

To enhance trauma care in general and particularly for those with TBIs, we would like to draw attention to the potential benefits of intermediate care units. These units reduce the gap between the wards and ICU and can act as step-up units for deteriorating and step-down units for improving patients.[23]

Considering our findings of an increased number of deaths among patients with minor to moderate TBI, we believe that close monitoring at an intermediate care unit could offer a solace. While reducing ICU demand, and enabling close monitoring and an expedite transfer to the ICU in case of deterioration. Intermediate care units can offer a buffer capacity for the ICU. Unfortunately, the DNTR does not include detailed information on whether the hospitals they were treated had such an intermediate care unit. Hence, we were unable to assess the effects on outcomes at this time, however it seems to be of value in the future.

Other disease entities

The impact of the COVID-19 pandemic on other major diseases has also been evaluated. De Rosa and colleagues noticed a huge reduction in hospitalizations for myocardial infarction in Italy during the pandemic, with increased fatality and complication rates.[24] However, in their case, the admissions declined with a further concentration of the most severe cases, in contrast to the study presented here. In oncology care, a substantial increase in the number of avoidable cancer deaths was also reported.[25] The authors speculated that this was probably due to the backlog of diagnostic procedures.[25] Additionally, patients with neurological conditions were reported to experience negative impacts on their conditions. Zhao and colleagues reported on the impact of the pandemic on stroke care in China,[26] as did Rinkel *et al.*, who observed a 24% decrease in suspected stroke presentations in the Amsterdam region in the Netherlands during the COVID-19 outbreak. In contrast to our findings, there was no evidence for a decrease in the quality of acute care.[27]

In contrast to our study, all of the previous studies examined care at the local or regional levels only. To the best of our knowledge, this is the first study to provide a nationwide comprehensive overview of the epidemiology and effects on major trauma care during the COVID-19 pandemic, with far-reaching consequences for the organization, design, and allocation of care and resources during such a crisis. This study also has limitations. A coinciding COVID-19 infection is likely to negatively affect outcomes after trauma. Unfortunately, the COVID-19 infection status of major trauma patients is not documented in the DNTR, and the anonymization process prevents retracement. Because this study contains data only from the first COVID-19 peak period, further research is needed to assess the long-term impact of the COVID-19 pandemic on trauma-related injuries.

CONCLUSION

The number of major trauma patients significantly declined during the first COVID-19 peak, likely due to the restrictive regulations of society. Nevertheless, competition for the restricted available ICU beds coincided with diminished ICU admission rates for major trauma patients and increased mortality among specifically major trauma patients who sustained minor to moderate TBI or had a predicted mortality rate between 51% and 75%.

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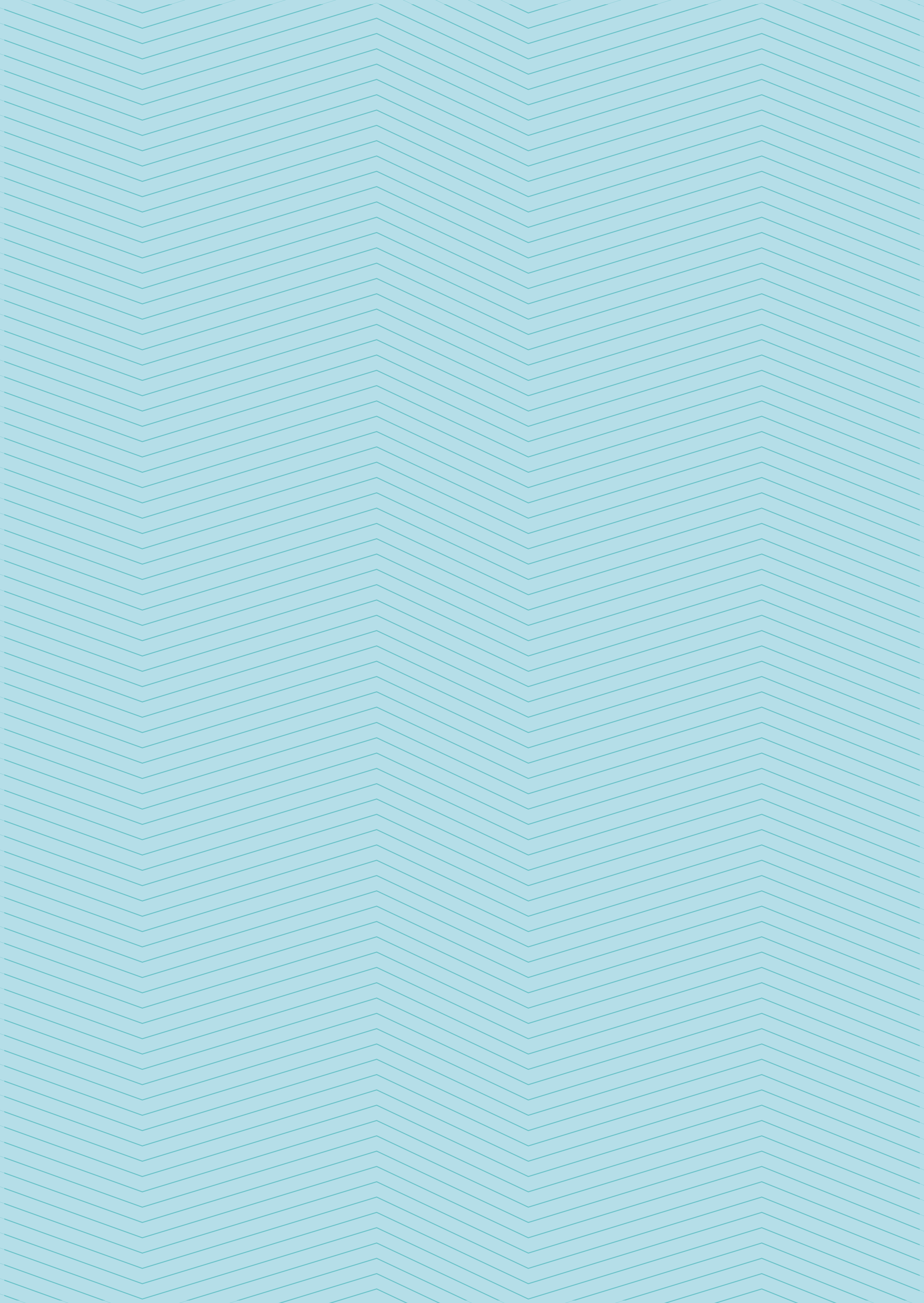
APPENDIX

Supplemental Digital Content Table 1. Trauma resource use and outcome for major trauma patients treated during the first COVID-19 peak versus the reference period.

	Peak 2020	**Reference 2018 – 2019**	**p–value**
Total number patients	520	1139	
MTC care	358 (68.8%)	787 (69.1%)	0.919
CT scan performed	520 (100%)	1138 (99.9%)	0.499
Direct transfer to another hospital	33 (6.3%)	70 (6.1%)	0.875
Direct ICU/OR admission	249 (47.9%)	577 (50.7%)	0.310
Admitted to ICU	258 (49.6%)	636 (55.8%)	0.016
ISS 16– 24	128 (40.3%)	320 (45.9%)	0.102
ISS 25– 49	116 (62.7%)	288 (70.8%)	0.044
ISS 50– 75	14 (77.8%)	28 (80.0%)	0.850
ICU Respiratory support	161 (62.4%)	319 (50.2%)	0.049
ICU Days of respiration support (IQR)	3 (1 – 7)	3 (2 – 10)	0.124
Median ICU LOS in days	3 (2 – 6)	3 (2 – 8)	0.013
Median hospital admission LOS	7 (3 – 13)	8 (3 – 16)	0.021
GOS – severe or vegetative state	138 (32.5%)	260 (27.9%)	0.137
Mortality	96 (18.5%)	203 (17.8%)	0.753
Mortality ICU admitted	62 (11.9%)	128 (11.2%)	0.196
Mortality direct ICU/OR admitted	58 (11.1%)	116 (10.2%)	0.308
MTC mortality	81 (22.6%)	157 (19.9%)	0.301
Non-MTC mortality	15 (9.2%)	46 (13.1%)	0.215
30-day mortality	127 (24.4%)	237 (20.8%)	0.095

Abbreviations: MTC: major trauma centre; CT: computer tomography; ICU: Intensive Care Unit: OR, operating room; LOS: length of stay; GOS: Glasgow Outcome Scale.
Peak: the period from March 23rd through May 10th, 2020.
Reference: the period from March 26th through May 13th for 2018, and the period from March 25th through May 12th for 2019



PART II

Changing the boundaries

D

CHAPTER 6

Evaluation of the Berlin polytrauma definition: a Dutch nationwide observational study

Journal of Trauma and Acute Care surgery

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ABSTRACT

Background

The Berlin polytrauma definition (BPD) was established to identify polytrauma patients with a high risk of mortality. The definition includes injuries with an Abbreviated Injury Score of ≥3 in ≥2 body regions (2AIS≥3) combined with the presence of ≥1 physiological risk factors (PRF). The PRFs are based on age, Glasgow Coma Scale, hypotension, acidosis, and coagulopathy at specific cutoff values. This study evaluates and compares the BPD with two other polytrauma definitions used to identify patients with high resource utilization and mortality risk, using data from the Dutch National Trauma Register (DNTR).

Methods

The evaluation was performed based on 2015-2018 DNTR data. First, patient characteristics for 2AIS≥3, ISS≥16 and BPD patients were compared. Second, the PRFs prevalence and odds ratios of mortality for 2AIS≥3 patients were compared with those from the Deutsche Gesellschaft für Unfallchirurgie Trauma Register (DGU-TR). Subsequently, the association between PRF and mortality was assessed for 2AIS≥3-DNTR patients and compared with those with an ISS≥16.

Results

The DNTR recorded 300,649 acute trauma admissions. A total of 15,711 patients sustained an ISS≥16, and 6263 patients had suffered an 2AIS≥3 injury. All individual PRFs were associated with a mortality of >30% in 2AIS≥3-DNTR patients. The increase in PRFs was associated with a significant increase in mortality for both 2AIS≥3 and ISS≥16 patients. A total of 4264 patients met the BPDs criteria. Overall mortality (27.2%), ICU admission (71.2%) and length of stay were the highest for the BPD group.

Conclusion

This study confirms that the BPD identifies high-risk patients in a population-based registry. The addition of PRFs to the anatomical injury scores improves the identification of severely injured patients with a high risk of mortality. Compared to the ISS≥16 and 2AIS≥3 polytrauma definitions, the BPD showed to improve the accuracy of capturing patients with a high medical resource need and mortality rate.

BACKGROUND

The structured and reproducible denomination of severely injured patients is complex and has been the subject of discussion for decades.[1] Almost fifty different polytrauma definitions have been described.[1] The most widely used definition is the Injury Severity Score (ISS).[2] The ISS is based on an anatomical injury severity classification, the Abbreviated Injury Scale (AIS).[3] Thirty years ago, an ISS cutoff of ≥16 points was chosen to describe the severely injured because these patients had an expected mortality rate of over 20%.[4] Due to the introduction of trauma systems[5–9] and enhanced medical care, mortality is currently considerably lower for ISS ≥16 patients and ranges between 9.0% and 12.3%.[10] These observations reopened the discussion on the ISS ≥16 definition's usability to identify severely injured patients. Butcher and colleagues reported that patients with an AIS of ≥3 in at least two different AIS body regions captured more clinically defined polytrauma patients with a worse outcome than the definition of an ISS ≥16 or ISS ≥18.[11] The physiological derangement characteristics following trauma have been described in multiple studies, however, the application within a trauma definition was proven to be questionable, mostly due to practical limitations. [12–15] Going forward from there, an expert panel introduced the Berlin polytrauma definition in 2014, presented in an article by Pape et al.[16] This definition combines the anatomical classification of injury, i.e., the AIS, with the physiological response. For the development of the Berlin polytrauma definition, the mortality cutoff value was set at a minimum of 30%. According to the Berlin polytrauma definition, critically injured patient (polytrauma) patients have sustained injuries with an AIS of ≥3 in at least two different AIS body regions and have one or more of the following five physiologic parameters: hypotension [systolic blood pressure ≤90 mmHg], unconsciousness [Glasgow Coma Scale score ≤8], acidosis [base excess ≤ -6.0], coagulopathy [partial thromboplastin time ≥40 s or an international normalized ratio (INR) ≥1.4], and age [≥70 years].[16]
The Berlin polytrauma definition differs from the ISS ≥16 definition in that it includes physiological parameters, and it requires trauma patients to have sustained at least two significant injuries (AIS ≥3) in separate body regions. Thus, severe mono trauma patients and patients with an ISS <18 do not meet the Berlin polytrauma definition.
The Berlin polytrauma definition aims to identify critically ill patients who require multidisciplinary care and overarching management by trauma specialists. The definition was developed and tested on data recorded in the Deutsche Gesellschaft für Unfallchirurgie Trauma Register (DGU-TR). The DGU-TR focuses on patients with multiple injuries admitted to intensive care facilities. External validation of the definition in a broader trauma population has yet to be performed. The Dutch National Trauma register (DNTR) provides this opportunity as it has national coverage and includes all acute trauma admissions.[17] The purpose of this study was to reassess the

Berlin polytrauma definition on the Dutch trauma registry data, including all acute trauma admissions, and to compare results with those previously reported by the expert consensus study on intensive care admissions in Germany.[16] Moreover, we aimed to compare patient characteristics, resource use, and outcomes for; patients with an ISS >15, patients with an AIS ≥3 in at least two body regions, and patients that meet the Berlin polytrauma definition (i.e., patients with not only two AIS ≥3 in at least two body regions but also at least one physiological risk factor). Finally, we explored the value of adding physiological risk factors to anatomical injury definitions of both the ISS>15 patients and patients with at least two AIS ≥3 for identifying patients with a high mortality risk.

METHODS

Patients

The DNTR includes all injured patients directly admitted to the hospital through the emergency department (ED) within 48 hours after trauma. Patients without vital signs upon arrival at the ED were excluded. Since 2015, 100% of trauma-receiving hospitals in the Netherlands have participated in the Dutch National Trauma Registry (DNTR) [17]. For this study, all patients recorded in the DNTR between January 1, 2015, and December 31, 2018, were included. According to the inclusion criteria, patients transferred within 48 hours after the incident are registered twice. Therefore, patients who were secondarily transferred to the hospital after ED treatment at another hospital were excluded.

For this study, we defined the following patient subgroups: (1) all patients with an AIS≥3 in at least two body regions [2AIS≥3-DNTR]. This group matches the population that was used in the expert consensus study by Pape et al. [2AIS≥3-DGU-TR][16]; (2) patients corresponding to the Berlin polytrauma definition's criteria, i.e., patients with an AIS ≥3 in at least two body regions and the presence of at least one of the five physiological risk factors [BPD-DNTR]. (3) patients with an ISS ≥16, [ISS16-DNTR].

Statistical analysis

We compared the patient characteristics of 2AIS≥3-DNTR patients with those of the 2AIS≥3-DGU-TR patients. Additionally, we described these characteristics for the BPD-DNTR and the ISS16-DNTR patients. The prevalence, in-hospital mortality rate, and odds ratio (OR) for mortality were calculated for each physiological risk factor in the 2AIS≥3-DNTR patient group and compared with those reported in the 2AIS≥3-DGU-TR population. Furthermore, to investigate the additional value of including physiological risk factors within a trauma definition, we graphically assessed the association between the number of physiological risk factors and in-hospital mortality within the 2AIS≥3-DNTR and the ISS16-DNTR patient group.

Missing data

In this study, we assumed that risk factors were absent if the data were missing. In particular, values for coagulopathy (international normalized ratio, INR) and base excess (BE) were often not recorded. The exact number of missing values for the variables used in this study are listed in Table 1 of the Supplemental Digital Content (SDC). Unfortunately, the DNTR does not capture variables such as thromboplastin or lactate that are positively correlated with INR and BE [16]. Therefore, multiple imputations on missing values could not be performed. To assess if there were any differences between patients for whom risk factor values were missing versus non-missing, we compared these groups on age, ISS, intensive care units (ICU) admission, and MAIS and body region from the AIS ≥3 scores. These comparisons show that patients with missing values for INR and BE tended to be elderly, less severely injured, less often admitted to the ICU, and were less likely to die from their injuries (SDC, Table 2-5). These findings support our data handling assumption that risk factors were absent if missing.

RESULTS

From January 1, 2015, to December 31, 2018, a total of 323,106 cases were recorded in the DNTR. After the exclusion of patients transferred to another hospital, 300,649 acute trauma admissions were included. For 3912 (1,3%) patients, the AIS specification was missing, and these patients were excluded.

Comparison of the Dutch and German polytrauma patients

Application of the anatomical criteria of the polytrauma Berlin definition to the DNTR, i.e., selecting patients with an AIS ≥3 in at least two AIS separate body regions [2AIS≥3-DNTR], resulted in 6263 (2.1%) patients. Table 1 shows patient characteristics, resource use, and in-hospital mortality of these patients versus their counterparts from the DGU-TR.

Both the 2AIS≥3-DGU-TR and the 2AIS≥3-DNTR group consisted mainly of men (72.4% vs. 67.5%) and predominantly sustained blunt injuries (96.9% vs. 97.9%). For both the 2AIS≥3-DGU-TR and 2AIS≥3-DNTR group, the majority of injuries involved the AIS regions of the thorax and head, closely followed by extremity injuries. Compared to their DGU-TR counterparts, the 2AIS≥3-DNTR patients had a higher mean age (42.9 vs. 50.0), a lower mean ISS score (30.5 vs. 26.6), a lower ICU admission rate (92,9% vs. 63,2%), and a lower percentage of patients with a MAIS of four or higher (70,8% vs. 51.2%). The overall in-hospital mortality was comparable between the Dutch and German groups of 2AIS≥3 patients.

Table 2 describes the prevalence of the five physiological risk factors, the mortality rate, and the odds ratios of death per risk factor for the 2AIS≥3-DNTR and the 2AIS≥3-DGU-TR datasets. Except for age, the prevalence of the risk factors was higher in the 2AIS≥3-DGU-TR group. In the German and the Dutch 2AIS≥3 groups, mortality for the physiological risk factors was well above 30%. In general, 2AIS≥3-DNTR patients showed higher mortality rates in the presence of each individual risk factor except for older age (38.0% vs. 31.0%). The odds ratio of death for the unconscious patients was notably higher in the DNTR dataset (4.90 vs. 7.09).
Of the 6263 2AIS ≥3-DNTR patients, 4265 (1.4%) also had physiological risk factor(s) and met the Berlin polytrauma definition criteria [BPD-DNTR]. The overall mortality in the BPD-DNTR was 27.2%, which is significantly higher compared to the 18.7% and 19.9% for respectively the 2AIS≥3 groups.

Table 1. Characteristics of BPD patients in the DGU-TR and DNTR datasets, and for DNTR trauma patients with AIS score ≥3 in two body regions, and for patients with an ISS≥16.

	2AIS≥3-DGU-TR (n=28,211)	**2AIS≥3-DNTR (n=6267)**	**BPD-DNTR (n=4264)**	**ISS≥16-DNTR (n=15,711)**
Male	72.4% (n=20,433)	67.5% (n=4231)	65.5% (n=1470)	66.0% (n=10,377)
Age in years, mean (SD)	42.9 (20.2)	50.0 (24.8)	55.1 (25.1)	54.5 (22.6)
Penetrating injury	3.1% (n=886)	2.1% (n=130)	1.7% (n=74)	3.0% (n=467)
ISS Mean (SD)	30.5 (12.2)	26.6 (12.1)	28.8 (12.4)	23.8 (9.5)
ICU admission	92.9% (n=26,130)	63.2% (n=3963)	71.2% (n=3030)	53.6% (n=8419)
ICU LOS in days, mean (SD)	NA	4 (2 - 9)	4 (2 – 11)	3 (2 - 6)
Overall LOS in days, mean (SD)	NA	8 (3 – 18)	10 (3 - 20)	9 (4 - 18)
MAIS				
3 points	29.1% (n=8212)	48.7% (n=3050)	49.4% (n=1722)	28,9% (n=4527)
4 points	40.2% (n=11,362)	25.9% (n=1628)	27.7% (n=1181)	43.4% (n=6812)
5 points	29.1% (n=8207)	24.2% (n=1517)	30.4% (n=1298)	25.9% (n=4072)
6 points	1.5% (n=430)	1.1% (n=72)	1.5% (n=63)	1.1% (n=166)
AIS ≥3				
Head injuries	54.1% (n=15,279)	53.8% (n=3374)	66.3% (n=2826)	58.7% (n=9221)
Thoracic injuries	66.7% (n=18,824)	65.9% (n=4134)	68.2% (n=2949)	47.1% (n=7405)
Abdominal injuries	24.8% (n=7005)	16.5% (n=1036)	15.9% (n=680)	10.7% (n=1683)
Extremity injuries	43.5% (n=12,290)	52.2% (n=3273)	51.5% (n=2196)	20.7% (n=3260)
Mortality	18.7% (n=5277)	19.9% (n=1251)	27.2% (n=1161)	17.1% (n=2679)
Level 1 trauma center care	NA	71.6% (n=4486)	76.4% (n=3256)	65.8% (n=10,338)

Abbreviations: BPD, Berlin Polytrauma Definition; AIS, Abbreviated Injury Score; DGU-TR, Deutsche Gesellschaft für Unfallchirurgie Trauma Register; DNTR, Dutch National Trauma Register; ISS, Injury Severity Score; ICU, intensive care unit; MAIS, maximum abbreviated injury scale; NA: not available.

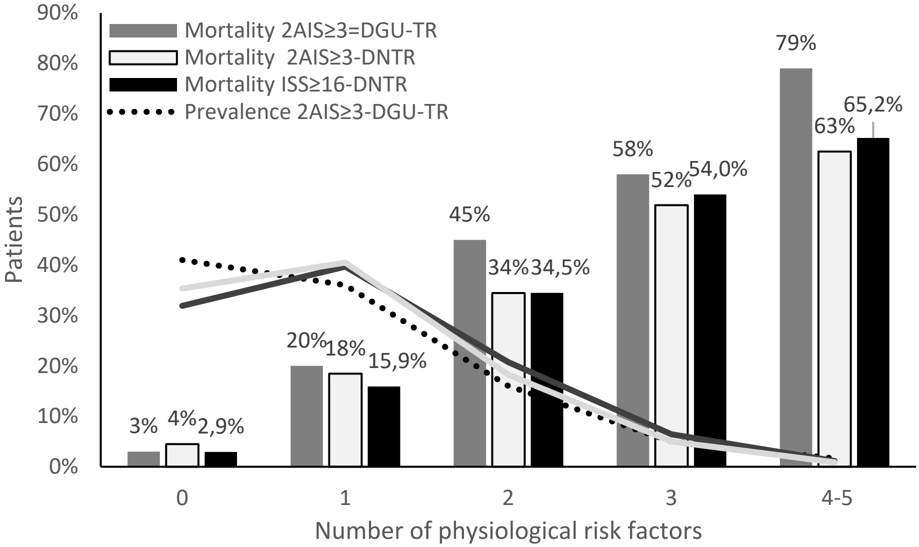

Figure 1. Prevalence and mortality rates for the 2AIS≥3-DGU-TR, 2AIS≥3-DNTR, and ISS≥16-DNTR patients versus the number of physiological risk factors.

Comparison of Dutch 2AIS≥3, ISS ≥16, and the Berlin polytrauma patients

Compared to the 2AIS≥3-DNTR patients, ISS16-DNTR patients were relatively older (50.0 vs. 54.5) and had a lower mean ISS (26.6 vs. 23.8), see also table 1. Moreover, ISS16-DNTR patients were less often admitted to the ICU (63.2% vs. 53.6%) and had a slightly lower mortality rate (19.9% vs. 17.1%). The most affected body region in the ISS16-DNTR group was the head, followed by the thorax, whereas for 2AIS≥3-DNTR patients, thoracic injuries were the most common.

The patients included in the BPD-DNTR group were older (55.1 years) and more severely injured (ISS 28.8) than the ISS16-DNTR and 2AIS≥3-DNTR group (Table 1). Resource use based on ICU admission, ICU LOS, and s LOS was higher for every parameter for the BPD-DNTR group compared to 2AIS≥3 and ISS≥16 patients. Approximately 71.2% of patients were ICU admitted for a median period of 4 days (IQR, 2-11), and 76.4% of patients received level 1 trauma centre care. The BPD-DNTR group also recorded the highest mortality rate (27.2%) compared to 2AIS≥3-DNTR and the ISS16-DNTR group with respectively 19.9% and 17.1%.

Adding physiological risk factors to the injury definition

Figure 1 presents the association of the number of physiological risk factors with mortality for the 2AIS≥3-DGU-TR, the 2AIS≥3-DNTR, and the ISS16-DNTR groups. Due to the low number of 2AIS≥3- and ISS16-DNTR patients with all five risk factors present (n=138 and n=72, respectively), mortality for the presence of four and five risk factors are combined in the chart. Unlike the 2AIS≥3-DGU-TR, the highest prevalence for the 2AIS≥3-DNTR-TR and ISS≥16-DNTR was found when one risk factor was involved (ranging from 40.0% to 40.5%). The lowest prevalence occurred when all five risk factors were present (ranging from 0.9% to 1.7%). Moreover, both datasets show that mortality is almost negligible without any risk factors (2.9% vs. 4.5%). Patients with an increasing number of risk factors had an increased risk of mortality. In general, mortality was lower in the 2AIS≥3-DNTR group compared to the 2AIS≥3-DGU-TR group. The 2AIS≥3-DNTR showed similar mortality rates as the ISS≥16-DNTR group, except if four or five risk factors were present, then the slightly higher mortality rates were found for the ISS≥16-DNTR group. The 2AIS≥3-DGU-TR showed better discriminative performance with higher prevalence rates of patients with one or more risk factors.

Table 2. Prevalence of physiological risk factors and in-hospital mortality for German and Dutch patients with an AIS ≥3 in two or more body regions.

Physiological risk factor	**Registry population**	**Prevalence %**	**Mortality %**	**Odds ratio**	**(95% CI)**
≥70 years	2AIS≥3-DGU-TR	13.00	38.00	2.99	
	2AIS≥3-DNTR	26.40	31.05	2.36	(2.06 - 2.69)
GSC score of ≤8	2AIS≥3-DGU-TR	34.60	38.30	4.90	
	2AIS≥3-DNTR	31.50	42.70	7.09	(6.19 - 8.11)
SBP of ≤ 90mmHg	2AIS≥3-DGU-TR	29.50	35.30	4.90	
	2AIS≥3-DNTR	9.62	42.60	3.49	(2.92 - 4.15)
Base excess ≤ -6	2AIS≥3-DGU-TR	24.90	38.30	3.32	
	2AIS≥3-DNTR	13.00	43.66	3.94	(3.37 - 4.60)
INR ≥1.4	2AIS≥3-DGU-TR	26.20	38.40	5.81	
	2AIS≥3-DNTR	10.30	44.96	3.96	(3.34 - 4.69)

Abbreviations: DGU-TR, Deutsche Gesellschaft für Unfallchirurgie Trauma Register; DNTR, Dutch National Trauma Register; GCS, Glasgow Coma Scale; SBP, systolic blood pressure; INR, international normalized ratio; CI: confidence interval

DISCUSSION

This is the first study that evaluated the Berlin polytrauma definition in an extensive population-based trauma registry that includes all acute trauma admissions. Our research shows that the Berlin polytrauma definition also performs well for a broader trauma population. Moreover, our study confirms the additional value of adding physiological variables on top of the anatomical injury classification in identifying severely injured individuals with a high risk of mortality. The presence of each physiological risk factor used in the Berlin polytrauma definition showed a positive association with in-hospital mortality. The Berlin polytrauma definition gives an adequate reflection of resource utilization and observed death rate compared to polytrauma definitions based on the definition ISS ≥16 or even with at least two injuries with an AIS ≥3**.**

The Dutch 2AIS≥3 patients' characteristics have a considerable number of similarities to their German counterparts. However, except for age, we found lower prevalence rates of the Dutch 2AIS≥3 patients' physiological risk factors. Furthermore, the Dutch 2AIS≥3 patients with physiological risk factors had slightly higher mortality rates than German patients with similar injuries. One of the differences stems from the different inclusion criteria of the trauma registries. The primary inclusion criterium for the German register is ICU admission.
In contrast, in the Netherlands, all acute trauma admissions are registered, which translates to only 8% ICU admissions in the DNTR population. Furthermore, the German register excludes, for instance, patients with hip fractures, these concern about 4% of DNTR patients with an ISS≥16. These broader inclusion criteria may explain the higher number of elderly patients and less physiologically impaired patients in the DNTR.
Furthermore, differences in pre-hospital management, urbanization within trauma systems, and distances to trauma-receiving hospitals may also play a role. On average, the total pre-hospital times are shorter in the Netherlands (55 minutes) than in Germany (68 minutes).[18] This time interval difference was smaller for patients with an ISS ≥16, with 61 minutes for the Dutch group and 66 minutes for their German counterparts.[19] However, Timm et al. did not find clinically relevant differences in outcome parameters of severely injured patients that could be accounted for this five-minute advantage in favor of the Dutch.[19]
Another notable difference is the higher mortality rate of the unconscious (GCS ≤8) patients in the DNTR population. A possible explanation for this difference could be the number of patients who sustained traumatic brain injuries (TBI) for which life-sustaining treatment was withdrawn; this mostly concerns elderly patients and can be initiated if there is little anticipated chance of recovery to an

acceptable quality of life. A single-centre study in the Netherlands showed that life-sustaining treatment was withdrawn in 82% of TBI patients who died during admission.[20] It is unclear whether German policies on withdrawal of life-sustaining treatment differ from the Dutch policies. However, an international comparison study by Timm et al. reported that 3.8% of German patients surviving a severe injury (ISS $\geq$16) had a "persistent vegetative state" as an outcome, whereas this was only 0.7% in the Netherlands.[19] An international comparison study is needed to assess these national dissimilarities fully.

The early identification of trauma patients with a high risk of mortality is essential in getting the patient to the right place at the right time. The applicability of the Berlin polytrauma definition, for this reason, has several limitations. First, it is important to note that some form of hospital diagnostic is needed for an accurate assessment of the injury severity, and the ISS is most often scored after admission. Second, the base excess and coagulation risk factors are based on laboratory values that are not assessed before hospitalization; moreover, they take some time to evaluate and are not necessarily analyzed in all settings. Currently, the Berlin polytrauma definition can only reach its full potential in secondary triage. However, the PRFs have shown to be an excellent determinant for predicting mortality in trauma patients. Conceivably better than the anatomical criteria of ISS $\geq$16. Studies by Brown and Fukuma showed promising results in pre-hospital management; the addition of on-scene lactate measurement significantly improved the predictive value for trauma activation algorithms and immediate intervention in hemorrhagic trauma patients.[21,22] These findings can be useful in the development of new and enhanced pre-hospital triage protocols. At which point, the Berlin polytrauma definition can be used as the golden standard for the evaluation of these pre-hospital triage protocols.

An important strength of our study is the fact that the Dutch trauma registry has national coverage and records all acute trauma admissions.[13] The original German derivation dataset included a specific subgroup of the entire trauma population. These inter-institutional differences make definition validation difficult.

Our analysis also has several limitations, including the retrospective design and missing data. If a specific risk factor was not available due to missing values, we assumed that this factor was not present. This assumption may have led to an underestimation of the risk factor prevalence. Moreover, risk factors were not individually analyzed; thus, the estimated mortality for the individual risk factors could, to some degree, be the confluence of multiple risk factors. Another limitation is that although we included over 300,000 patients in this study, a relatively limited number of patients with four or more physiological risk factors were found, weakening the conclusions for this specific subgroup.

CONCLUSION

Application of the Berlin polytrauma definition in the DNTR shows similar results regarding those with application in the DGU-TR development set. The addition of physiological risk factors to anatomical injury scores contributes to the identification of severely injured patients with a high risk of mortality. The individual physiological risk factors for age, unconsciousness, hypotension, acidosis, and coagulopathy all showed mortality rates of ≥30% in the DNTR population. Compared to the definitions that require an ISS ≥16 or two injuries with an AIS ***≥3***, the Berlin polytrauma definition showed to improve the accuracy of capturing patients with the worst clinical outcomes and highest medical resource utilization.

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APPENDIX

Supplemental Digital Content Table 1. The percentages of missing values per variable for the DNTR and DNTR subgroups used in this study

	All DNTR (n=300,649)	POLY DNTR (n=6263)	MONO DNTR (n=7846)	ISS <16 (n=282,628)
Age	0.0%	0.0%	0.0%	0.0%
ISS	0.8%	0.8%	0.8%	0.0%
AIS	0.0%	0.0%	0.0%	0.0%
GCS	20.3%	10.8%	10.8%	6.7%
SBP	19.6%	11.0%	9.8%	20.0%
BE	94.9%	59.6%	71.5%	96.4%
INR	89.2%	50.6%	60.9%	91.0%

Abbreviations: ISS, Injury Severity Score; AIS, Abbreviated Injury Scale; GCS, Glasgow Coma Scale; SBP, Systolic Blood Pressure; BE, Base Excess; INR, International Normalized Ratio

Supplemental Digital Content Table 2. Patient characteristics for patients recorded in the DNTR for which the variable Base Excess was missing vs. non-missing

	Missing Base Excess (n=2925)	Non-missing Base Excess (n=2156)
Male	1921 (65.8%)	1537 (71.3%)
Age, years, mean (SD)	56.5 (22.8)	48.6 (22.4)
ISS (SD)	26.5 (9.4)	31.8 (10,9)
ICU admission	1626 (55,6%)	1832 (85,0%)
MAIS		
3	1748 (59,8%)	835 (38,7%)
4	706 (24,1%)	646 (30,0%)
5	442 (15,1%)	648 (30,1%)
6	29 (1,0%)	27 (1,3%)
AIS ≥3		
Head	1906 (65.0%)	1451 (67,3%)
Thoracic	1969 (67.3%)	1677 (77.7%)
Abdominal	527 (18.0%)	492 (22.8%)
Extremities	1270 (43.4%)	847 (39.3%)
Mortality	541 (16.6%)	513 (23.8%)

Abbreviations: ISS, Injury Severity Score; ICU, Intensive Care Admission; MAIS, Maximum Abbreviated Injury Scale; AIS, abbreviated Injury Scale.

Supplemental Digital Content Table 3. Patient characteristics for patients recorded in the DNTR for which the International Normalized ratio variable for coagulopathy was missing vs. non-missing

	Missing INR (n=2295)	Non-missing INR (n=2786)
Male	1500 (65.4%)	1961 (70.4%)
Age, years (SD)	55.1 (23.5)	51.5 (22.5)
ISS (SD)	26.2 (9.6)	30.8 (10.6)
ICU admission	1117 (48.7%)	2337 (83.9%)
MAIS		
3	1414 (61.6%)	1169 (42.0%)
4	535 (23.3%)	817 (29.3%)
5	321 (14.0%)	769 (27.6%)
6	25 (1.1%)	31 (1.1%)
AIS ≥3		
Head	1424 (62.0%)	1933 (69.4%)
Thoracic	1550 (67.5%)	2095 (75.2%)
Abdominal	425 (18.5%)	594 (21.3%)
Extremities	1021 (44.5%)	1198 (43.0%)
Mortality	353 (15.1%)	651 (23.4%)

Abbreviations: INR, International Normalized Ratio; ISS, Injury Severity Score; ICU, Intensive Care Admission; MAIS, Maximum Abbreviated Injury Scale; AIS, abbreviated Injury Scale.

Supplemental Digital Content Table 4. Patient characteristics for patients recorded in the DNTR for which the Glasgow Coma Scale was missing vs. non-missing

	Missing GCS (n=558)	**Non-missing GCS (n=4523)**
Male	366 (65.6%)	3098 (68.5%)
Age, years (SD)	55.1 (23.9)	52.9 (22.9)
ISS (SD)	29.1 (11.4)	28.7 (10.3)
ICU admission	348 (62.4%)	3107 (68.7%)
MAIS		
3	286 (51.3%)	2297 (50.8%)
4	131 (23.5%)	1221 (27%)
5	136 (24.4%)	954 (21.1%)
6	5 (0.9%)	51 (1.1%)
AIS ≥3		
Head	358 (64.1%)	2999 (66.3%)
Thoracic	385 (68.9%)	3261 (72.1%)
Abdominal	126 (22.5%)	893 (19.4%)
Extremities	259 (46.4%)	1858 (41.1%)
Mortality	124 (22.2%)	873 (19.3%)

Abbreviations: GCS, Glasgow Coma Scale; ISS, Injury Severity Score; ICU, Intensive Care Admission; MAIS, Maximum Abbreviated Injury Scale; AIS, Abbreviated Injury Scale.

Supplemental Digital Content Table 5. Patient characteristics for patients recorded in the DNTR for which the Systolic Blood Pressure was missing vs. non-missing

	Missing SBP (n=479)	**Non-missing SBP (n=4602)**
Male	312 (65.3%)	3147 (68.4%)
Age, years (SD)	53.7 (24.4)	53.0 (22.8)
ISS (SD)	31.2 (11.7)	28.5 (10.2)
ICU admission	296 (61.8%)	3161 (68.7%)
MAIS		
3	198 (41.3%)	2385 (51.8%)
4	129 (26.9%)	1223 (26.6%)
5	140 (29.2%)	950 (20.6%)
6	12 (2.5%)	44 (1.0%)
AIS ≥3		
Head	306 (63.9%)	3051 (66.3%)
Thoracic	358 (74.7%)	3288 (71.4%)
Abdominal	109 (22.7%)	910 (19.8%)
Extremities	220 (46.9%)	1897 (41.2%)
Mortality	163 (34.2%)	837 (18.1%)

Abbreviations: SBP, Systolic Blood Pressure; ISS, Injury Severity Score; ICU, Intensive Care Admission; MAIS, Maximum Abbreviated Injury Scale; AIS, Abbreviated Injury Scale.

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CHAPTER 7

Severe isolated injuries have a high impact on resource use and mortality: A Dutch nationwide observational study

European Journal of Trauma and Emergency Surgery

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ABSTRACT

Purpose

The Berlin polytrauma definition (BPD) has proven to be a valuable way of identifying patients with at least a 20% risk of mortality, by combining anatomical injury characteristics with the presence of physiological risk factors (PRFs). Severe isolated injuries (SII) are excluded from the BPD. This study describes the characteristics, resource use and outcomes of patients with SII according to their injured body region, and compares them with those included in the BPD.

Methods

Data was extracted from the Dutch National Trauma Registry between 2015 and 2019. SII patients were defined as those with an injury with an Abbreviated Injury Scale (AIS) score ≥4 in one body region, with at most minor additional injuries (AIS≤2). We performed an SII subgroup analysis per AIS region of injury. Multivariable linear and logistic regression models were used to calculate odds ratios (ORs) for SII subgroup patient outcomes, and resource needs.

Results

A total of 10.344 SII patients were included; 47.8% were ICU admitted, and the overall mortality was 19.5%. The adjusted risk of death was highest for external (2.5, CI 1.9–3.2) and for head SII (2.0, CI 1.7–2.2). Patients with SII to the abdomen (2.3, CI 1.9–2.8) and thorax (1.8, CI 1.6–2.0) had a significantly higher risk of ICU admission. The highest adjusted risk of disability was recorded for spine injuries (10.3, CI 8.3–12.8). The presence of ≥1 PRFs was associated with higher mortality rates compared to their polytrauma counterparts, displaying rates of at least 15% for thoracic, 17% for spine, 22% for head and 49% for external SII.

Conclusion

A severe isolated injury is a high-risk entity and should be recognized and treated as such. The addition of PRFs to the isolated anatomical injury criteria contributes to the identification of patients with SII at risk of worse outcomes.

INTRODUCTION

Despite preventive measures and the maturation of introduced trauma systems as well as more sophisticated medical care, approximately 4.8 million deaths globally are attributed to injury every year [1–3]. Trauma can affect anyone, in one or multiple body regions, and in numerous combinations. Over 45 definitions have been described to identify the most severely injured with high risk of morbidity and mortality [4]. Most definitions tend to focus only on anatomical injury characteristics. However, trauma can also induce a series of physiological disturbances or organ failure that affect outcome [5].

A consensus meeting led by international experts resulted in the introduction of the Berlin polytrauma definition (BPD). This definition includes several physiological parameters next to anatomical injury classification [6]. Recent studies evaluated this polytrauma definition and confirmed the additional value of adding physiological variables to an anatomical injury classification in identifying patients with multiple severe injuries that pose a high risk of mortality [7,8].

Patients with severe isolated injuries are excluded from the BPD. Compared to the numerous reports on polytrauma patients [4,6–9], literature on isolated injuries is relatively scarce. This is remarkable as approximately 50% of patients with an injury severity score (ISS) $\geq$16 concerns patients with an isolated injury (SII) with an associated mortality of 21% [7]. Furthermore, most studies regarding isolated injuries tend to focus on severe injuries to the head. Yet this leaves out about 40% of patients with severe isolated injuries in other body regions [7,10]. Understanding the characteristics, resource needs, and outcomes of patients with severe isolated injuries, will help to define which patients are in need of specialized trauma care.

This study aims to describe the characteristics, resource use and outcomes of patients with SII according to their injured body region, as well as to investigate the prevalence of physiological risk factors and their association with mortality. Overall aim is to adjudicate whether it is justified to exclude SII patients from trauma definitions like the BPD.

METHODS

Patients

A cohort study was conducted based on prospectively gathered data from the Dutch National Trauma Register (DNTR) over 2015-2019. The DNTR includes all injured patients directly admitted to the hospital through the emergency department (ED) within 48 hours after trauma. Patients without vital signs upon arrival at the ED were excluded [11]. Patients transferred to another hospital within 48 hours after the incident were likely to be registered twice. Therefore, we excluded patients who were secondarily transferred to the hospital after emergency department treatment at another hospital.

The DNTR dataset, based on the Major Outcome Study[12], includes the Utstein template for uniform reporting and covers 100% of the trauma-receiving hospitals in the Netherlands [11,13]. Injuries are coded according to the Abbreviated Injury Scale (AIS) 2005 update 2008[14].

The study is exempted from the need for informed consent because it is not subject to the Medical Research Involving Human Subjects Act. Trauma patient registration is facilitated by Dutch law, which patient anonymity is warranted. Patients or the public were not involved in the design, conduct, reporting, or dissemination plans of our study.

Definitions and outcomes

In this study, SIIs were defined as patients who sustained a trauma with a maximum AIS (MAIS) ≥4 in one AIS body region and without any significant injuries in other AIS body regions (MAIS ≤2). The number of additional minor injuries per severe injury location subgroup is listed in Table 1 of the Supplemental Digital Content (SDC). SII subgroups were made following the anatomical AIS regions: head, thorax, spine, abdomen, (upper and lower) extremities, and external[14]. Among others, external injuries concern: second- or third-degree burns affecting >20% of the total body surface area, asphyxia and drowning.

Medical resource use concerned the Intensive Care Unit (ICU) admission rate, ICU length of stay (LOS) and the overall in-hospital LOS in days of admission. The severity of trauma was measured using the injury severity score (ISS) and the revised trauma score (RTS) [15,16]. The outcome variables were in-hospital mortality and Glasgow Outcome Scale (GOS). GOS was measured at hospital discharge and was dichotomously recoded, either 0 (good recovery or mild disabilities) or 1 (severe disabilities or vegetative state). Patients who died during hospital admission were excluded from the GOS categories because mortality concerned a separate outcome measure.

We examined the prevalence of the physiological risk factors (PRFs) described in the Berlin definition and their association with in-hospital mortality. The PRFs present upon ER arrival concern: hypotension [systolic blood pressure ≤90 mmHg], unconsciousness [Glasgow Coma Scale score ≤8], acidosis [base excess (BE) ≤-6.0], coagulopathy [partial thromboplastin time ≥40 s or the international normalized ratio (INR) ≥1.4], and age [≥70 years] [6]. Because the prevalence of SII patients with all five risk factors present upon emergency department (ED) arrival was rather low, these patients were combined with those who had four PRFs present. The association of the number of PRFs present at ER presentation and mortality was analysed for SII patients and compared with results for polytrauma patients from the BPD evaluation study [8].

Missing data

In this study, we assumed that a PRF was absent if the specific data were missing. The number of missing values per variable is listed for every SII subgroup in Table 2 of the Supplemental Digital Content (SDC). Multiple imputations on missing values could not be accurately performed as the DNTR does not capture parameters with good correlation with INR and BE, such as thromboplastin or lactate [6].

Statistical analyses

The study was performed according to STROBE guidelines for observational studies (SDC Table 3) [17]. Descriptive statistics were used for demographic data, injury characteristics, medical resource use, and outcomes. These included means and standard deviations as well as medians and quartiles as appropriate.

For the SII subgroups categorized into AIS body regions, multivariable logistic and linear regression models were developed to assess the patients' odds ratios (ORs) or beta values for resource use and mortality as appropriate. In these models the outcome of each individual anatomical AIS region was compared with the outcomes of the other SII patient subgroups.

The AIS body region subgroup models were adjusted for confounding variables by including systolic blood pressure, age, Glasgow Coma Scale (GCS) and the number of additional (MAIS ≤2) injuries as independent variables. An exception was made assessing the probability of an isolated head injury, which was not adjusted for the GCS due to collinearity. Statistical analysis was performed using IBM SPSS statistics 24 [18].

RESULTS

From January 1, 2015, to December 31, 2019, a total of 422,051 cases were recorded in the DNTR. After the exclusion of patients transferred from another hospital, we included 399,243 acute trauma admissions of which 10,344 (2.5%) concerned SII patients.

Patient characteristics

More than half of SII patients incurred a head injury (57%), of whom 45.8% were elderly (≥70 years) [Table 1]. Patients with isolated abdominal injuries were the youngest subgroup, with a median age of 30 (IQR, 18 – 51). The patients with external injuries were the most severely injured, based on the median AIS of 25 (IQR, 25-26) and a mean RTS at emergency department presentation of 8.4 (SD, 2.9). On average 9% of SII patients required emergency surgery following ED resuscitation, patients with an isolated extremity injury (19.3%) and abdominal injuries (16.5%) were most frequently in need of surgical treatment.

Table 1. Patient characteristics of patients with severe isolated injuries to the anatomical region of the head, thorax, spine, abdomen, extremity or external.

	All SII (n=10.344)	**Head (n=5893)**	**Thorax (n=1870)**	**Spine (n=675)**	**Abdomen (n=740)**	**Extremities (n=552)**	**External (n=614)**
Median age years (IQR)	60 (36 –76)	68 (46–81)	56 (40–70)	60 (44–73)	30 (18–51)	53 (31–71)	42 (22–62)
Age 0-19	9.2%	8.2%	5.0%	3.1%	25.9%	6.5%	21%
Age 20-49	25.1%	19.2%	29.0%	26.7%	44.5%	35.3%	36.2%
Age 50-69	26.2%	24.0%	36.3%	32.1%	16.6%	25.9%	22%
Age >70	36.0%	45.8%	25.5%	32.3%	8.8%	28.3%	16.8%
Male gender	64.4%	60.1%	73.8%	71.7%	69.2%	61.2%	65.7%
Median ISS (IQR)	21 (17–25)	21 (17–26)	20 (16–24)	20 (16–26)	17 (16–21)	21 (17–25)	25 (25–26)
Mean RTS ED (SD)	10.9 (1.8)	10.7 (1.7)	11.5 (1.5)	11.6 (1.2)	11.7 (1.1)	11.5 (1.4)	8.4 (2.9)
MAIS							
4 points	63.9%	55.8%	85.0%	62.8%	86.5%	92.0%	25.4%
5 points	34.9%	43.3%	13.6%	32.1%	13.2%	8.0%	72%
6 points	1.3%	1.0%	1.3%	5.0%	0.3%	-	2.6%
Blunt trauma	91.3%	95.1%	82.0%	96.4%	81.8%	84.2%	95.9%
MMT at scene	20.0%	19.9%	17.2%	17.2%	10.0%	16.8%	47.9%
Prehospital intubation	19.7%	21.6%	11.7%	6.9%	2.6%	5.1%	63.1%
MTC	60.7%	63.7%	52.7%	68%	45.9%	54.9%	70.4%
Emergency surgery	9.0%	8.7%	5.3%	11.8%	16.5%	19.3%	1.6%
ICU admission	47.8%	44.1%	53.9%	47.6%	60.1%	32.6%	65%
Median ICU in days LOS (IQR)	3 (2–7)	7 (2–8)	3 (2–5)	6 (3–11)	2 (2–3.25)	2 (2–4)	3 (2–5)
Median LOS in days (IQR)	6 (2–13)	5 (2–12)	7 (4–12)	11 (4–19)	7 (4–11)	10 (4–18)	2 (1–6)
GOS (SD)							
Good or mild disabilities	75.0%	74.8%	87.9%	34.3%	88.9%	73.2%	65.3%
Severe disability or vegetative state	25.0%	25.2%	12.1%	65.7%	11.1%	26.8%	34.7%
Died in de ED	2.0%	1.2%	2.5%	0.3%	0.5%	1.5%	13.1%
Mortality	19.5%	23.8%	8.7%	12.7%	4.7%	5.4%	49.5%

Abbreviations: SII, severe isolated injury; ISS, Injury Severity Score; RTS, Revised Trauma Score; ED, Emergency Department; MAIS, Maximum Abbreviated Injury Score; MMT, Mobile Medical Team; MTC, major trauma centre; ICU, Intensive Care Unit; LOS, Length of Stay; PRF, Physiological Risk Factor; GOS, Glasgow Outcome Scale.

Table 2. Linear and logistic regression coefficients, 95% confidence intervals, and p–values for interactions between anatomical injury location and mortality, intensive care admission, intensive care length of stay and Glasgow Outcome Score.

Body region	**Coefficients***									
	Mortality (OR)	p–value	GOS (OR)	p–value	ICU admission (OR)	p–value	ICU LOS (Beta)	p-value	Hospital LOS (Beta)	p-value
Head**	1.95 (1.72 – 2.22)	<0.001	1.04 (0.92 – 1.18)	0.688	0.94 (0.85 – 1.03)	0.160	0.59 (0.25 – 0.92)	0.001	- 0.01 (-0.65 – 0.62)	0.966
Thorax	0.67 (0.52 – 0.85)	0.001	0.41 (0.33 – 0.50)	<0.001	1.79 (1.58 – 2.04)	<0.001	0.08 (-0.35 – 0.52)	0.702	- 0.96 (-1.80 – 0.13)	0.024
Spine	1.33 (0.98 – 1.80)	0.063	10.27 (8.25 – 12.77)	<0.001	1.39 (1.15 – 1.66)	0.001	3.75 (3.12 – 4.38)	<0.001	5.14 (3.92 – 6.36)	<0.001
Abdomen	0.98 (0.61 – 1.58)	0.940	0.51 (0.38 – 0.67)	<0.001	2.30 (1.90 – 2.79)	<0.001	- 0.37 (-1.02 – -0.27)	0.258	- 1.09 (-2.35 – 0.17)	0.090
Extremities	0.59 (0.37 – 0.94)	0.028	1.62 (1.27 – 2.08)	<0.001	0.64 (0.51 – 0.80)	<0.001	- 1.04 (-1.79 – -0.29)	0.007	5.58 (4.17 – 6.98)	<0.001
External	2.45 (1.89 – 3.18)	<0.001	0.83 (0.60 – 1.15)	0.262	0.94 (0.73 – 1.22)	0.656	- 0.92 (-1.67 – -0.17)	0.016	- 4.14 (-5.62– -2.66)	<0.001

* Coefficients were calculated reference to all severe isolated injury patients with exclusion of the investigated region and were adjusted for systolic blood pressure, age, Glasgow Coma Scale, and the number of additional injuries in other body regions with a maximum abbreviated injury score ≤2.

** Adjusted for systolic blood pressure and age due to collinearity with GCS.

Abbreviations: ICU, Intensive Care unit; LOS, Length of stay, GOS, Glasgow Outcome Score.

Resource use, disability and mortality

Patients with isolated external injuries were most frequently taken to higher level facilities (70.4%), and ICU admitted (65.0%). Approximately one in every five patients with isolated extremity injuries required emergency surgery. Yet, they were the least frequently admitted to the ICU (32.6%), and had, together with isolated abdominal trauma, the shortest ICU length of stay (2 days (IQR, 2 – 4)). Approximately 65% of the patients with isolated spinal injury had a severe disability at hospital discharge (Table 1).

Table 2 describes the adjusted risks of resource use and mortality for the individual anatomical AIS regions. The following injury locations showed a significant higher OR for ICU admission: abdomen (OR 2.3 (95% CI, 1.9 - 2.8), thorax (OR 1.8 (95% CI, 1.6 - 2.0)) and spine (OR 1.4 (95% CI, 1.2 - 1.7)). A SII to the spine was associated with a significant risk of prolonged ICU length of stay of 3.8 (3.1 – 4.4). Extremity and spinal injuries were significantly associated with a risk of prolonged period hospital admission, with odds ratios of 5.6 (95% CI, 4.2 - 7.0) and 5.1 (95% CI, 3.9 - 6.4), respectively. Moreover, these SIIs showed the greatest risk of a severe disability at hospital discharge, with odds ratios of 1.6 (95% CI, 1.3 - 2.1), and 10.3 (95% CI, 8.3 - 12.8), respectively.

Overall, almost one out of five SII patients died during hospital admission (19.5%). The mortality of subgroups ranged between 4.7% in abdominal trauma and 49.5% in patients with external injuries. Significantly higher risk of mortality was observed for SII patients with an external injury (OR 2.5 (95% CI, 1.9 - 3.2)), head injury (OR 2.0 (95% CI, 1.7 - 2.2)), followed by spinal injuries (OR 1.3 (95% CI, 1.0 - 1.8)).

Physiological risk factors

A total of 5834 SII patients (56%) had at least one PRF present during emergency department evaluation (***Supplemental Digital Content*** Table 2). Compared to SII patients without PRFs, patients with ≥1 PRF present were older (60 (36 - 76) vs. 67 (56 – 83), p= <0.001), had a higher AIS score (21 (IQR, 17 – 25) vs. 24 (IQR, 17 – 26), p= <0.001), were more often prehospital treated by mobile medical teams (MMTs) (20.0% vs. 25.7%, p=<0.001), and had higher mortality rates (19.5% vs. 32.2%, p=<0.001). Except for the spine subgroup, all SII subgroups with ≥1 PRF were more frequently admitted to the ICU (47.8% vs. 51.8%) and for a more extended period than the unspecified SII patients (SDC Table 4).

Table 3. Prevalence of physiological risk factors, in-hospital mortality, and the odds-ratio of mortality per risk factor for severe isolated injuries categorized based on the anatomical injury location

		All SII (n=10.344)	**Head (n=5893)**	**Thorax (n=1870)**	**Spine (n=675)**	**Abdomen (n=740)**	**Extremity (n=522)**	**External (n=614)**
Age ≥70 years	Prevalence	36.0%	45.8%	25.5%	32.3%	8.8%	70.6%	16.8%
	Mortality	31.3%	34.0%	18.9%	28.0%	21.5%	12.8%	59.2%
	Odds ratio	3.0 (2.8 – 3.4)	2.9 (2.5 – 3.2)	4.2 (3.0 – 5.8)	6.7 (4.1 – 11.1)	8.5 (4.1 – 17.8)	5.7 (2.6 – 12.4)	1.6 (1.0 – 2.5)
GCS score of ≤8	Prevalence	22.8%	28.9%	9.2%	6.2%	3.5%	13.6%	62.5%
	Mortality	45.5%	47.8%	43.0%	57.1%	38.5%	26.7%	62.0%
	Odds ratio	8.2 (7.4 – 9.1)	5.6 (4.9 – 6.4)	13.6 (9.4 -19.7)	12.3 (6.3 – 23.9)	17.2 (7.1 – 41.7)	8.3 (3.3 – 20.6)	4.0 (2.8– 5.7)
SBP of ≤90 mmHg	Prevalence	6.0%	2.2%	4.5%	6.5%	7.2%	6.3%	15.3%
	Mortality	44.0%	58.8%	38.9%	29.5%	13.2%	28.6%	69.1%
	Odds ratio	3.8 (3.1 - 4.6)	4.7 (3.2 – 6.9)	8.0 (5.0 – 12.9)	3.2 (1.6 – 6.4)	3.6 (1.5 – 8.6)	9.9 (4.2 – 23.5)	2.6 (1.6 - 4.2)
Base excess ≤-6	Prevalence	52.7%	4.1%	6.6%	3.3%	4.3%	6.0%	29.1%
	Mortality	19.6%	53.3%	22.1%	41.0%	15.6%	18.2%	56.8%
	Odds ratio	3.6 (3.0 – 4.2)	3.9 (3.0 – 5.1)	3.4 (2.1 – 5.4)	5.1 (2.1 – 12.4)	4.1 (1.5 – 11.5)	4.8 (1.8 – 12.7)	1.5 (1.0 –2.1)
INR ≥1.4	Prevalence	8.2%	9.8%	4.8%	6.2%	5.3%	5.9%	11.2%
	Mortality	43.9%	46.3%	32.6%	38.1%	23.1%	9.1%	71.0%
	Odds ratio	3.7 (3.2 – 4.3)	3.1 (2.7 – 3.8)	5.9 (3.7 – 9.6)	4.9 (2.5 – 9.7)	7.8 (3.3 – 18.0)	1.8 (0.5 – 6.4)	2.8 (1.6 – 4.8)

Abbreviations: SII, severe isolated injury; GCS, Glasgow Coma Scale; SBP, systolic blood pressure; INR, international normalized ratio.

Prevalence of physiological risk factors and associated odds ratio of in-hospital mortality

Table 3 describes the prevalence of five physiological risk factors, the mortality rate, and the odds ratios of death per risk factor for the five subgroups. The most prevalent PRF in all subgroups, except for external injuries, was older age, ranging from 8.8% to 70.6%. Patients with abdominal injuries showed the lowest mortality rates in the case PRFs were present (ranging between 13.2% for an SBP ≤90 mmHg to 38.5% in case of an GCS score of ≤8). For all SII subgroups, except for SII patients with an extremity injury, the highest OR of death was recorded when the GCS was ≤8, ranging from 4.0 to 17.2.

Figure 1 presents the number of risk factors present and associated mortality for the SII subgroups. Without any risk factors mortality ranged between 0.7% for abdominal injuries to 3.3% for head injuries and 18% for injuries to the external body region. Overall SII mortality increased from 3% without any PRFs, to 21%, 53%, 69% and 77%, in the presence of one, two, three or four and five PRFs respectively. These mortality rates of the total group of SII patients appeared to be higher than those of polytrauma patients. Moreover, in certain subgroups SII mortality tended to be higher than for polytrauma patients. Mortality for SII patients with head or external injuries was higher in all PRF categories. Moreover, SII mortality for injuries to the thorax and spine was higher if ≥2 PRFs were present.

External injuries

A more detailed insight in the subcategories of patients with external injuries is presented in Table 4. Acute trauma admissions as a result of drowning concern the youngest group of patients with external injuries (29 (IQR, 8 - 54)) and the have widest range of injury severity scores (25(IQR, 25 - 34)). Although, burn patients were the least frequently ICU admitted group (51.8%), they required the longest ICU length of stay (2 days (IQR, 1 - 21)). Mortality in the subcategory admitted with severe burns was considerably lower compared to the other subgroups (27.3% vs. (45.6% - 64.1%)).

Table 4. Patient characteristics of four subcategories of patients whom sustained severe isolated injuries to external body region

	Burns (n=126)	Drowning (n=170)	Asphyxia (n=138)	Other (n=180)
Median age in years (IQR)	50 (30 – 67)	29 (8-54)	39 (25-57)	52 (30-70)
ISS	25 (16-25)	25 (25-34)	25 (25-25)	25 (17-26)
MMT at scene	30.3%	45.2%	66.3%	52.9%
Prehospital intubation	52.5%	40.7%	75.7%	79.8%
MTC	66.6%	50.8%	86.5%	73.2%
Emergency surgery	1.6%	3.0%	0.0%	1.7%
Hospital LOS in days (IQR)	2 (1-6)	2 (1-6)	3 (2-5)	2 (1-8)
ICU admission	51.8%	70.6%	83.6%	62.1%
Median ICU LOS in days (IQR)	2 (1-21)	3 (2-6)	3 (2-4.75)	3 (2-6)
Died in the ED	4.0%	22.5%	6.5%	15.6%
Mortality	27.3%	56.0%	64.1%	45.6%

Abbreviations: ISS, Injury Severity Score; MMT, Mobile Medical Team; MTC, major trauma centre; ICU LOS, length of stay; ICU, intensive care unit; ER: Emergency Department.

DISCUSSION

This study provides a comprehensive outline of the differences in medical resource use and outcomes between different types of severe isolated injuries based on their anatomical location. Furthermore, our study underlines that the addition of PRFs to the anatomical definition of severe isolated trauma contributes to identifying patients with a high risk of resource use and mortality. The number of PRFs had a strong association with an increase in resource utilization as well as in-hospital mortality for SII patients. We even found that the total group of SII patients with ≥1 PRF had higher mortality rates than their polytrauma counterparts. Clearly SII patients, and specifically those with at least one PRF, should not be underestimated.

Physiological risk factors

The importance of PRFs is undervalued but not something new, yet much can still be learned as some observed associations between PRFs and mortality are more straightforward than others. For example, an observed decreased blood pressure in a patient with an extremity, head or spinal injury is likely the result of the occurrence of hypovolemic shock due to exsanguination or neurogenic shock as a result of damage to the central nervous system. Moreover, an observed decreased GCS is known to have a poor prognostic outcome in traumatic brain injury [19] and is closely monitored during resuscitation and follow-up. However, our results show also that a decreased GCS has an even stronger association with mortality for patients who sustained a severe isolated injury to the abdomen, thorax, spine or extremity. These findings are of great value in our understanding of the physiological disturbances inflicted by trauma to different anatomical regions and can serve as discriminating factors in a more specific prehospital triage and resuscitation algorithms.

External injuries

We would like to draw specific attention to external injuries. These injuries form a distinct type of trauma including second or third-degree burns, asphyxia, drowning injuries, on which in contrast to head injuries we know relatively little about. As shown in this study these injuries are frequently associated with ICU admission and high mortality rates. Although not described in our results, we would like to address that 48% of patients with external injuries that had no PRFs present during Emergency Department (ED) presentation were admitted with severe burns. These injuries are known for not only causing significant injury at the local burn site but also a systemic response throughout the body. Generally occurring over the first 24 hours, peaking at around six to eight hours after injury. Which can lead to many complications including respiratory problems, hypothermia, burn shock, rhabdomyolysis, thrombosis, infection and sepsis [20]. These findings give a possible explanation why 17.7% of these patients have died, without displaying any physiological derangement at ED presentation. Another possible explanation for the higher mortality rate for patients with external injuries could be associated with potential brain damage due to hypoxia as a result of drowning or asphyxia, for which life-sustaining treatment was withdrawn. A Dutch single-centre study showed that at least for older patients with moderate to severe traumatic brain injury patients, this is an accepted measure, if there is little anticipated chance of recovery to an acceptable quality of life [21]. In-addition, we would like to address that as described in this study, patients with SII to the external region form an exceptional heterogenous population. Which is inherent to the spectrum of AIS-codes included within this particular group. Although, all SII patients should receive specialized trauma care, at least in our opinion. The Association for the advancement of automotive medicine, might want to further differentiate external injuries in order to determine specific patient needs in the future.

Triage

Improving SII patients' outcomes starts with triage accuracy. Level 1 trauma centre care is associated with reduced in-hospital and 1-year mortality, a reduced number of readmissions, and higher cost-effectiveness [22–26]. In this national comprehensive study, only 62% of severe isolated injury patients were directly transported to level 1 trauma centres, which is markedly lower than the 72% found in the BPD population [8]. These percentages are consistent with a recent systematic review, which concluded that nearly all of the studied prehospital trauma triage protocols were unable to adequately identify severely injured patients with an ISS ≥16 [27]. Basic patients' characteristics form a possible explanation for this lower level 1 centre admission rate, as SII patients tend to be older on average (68 years vs. 50 years) and more frequently of the female sex (47.1% vs. 32.5%) compared to the BPD population. Both, higher age and female gender are associated with pre-hospital undertriage [8,28]. The physiological risk factors and anatomical injury criteria covered in this study can be of great value for prehospital identification of severely injured patients. As illustrated in this study, patients with severe isolated injuries and more than one PRF were found to have higher ICU admission rates, longer LOS, more severe disabilities at discharge, and higher mortality rates. More supporting scientific evidence was added by a recently developed prehospital triage prediction model that showed a strong correlation with resource needs. This model incorporates isolated head and thoracic injuries, as well as 3 out of 5 PRFs defined in the Berlin polytrauma definition [6,29,30].

SII patients that have one or more PRFs display high resource utilization and mortality rates. We therefore strongly advise that these patients are included in future severe trauma definitions and are preferably transferred to a facility that offers specialized trauma care. Currently 62.6% of the advised patients were treated at one of the eleven major trauma centres in the Netherlands. When accurately triaged, approximately 2200 additional SII patients will be transferred to one of these specialized trauma centres over a 5-year period. These numbers will presumably not pose a major strain on their capacity, in contrast to the presumed beneficial impact on SII patients' outcomes [26].

Emergency surgery

Damage control orthopaedic (DCO) surgery is intended for patients with multiple injuries that cannot be cleared for initial definitive care. We support the introduction of the recently suggested "MUST surgery" term.[31] MUST describes patients with severe isolated musculoskeletal trauma in the absence of physiological relevant trauma load that must have access to operating room for definitive care.

In this study we show that a substantial amount of SII patients is in need of emergency surgery directly following ED resuscitation. This percentage increased in the presence of one or more physiological risk factors defined in the Berlin definition. Moreover, although not shown in this study, we recorded that 34.9% of SII patients without any PRFs present at ED presentation, required one or more surgical procedures after their initial emergency surgery. The highest percentage was found for extremity injuries 72.7% and the lowest incidence of staged procedures was recorded for thoracic injuries (20%). For patients that did have one or more PRFs during ED presentation, the mean incidence (36%) of staged surgical intervention was quite similar to the SII patients without a PRF, ranging from 88% in extremity injuries and 21% in thoracic injuries. Unfortunately, comprehensive data regarding the specific indication or the type of intervention that was performed is not consistently recorded. Moreover, the number of performed procedures has a relatively high missing value count, making the actual volume of patients that were treated by definitive or a staged procedure, more difficult to assess. However, these results support the opinion that the indication for damage control procedures in orthopaedic trauma should not only be made according to a patient's number of sustained anatomical injuries or physiological derangements.[32–34] Further research is needed to further specify indications for DCO and MUST.

Strengths and limitations

The most important strength of our study is the differentiation of severe isolated injuries according to the anatomical AIS regions. Moreover, due to the national coverage of the Dutch trauma register, and the inclusion of all acute trauma related hospital admissions, we were able to perform analyses on a population-based dataset and included significant numbers of patients in all subgroups which assures generalizability. However, our analysis also has several limitations, including missing data. If a specific physiological risk factor was not available due to missing values, we assumed that this factor was normal. This assumption could lead to an underestimation of the prevalence of those risk factors. However, this assumption is line with the methods used in the recent BPD evaluation study [8]. Finally, our analyses differentiated between six anatomical regions, however it would have been of interest to further specify the injury groups. For example, spinal injuries could be differentiated to cervical, thoracal and lumbar trauma. Furthermore, upper and lower extremity, and pelvic and lower extremity injuries could be separated. One should keep in mind that adding additional subgroups, requires the inclusion of a lot more patients.

CONCLUSION

Severe isolated injuries form a high-risk entity in terms of worse outcomes and high resource use and should be recognized and treated as such. Patients with a severe isolated injury to the head, thorax, spine, or external region are associated with the highest medical resource use and risk of mortality. The addition of physiological risk factors to anatomical injury scores contributes to the identification of severe isolated injury patients with a high risk of mortality. Integrating these discriminating factors in trauma definitions or triage protocols will be beneficial in facilitating better and more specific patient-tailored trauma care.

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APPENDIX

Supplemental Digital Content Table 1. The number of patients included in this study with a maximum AIS of 4 and the number of additional injuries per AIS body region

	MAIS 4	**No additional injuries n (%)**	**1 or 2 AIS of ≤2 n (%)**	**≥3 AIS of ≤2 n (%)**
Head	5893	3673 (62.3)	2102 (35.7)	118 (2.0)
Thorax	1870	687 (36.7)	1014 (54.2)	169 (9.0)
Spine	675	335 (49.6)	317 (47.0)	23 (3.4)
Abdomen	740	378 (51.1)	332 (44.9)	30 (4.1)
Extremities	552	281 (50.9)	242 (43.8)	29 (5.3)
External	614	473 (77.0)	138 (22.5)	3 (0.5)
Total	10344	5827 (56.3)	4145 (40.1)	372 (3.6)

Abbreviations: MAIS, maximum abbreviated injury score. AIS, abbreviated injury score.

Supplemental Digital Content Table 2. Number of missing values for patients with severe isolated injuries to the anatomical region of the head, thorax, spine, abdomen, extremity or external body region

	All SII (n=10.344)	**Head (n=5893)**	**Thorax (n=1870)**	**Spine (n=675)**	**Abdomen (n=740)**	**Extremities (n=552)**	**External (n=614)**
Age	1 (0.0)	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Gender	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
GCS	1289 (12.4)	673 (11.4)	258 (13.8)	79 (11.7)	112 (15.1)	80 (14.5)	87 (14.2)
SBP	1090 (10.5)	537 (9.1)	218 (11.7)	42 (6.2)	75 (10.1)	73 (13.2)	145 (23.6)
Base excess	7319 (70.7)	4258 (72,3)	1303 (69.7)	451 (66.8)	539 (72.8)	411 (74.5)	346 (56.4)
INR	6151 (59.5)	3282 (55.7)	1257 (67.2)	394 (58.4)	508 (68.6)	377 (68.3)	342 (54.3)
ISS	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
RTS ED	3808 (36.8)	2129 (36.1)	670 (35.8)	200 (29.6)	277 (37.4)	204 (37.0)	328 (53.4)
Blunt trauma	545 (5.3)	199 (3.4)	190 (7.9)	19 (2.8)	56 (7.6)	59 (10.7)	22 (3.6)
MMT at the scene	345 (3.3%)	172 (2.9%)	87 (4.7%)	12 (1.8)	36 (4.9%)	30 (5.4%)	8 (1.3%)
Prehospital intubation	2377 (23.0%)	1225 (20.8%)	561 (30.0%)	124 (18.4%)	206 (27.8%)	178 (32.2%)	83 (13.5%)
MTC	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Emergency surgery	92 (0.9%)	42 (0.7%)	32 (1.7%)	6 (0.9%)	6 (0.8%)	4 (0.7%)	2 (0.3%)
ICU admission	318 (3.1)	191 (3.2)	42 (2.2)	21 (3.1)	26 (3.5)	25 (4.5)	13 (2,1)
ICU LOS	787 (7.6)	435 (7.4)	152 (8.1)	44 (6.5)	45 (6.1)	84 (15.2)	27 (4.4)
Hospital LOS	337 (3.3)	162 (2.7)	73 (3.9)	17 (2.5)	30 (4.1)	24 (4.3)	31 (5.0)
GOS	430 (4.2)	192 (3.3)	132 (7.1)	24 (3.6)	39 (5.3)	29 (5.3)	14 (2.3)
Died in the ED	92 (0.9%)	42 (0.7%)	32 (1.7%)	6 (0.9%)	6 (0.8%)	4 (0.7%)	2 (0.3%)
Mortality	2 (0.0)	1 (0.0)	163 (8.7)	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)

Abbreviations: SII, severe isolated injury; GCS, Glasgow Coma Scale; SBP, systolic blood pressure; INR, international normalized ratio; ISS, Injury Severity Score; RTS, Revised Trauma Score; ED, Emergency Department; ICU, Intensive Care Unit; LOS, Length of Stay; GOS, Glasgow Outcome Scale.

Supplemental Digital Content Table 4. Patient characteristics of patients with severe isolated injuries to the anatomical region of the head, thorax, spine, abdomen, extremity or external that had ≥1 PSF present at Emergency Department presentation

	All SII (n=5834)	**Head (n=3942)**	**Thorax (n=731)**	**Spine (n=284)**	**Abdomen (n=166)**	**Extremity (n=221)**	**External (n=490)**
Median age (IQR)	67 (56 – 83)	76 (62 – 84)	74 (58 – 81)	76 (70 – 73)	51 (29 – 76)	70 (64 – 85)	45 (26 – 66)
Age 0 -19	5.4%	4.7%	3.1%	0.7%	25.9%	1.4%	16.3%
Age 20-49	14.6%	11.5%	15.0%	6.3%	44.5%	16.3%	36.7%
Age 50-69	14.2%	13.6%	14.0%	14.4%	16.6%	9.5%	22.5%
Age >70	63.8%	68.5%	65.3%	76.8%	8.8%	70.6%	21.2%
Male gender	55.5%	52.6%	62.9%	54.4%	69.0%	46.3%	66.8%
Median ISS (IQR)	24 (17 – 26)	25 (17 – 26)	20 (16 – 24)	21 (17 – 26)	20 (16 – 24.25)	17 (16 – 21)	25 (25 – 26)
Mean RTS ED (SD)	10.2 (2.1)	10.3 (1.8)	10.7 (2.3)	11.1 (1.7)	10.6 (2.0)	10.9 (2.1)	7.7 (2.8)
MAIS							
4 points	***53.1%***	48.9%	79.2%	58.2%	80.1%	89.2%	20.8%
5 points	***45.2%***	50.0%	18.8%	32.7%	19.2%	19.8%	76.7%
6 points	***1.7%***	1.2%	2.0%	9.1%	0.6%		2.5%
Blunt trauma	92.4%	95.4%	81.8%	96.0%	67.9%	84.2%	96.3%
MMT at scene	25.7%	24.2%	21.6%	19.6%	17.3%	16.8%	52.8%
Prehospital intubation	31.7%	29.9%	26.3%	13.8%	11.1%	11.6%	74.2%
MTC	62.6%	64.1%	53.3%	64.1%	52.4%	48.4%	72.8%
Emergency surgery	10.1%	10.3%	6.9%	9.3%	30.7%	20.1%	1.9%
ICU admission	51.8%	47.3%	60.9%	55.9%	74.4%	40.6%	71.1%
Median ICU LOS (IQR)	4 (2 – 8)	4 (2 – 9)	4 (2 – 7)	5 (3 – 11)	3 (2 – 5)	4 (2 – 8)	3 (2 – 5)
Median LOS (IQR)	6 (2 – 14)	6 (2 – 14)	9 (4 – 15)	10 (3 – 19)	8 (4.5 – 15.5)	10 (4 – 21)	3 (1 – 6)
GOS (SD)							
Good or mild disabilities	69.7%	69.7%	83.0%	31.1%	90.5%	67.8%	65.7%
Severe disability or	30.3%	30.3%	17.0%	69.9.3%	9.5%	33.2%	35.3%
Died in the ED	1.7%	5.9%	0.4%	1.8%	3.2%	14.7%	3.3%
Mortality	32.2%	33.6%	20.6%	26.2%	19.9%	12.7%	57.9%

Abbreviations: SII, severe isolated injury; ISS, Injury Severity Score; RTS, Revised Trauma Score; ED, Emergency Department; MAIS, Maximum Abbreviated Injury Score; MMT, Mobile Medical Team; MTC, major trauma centre; ICU, Intensive Care Unit; LOS, Length of Stay; PRF, Physiological Risk Factor; GOS, Glasgow Outcome Scale.

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CHAPTER 8

Modification of the TRISS: simple and practical mortality prediction after trauma in an all-inclusive registry

European Journal of Trauma and Emergency Surgery

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ABSTRACT

Purpose

Numerous studies have modified the Trauma Injury and Severity Score (TRISS) to improve its predictive accuracy for specific trauma populations. The aim of this study was to develop and validate a simple and practical prediction model that accurately predicts mortality for all acute trauma admissions.

Methods

This retrospective study used Dutch National Trauma Register data recorded between 2015 and 2018. New models were developed based on nonlinear transformations of TRISS variables (age, systolic blood pressure (SBP), Glasgow Coma Score (GCS) and Injury Severity Score (ISS)), the New Injury Severity Score (NISS), the sex*age interaction, the best motor response (BMR) and the American Society of Anesthesiologists (ASA) physical status classification. The models were validated in 2018 data and for specific patient subgroups. The models' performance was assessed based on discrimination (areas under the curve (AUCs)) and by calibration plots. Multiple imputation was applied to account for missing values.

Results

The mortality rates in the development and validation datasets were 2.3% (5709/245363) and 2.5% (1959/77343), respectively. A model with sex, ASA class, and nonlinear transformations of age, SBP, the ISS and the BMR showed significantly better discrimination than the TRISS (AUC 0.915 vs. 0.861). This model was well calibrated and demonstrated good discrimination in different subsets of patients, including isolated hip fractures patients (AUC: 0.796), elderly (AUC: 0.835), less severely injured (ISS16) (AUC: 878), severely injured (ISS≥16) (AUC: 0.889), traumatic brain injury (AUC: 0.910). Moreover, discrimination for patients admitted to the intensive care (AUC: 0.846), and for both non-major and major trauma centre patients was excellent, with AUCs of 0.940 and 0.895, respectively.

Conclusion

This study presents a simple and practical mortality prediction model that performed well for important subgroups of patients as well as for the heterogeneous population of all acute trauma admissions in the Netherlands. Because this model includes widely available predictors, it can also be used for international evaluations of trauma care within institutions and trauma systems.

INTRODUCTION

The prediction of survival probabilities for individual trauma patients is essential for trauma system evaluation. Various models have been developed for this purpose. One of the first and most well-known models is the Trauma Injury and Severity Score (TRISS). This model was developed on the United States major trauma outcome study (MTOS) dataset with all trauma admissions and was first described in 1987.1,2 The TRISS uses the combination of patient age, the Injury Severity Score (ISS),3 and the weighted Revised Trauma Score (RTS) to predict a patient's likelihood of survival.4

Over the past decades, several suggestions have been proposed to overcome shortcomings of the TRISS method, including statistical measures,5–7 the addition of new variables and restructuring of existing variables to improve calibration. Additionally, a number of new models have been developed for specific patient categories, such as hip fractures, or to match specific trauma registry populations,8 Examples include the German RISC-II model 9 for acute intensive care unit (ICU) trauma admissions (or death before ICU admission) and the UK Ps14 model 10 for the Trauma Audit and Research Network (TARN) population, which includes patients with significant injuries who were either 1) admitted to the hospital for ≥ 3 days, 2) admitted to the ICU, or 3) transferred to a tertiary centre or 4) who died during admission within 30 days. Cross-validation of both scores showed that each score performed well in its respective registry, but a decrease in performance was observed in the other registry,11 which may partly be explained by population differences due to specific inclusion criteria. Previous studies have clearly stated that applying strict inclusion criteria may diminish the value of trauma registries,12–14 To analyze true hospital performance (between hospitals and within a hospital over time) and specifically all-inclusive trauma systems, a prediction model that performs well in the heterogeneous trauma population and in important subgroups such as patients with hip fractures or with traumatic brain injuries is essential. This study aimed to develop and validate a modified TRISS model (mTRISS-NL) to predict the mortality of all acutely admitted trauma patients. We started with refitting the TRISS model in data from the Dutch Trauma Registry (DNTR) and gradually improved the modelling of existing predictors and added new predictors.

METHODS

Patient selection

This retrospective study was conducted with data recorded in the DNTR. The DNTR documents all injured patients directly admitted to a hospital through the emergency department (ED) within 48 hours after trauma regardless of their age, injury location, and severity.[15] Patients without vital signs upon arrival at the ED were excluded. The Dutch trauma system consist of 11 regional trauma systems, each with at least one, level-1 major trauma centre (13 in total). All 86 trauma-receiving hospitals participate in the DNTR, and adhere to similar level criteria requirements as drafted by the American College of Surgeons Committee on Trauma (ACS-COT).[16] Two datasets were created based on admission year. The development dataset included all trauma patients admitted between 2015 and 2017, and the validation dataset included all trauma patients admitted in 2018.

Outcome

The main outcome of interest was in-hospital mortality.

Data collection and predictors

The DNTR dataset includes the Utstein template items for uniform reporting of data.[17] Data are collected prospectively in three consecutive time phases from the site of the accident until discharge from the hospital: (A) pre-hospital, (B) arrival at the Emergency Department (ED), (C) discharge. For this study, information about the injury, ED physiological data, and demographic variables, including age, sex and preinjury American Society of Anesthesiologists (ASA) physical status classification as a measure for comorbidities, were extracted from the DNTR.[18]

Injuries are coded according to the Abbreviated Injury Scale (AIS) 2005–Update 2008.[19] The ISS is calculated from the three most affected body regions as the sum of squares of the respective AIS severity levels.[3] The New Injury Severity Score (NISS) is calculated in a similar manner, but here, the three worst injuries were selected regardless of their locations.[6]

Descriptive statistics are provided as counts and percentages for categorical variables and as the medians and interquartile ranges (IQRs) for continuous variables. We aimed to adhere to the guidelines on transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD) in our reporting.[20]

Missing values were imputed using multiple imputation in both the development and validation datasets. We used Multivariate Imputation by Chained Equations (R-package mice) for multiple imputation of missing predictor values.[21,22]

Table 1. Outline of the variables incorporated in the derived TRISS model and the adjusted models

Predictor		Model 1	Model 2a	Model 2b	Model 3	Model 4	Model 5
Age	(>55 yes/no)	2.6260					
	Linear		2.2758				
	(age – 60)/30			2.6486	2.6224	2.6304	2.0545
	^2			1.3225	1.4858	1.3024	1.2226
	^3			-0.4818	-0.4701	-0.4810	-0.3234
	^4			-0.4005	-0.4495	-0.4001	-0.3345
Gender	I(sex=male)		-0.2437	-0.0053	-0.0336	0.0122	-0.0005
	fmale * fage		-0.3364	-0.6217	-0.5783	-0.6555	-0.5381
	fmale * fage ^2			-0.5217	-0.4977	-0.5534	-0.5349
	fmale * fage ^3			0.2588	0.2357	0.2838	0.2112
	fmale * fage ^4			0.1912	0.1759	0.2062	0.1828
ASA	ASA=1						Reference
	I(ASA=2)						0.6887
	I(ASA=3)						1.4601
	I(ASA=4 or ASA=5)						2.3800
GCS	linear	-0.2307	-0.2633				
	LN(GCS)			-0.3506	-0.3064		
	^2			-0.0084	-0.0057		
BMR						0.4125	0.3829
	^2					-0.1381	-0.1351
SBP (mmHg)	linear	-0.0083	-0.0116				
	MIN(MAX((RR-140)/30),50,200))			-0.3669	-0.3875	-0.3663	-0.3485
	^2			0.1023	0.1147	0.1045	0.1046
RR (breaths/min)	MIN(MAX((RR-15)/4),15,40))	0.0344	0.0380	0.3232	0.3257	0.3324	0.3129
ISS	linear	0.0897	0.0968				
	LN(ISS)			-0.5435		-0.9301	-0.6997
	^2			0.4120		0.6618	0.4738
NISS	LN(NISS)				-0.4609		
	^2				0.3456		
Constant		-2.8989	-0.6839	-6.4562	-6.5100	-3.8956	-4.4420
R^2		0.275	0.330	0.349	0.350	0.345	0.368
AUROC							
	Development	0.867	0.903	0.907	0.906	0.906	0.918
	Validation	0.862 (0.854 - 0.871)	0.899 (0.899 - 0.905)	0.902 (0.896 – 0.908)	0.901 (0.895 - 0.907)	0.899 (0.891 – 0.906)	0.915 (0.909 - 0.920)

Abbreviations: ASA: Anesthesiologists Physical Status; GCS: Glasgow Coma Scale; BMR: best motor response; SBP: Systolic Blood Pressure; RR: respiratory rate; ISS: Injury Severity Score; LN: natural logarithm; NISS: New Injury Severity Score.

Model development and validation

We compared the performance of five models in predicting mortality (Table 2). Model 1 represents the updated TRISS model, with coefficients calculated for the DNTR trauma population.[23] In Model 2a, the variable sex and the age*sex interaction term were introduced. For Model 2b, the continuous variables age, SBP, GCS and ISS were modelled with (nonlinear) polynomial transformations,[24] and the variable sex was introduced. Model 3 was designed to test whether incorporation of the NISS yielded better predictive performance than the ISS. Model 4 tested the predictive ability of the best motor response (BMR) instead of the GCS. Model 5 was designed to test the additional predictive ability of comorbidities expressed by the variable ASA class.[18] Statistical analyses was performed using R version 4.1.1 (2021-08-10) and the R package rms (Regression Modeling Strategies) for regression analyses.[21,25] Each model's performance in the development and validation datasets was assessed based on discrimination and calibration. Discrimination was measured using the area under the curve (AUC) and the overall percentage of variability explained by the model (Nagelkerke, pseudo R^2).[26,27] The discriminative ability of a model was classified as follows: an AUC of 0.5 suggests no discrimination, 0.7 to 0.8 is considered acceptable, 0.8 to 0.9 is considered excellent, and greater than 0.9 is considered outstanding.[28] Because of our large sample size, the risk of overfitting was negligible. Calibration was assessed visually with calibration plots in the validation set.

Previous research showed poor performance of the TRISS model in different subsets of trauma patients.[29,30] Therefore, the performance of the TRISS and the newly developed model (mTRISS-NL) was assessed in the following subgroups: elderly patients (≥70 years), patients with an isolated hip fracture, patients with an ISS≤15, patients with an ISS ≥16, patients with moderate to severe traumatic brain injury (head AIS ≥3), patients admitted to the ICU, patients admitted to a level two or three trauma centre (non-MTC), and patients admitted to a major trauma centre (MTC).[16]

Model presentation

To simplify clinical implementation, the newly developed mTRISS-NL prediction model is presented by a nomogram.

Patients and public involvement

The study is exempted from the need for informed consent because it is not subject to the Medical Research Involving Human Subjects Act. Trauma patient registration is facilitated by Dutch law, which warrants patient anonymity. Patients and the public were not involved in the design, execution, reporting, or dissemination plans of our study.

RESULTS

Datasets

In total, 245,363 patients were included in the development dataset. Males represented 49.7% (n=121,900) of the population. The median age was 62 years (IQR, 28–81), and the median ISS was 5 (IQR, 2-9). Overall mortality was 2.3% (n= 5708). All patient characteristics are presented in Table 2. Additionally, Table 2 shows the characteristics of 77,343 patients included in the validation dataset. Males represented 49.8% (n= 38,584) of the patients in the validation data. The median age was 64 years (IQR, 29-81), and the median ISS was 5 (IQR, 4-9). Overall mortality in this group was 2.5% (n=1959).

No significant differences were found between baseline characteristics or the number of missing values between the development dataset and the validation set. In both sets, deceased patients tended to be male and older, to have higher ISS and NISS scores, moderate to severe head injuries (AIS ≥3), and more pre-existing comorbidities, and to be treated at a major trauma centre and admitted to the ICU (Table 2).

Model development

Discrimination and explained variance improved markedly after introducing sex and its interaction with age into the model (Table 2; AUC: 0.862 with an R^2: 0.275 for Model 1; AUC: 0.903 with an R^2: 0.330 for Model 2a). Nonlinear transformations of age, GCS, SBP, and the ISS led to an increase in the discriminative ability (Model 2b: AUC: 0.907) and in the explained variance (R^2: 0.349). Cut-off values for SBP [50–220 mmHg] and RR [15-40 breaths a minute] were applied to avoid overfitting of polynomial effects at the extreme ends of the spectrum. Replacing the statistically corrected version of the ISS with the optimized NISS variable and replacing the GCS with BMR did not substantially change the discriminative ability (AUC for both

Models 3 and 4: 0.906) or the explained variance of (R^2: 0.350) and (R^2: 0.345). With the addition of the ASA classification in Model 5, the discriminative ability increased to an AUC of 0.918, with an explained variance of 0.368. In the final model, the most important predictors of mortality were age (Figure 1; chi^2=2441.8) and ISS (chi^2=2356.2), followed by BMR (chi^2=1563.2) and ASA class (chi^2=1257.9) and then RR (chi^2=471.2), sex (chi^2=288.6) and SBP (chi^2=256.2).

Table 2. Patient characteristics in the development and validation sets

		Development set		**Validation set**	
		n	**%**	**n**	**%**
Number of cases	Total	245,363		77,343	
	2015	83,835	34.2		
	2016	81,996	33.4		
	2017	79,532	32.4		
	2018			77,343	100
Mortality	Died in-hospital	5708	2.3	1959	2.5
Age (y)	Median (IQR)	62.7	(27.7 – 81.0)	64.4	(29.1 – 81.4)
	0-19 y	47,013	19.2	14,505	18.7
	20-54 y	48,797	19.9	15,033	19.4
	55-69 y	103,895	42.4	31,251	40.4
	≥70 y	101,779	41.5	33,479	43.2
	Missing	55	0.0	68	0.1
Deceased	Median (IQR)	83	(71 – 89)	83	(71 – 89)
Gender	Male	121,900	49.7	38,584	49.8
	Female	123,417	50.3	38,783	50.1
	Missing	46	0,0	67	0,1
Deceased	Male	3016	52.8	1074	54.8
Type of injury	Blunt	219,284	89.4	70,800	91.2
	Penetrating	7273	3.0	2326	3.0
	Missing	18,806	7.7	4308	5.8
Deceased	Blunt	5297	98.3	1847	98.7
GCS	Median (IQR)	15	(15 - 15)	15	(15 - 15)
	3	2431	1.0	781	1.0
	4-5	477	0.2	160	0.2
	6-8	793	0.5	396	0.5
	9-12	3116	1.2	1027	1.3
	13-15	157,177	64.1	49,435	63.8
	Missing	80,916	33.0	25,635	31.1
Deceased		15	(15 - 15)	15	(15 - 15)
BMR	Median (IQR)	6	(6 – 6)	6	(6 – 6)
	Missing	79,953	32,6	25,331	32,7
Deceased		6	(6 – 6)	6	(6 – 6)
Systolic blood	Median (IQR)	133	(120 - 150)	133	(120 - 150)
	0	286	0.1	91	0.1
	1-49	150	0.1	49	0.1
	50-75	527	0.2	188	0.2
	76-89	1224	0.5	356	0.5
	>89	165,314	67.4	52,931	68.4
	Missing	77,862	31.7	24,503	31.6
Deceased	Median (IQR)	132	(120 – 155)	133	(120 – 156)
Respiratory Rate	Median (IQR)	18	(15 - 20)	18	(15 - 20)
	0	348	0.1	114	0.1
	1-5	277	0.1	94	0.0
	6-9	357	0.1	109	0.2
	10-29	122,762	50.0	38,716	1.5
	>29	2234	0.9	693	0.9
	Missing	119,385	48.7	37,708	48.7
Deceased		18	(15 - 20)	18	(15 - 20)

Table 2. (continued)

		Development set		Validation set	
		n	**%**	**n**	**%**
ISS	Median (IQR)	5	(2 – 9)	5	(4 - 9)
	1-8	145,621	59.4	43,518	56.2
	9-15	84,529	34.5	29,031	37.5
	16-24	8043	3.3	2791	3.6
	>24	5029	2.1	1911	2.5
	Missing	2141	0.9	183	0.2
Deceased	Median (IQR)	9	(9 – 25)	9	(9 – 25)
NISS	Median (IQR)	6	(3 - 9)	8	(4 - 9)
Deceased	Median (IQR)	10	(9 – 30)	10	(9 – 34)
ASA*	1	87,345	35.6	28,779	42.1
	2	82,010	33.4	26,186	38.3
	3	28,858	11.8	12,625	18.5
	4 - 5	2834	1.2	725	1.0
	Missing	44292	18.1	9119	11.8
Deceased	1	541	11.9	197	11.8
	2	1925	42.3	596	35.7
	3	1687	37.1	712	42.7
	4 - 5	399	8.7	163	9.8
Head injury	Head AIS ≥3	14,546	5.9	5290	6.8
	Missing	1297	0.5	36	4.4
Deceased	Head AIS ≥3	5687	39.1	604	30.8
ICU admission	Yes	18,000	7.3	6027	7.8
	No	210,055	85.6	68,941	89.0
	Missing	17,308	7.1	2466	3.2
Deceased	Yes	2156	39.6	748	38.9
	No	3288	60.4	1175	61.1
Hospital	MTC	58,086	23.7	18,666	24.1
	Non-MTC	187,277	76.3	58,768	76.7
	Missing	0	0.0	0	0.0
Deceased	MTC	2361	41.4	825	42.1

Abbreviations: GCS: Glasgow Coma Scale; ISS: Injury Severity Score; NISS: New Injury Severity Score; ASA: Anesthesiologists Physical Status; ICU: Intensive Care Unit; MTC: Major Trauma Centre; non-MTC: non-Major Trauma Centre.

*ASA classification; ASA-1: a normal healthy patient, ASA-2: a patient with mild systemic disease, ASA-3: a patient with severe systemic disease, ASA-4: a patient with severe systemic disease that is a constant threat to life.

Final model validation

The validation dataset showed a considerable difference in discriminative ability between Model 1 and Model 5 (Model 1: AUROC: 0.862 [95% CI 0.854-0.871]) and (Model 5: AUROC: 0.915 [95% CI 0.909-0.920]) (Table 1). Model 5 was well calibrated for patients admitted in 2018 (Figure 2). The AUC was 0.795 (95% CI 0.779 – 0.812) for patients with isolated hip fractures, 0.835 (95% CI 0.825 – 0.845) for older patients (≥70 years) and 0.910 (95% CI 0.898 – 0.894) for patients who sustained moderate to severe traumatic brain injuries (Figure 3). The AUCs for severely injured patients (ISS ≥16) and for those with less severe injuries (ISS<16) were 0.889 (95% CI 0.878 – 0.900) and 0.878 (95% CI 0.879 – 0.894), respectively. Our model showed outstanding or excellent discriminative ability for patients admitted to intensive care (AUC: 0.846 (95% CI 0.831 – 0.860)) and for both major trauma centre and non-major trauma centre populations, with AUCs of 0.939 (95% CI 0.932 – 0.946) and 0.895 (95% CI 0.887 – 0.902), respectively.

Visual inspection of the calibration plots (Figures 2 and 3) shows slightly poorer calibration in the strata of a predicted mortality risk greater than 60%. The mortality risk was overestimated for high-risk patients with severe injuries (ISS ≥16) and moderate to severe traumatic brain injuries and those treated at major trauma centres (i.e., the predicted mortality was higher than the observed mortality).

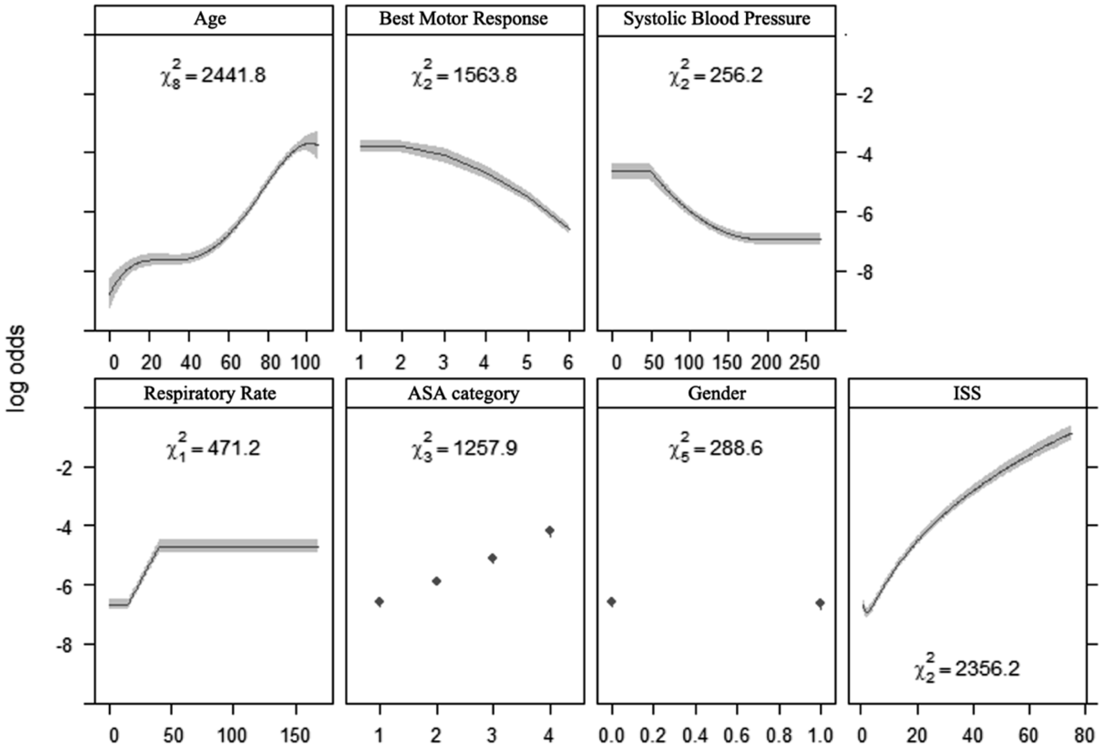

Figure 1. Multivariable effects of predictors of in-hospital death (development dataset). Abbreviations: ASA: Anesthesiologist Physical Status; BMR: best motor response; SBP: systolic blood pressure; ISS: Injury Severity Score.

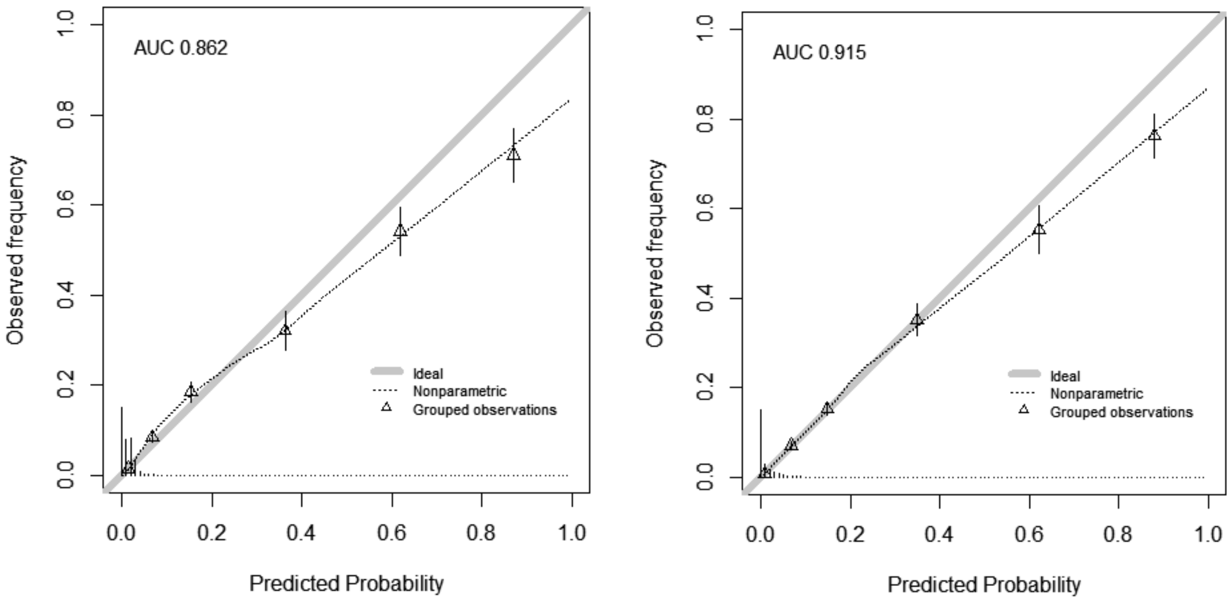

Figure 2. Calibration plots for Model 1 (left) and Model 5 (right) in the general trauma population admitted in 2018 (validation dataset). Observed mortality is plotted against predicted mortality. Note the decrease in pessimistic biasing in the higher predicted probability strata (≥0.6) in Model 5.

Model presentation

A nomogram was constructed to provide a graphic understanding of clinical prediction rules and a quick approximation of the outcome probability (Figure 4). The nomogram is based on the final multivariable logistic regression prediction model with the following seven predictors: age, sex, ISS, RR, SBP, BMR and ASA class. The location and length of each nomogram line illustrate its relative importance with respect to the risk of mortality. A vertical line upwards to the "Points" scale provides the numerical score for that predictor. The sum of the 7 predictors yields the "Total Points", which can be scaled to the final output—the probability of mortality. The formula for this prediction model is shown in Supplemental material Table 1.

According to the TRIPOD checklist, all relevant items are covered in this manuscript.

DISCUSSION

This study presents an accurate model for predicting mortality in the general hospitalized trauma population and in important subgroups of Dutch trauma patients. The model can be used to predict the survival of individual trauma patients and to subsequently compare actual survival with predicted survival in groups of patients admitted to hospitals or trauma systems to evaluate their performance.

The modified model

An important strength of the mTRISS-NL model is that in addition to age and sex, the model includes only five variables that are largely available from electronic medical records and do not impose a high administrative burden on physicians and nurses. The variables included in the model are part of the Utstein template for uniform reporting of data following trauma. Therefore, our model can likely be easily applied to trauma registry data in other countries. Several very advanced prediction models are available for specific subgroups of patients, which have been shown to perform well but require considerable effort to collect all required variables. An example is the German Revised Injury Severity Classification (RISC-II) score consisting of 13 variables, including multiple laboratory markers.[9] Although the DNTR is one of largest and most comprehensive trauma registers in the world,[15] several RISC-II variables are either not routinely measured in all trauma patients or not recorded at all.

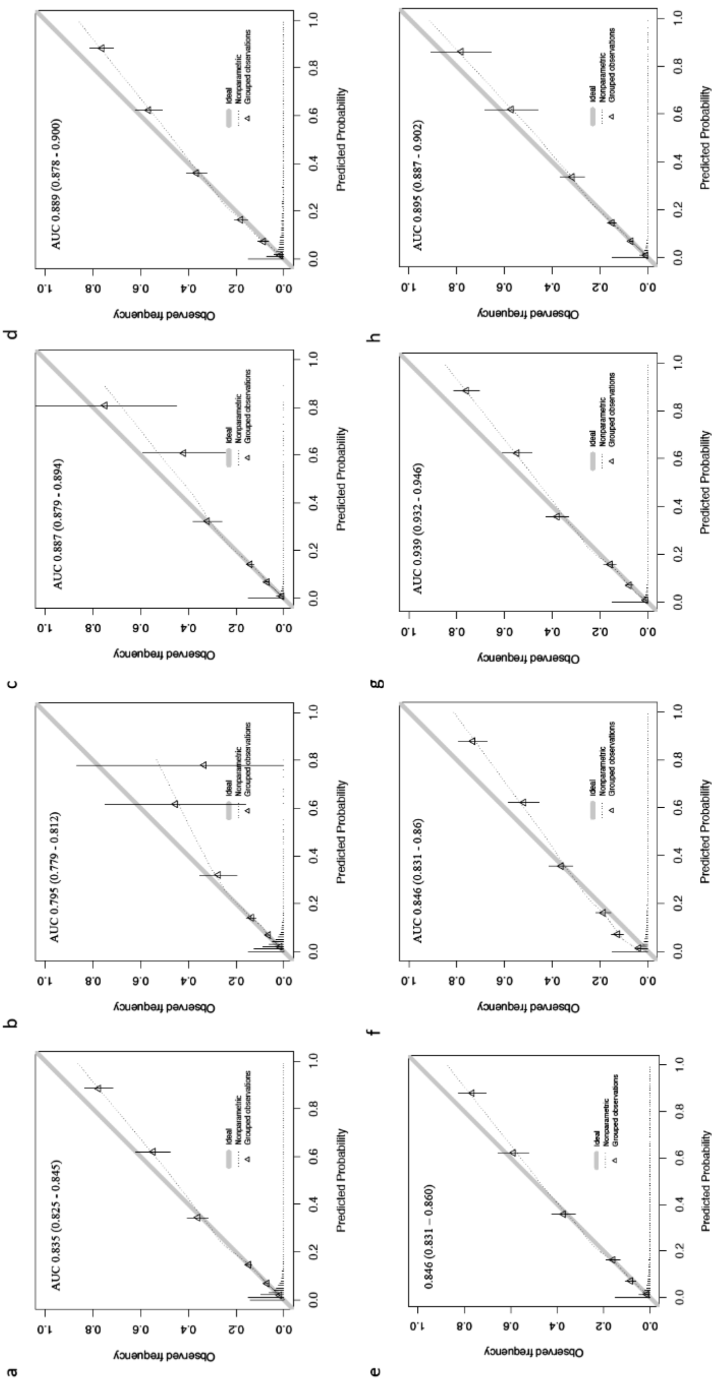

Figure 3. Calibration plots of Model 5 in the validation dataset. Observed mortality plotted against predicted mortality in multiple subgroups. The elderly (≥70) subgroup **(a)**, patients with isolated hip fractures (b), less severely injured patients (ISS ≤15) **(c)**, severely injured patients (ISS ≥16) **(d)**, traumatic brain injury (AIS ≥3) patients **(e)**, patients admitted to the intensive care unit (f), the MTC subgroup **(g)**, and the non-MTC subgroup **(h)**

Furthermore, the RISC model was developed for a very specific population of severely injured patients. Previously, we found that this selection of patients encompasses only 5% of all admitted trauma patients in the Netherlands and would leave out almost 70% of fatalities.[15] Therefore, an important group of patients with fatal outcomes would not be included in the outcome evaluation. Generally, models developed for a very specific population or contain a high number of variables, resulting a high explained variance are at risk of overfitting. Similar concerns apply to the Norwegian NORMIT-II and the United Kingdom's Ps14 model, which were developed to serve a more severely injured trauma population of patients who triggered a trauma alarm or were in need of critical care and exclude patients with hip fractures.[31,32] Because our final model includes easily determinable predictors that are widely available in trauma registries, the mTRISS-NL model is seemingly less susceptible to interregistry differences and is thus transferable to other trauma registries. However, an external validation study is needed to determine its actual performance in another registry.

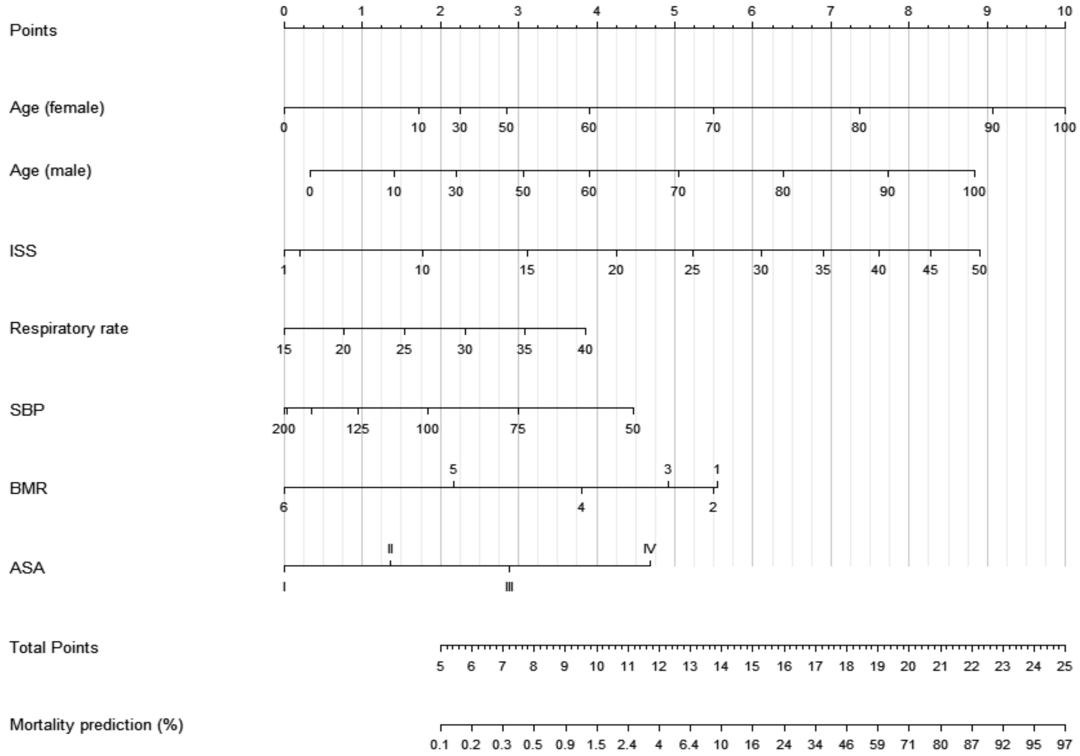

Figure 4. Model presentation using a nomogram. Abbreviations: ISS: Injury Severity Score; SBP: systolic blood pressure; BMR: best motor response; ASA: Anesthesiologist Physical Status.

We chose the classic TRISS model as the starting point for the development of a new model. All TRISS variables (age, ISS, SBP, RR, age) except for the GCS were retained in the mTRISS-NL model. However, we used fractional polynomial modelling to correct for nonlinearity. The GCS was replaced by the BMR to simplify the model and increase its applicability because the GCS may be difficult to determine in intoxicated or intubated patients.[33] By using the BMR as a single predictor instead of the three variables constituting the GCS, the number of missing values is reduced, and the inclusion of inaccurate estimates for intubated patients can be avoided. The exclusion of respiratory rate as a predictor may also reduce the number of missing values without sacrificing too much predictive power. However, since the DNTR does not offer an appropriate substitute, such as SpO2, we chose to retain the original respiratory rate. Finally, the NISS was tested but did not outperform the ISS. The new variables added to the classic TRISS model included ASA class and sex.

Laboratory markers

Future survival prediction models might become less reliant on clinical information, as several haematological and biochemical markers have been associated with worsening outcomes after trauma and might provide additional prognostic value. Base excess (BE) is one example of a marker that has been shown to correlate well with mortality, prolonged intensive care unit admission, transfusion requirements and the development of various complications.[34] Importantly, predictors obtained from laboratory data should be less influenced by subjective assessments of vital signs, which might be less reliable in cases of intubation, sedation, or intoxication. Structural testing of more laboratory diagnostics for all trauma patients and enabling automated processing to trauma registers would enable the development and usage of novel, more sophisticated prediction models.

Strengths and limitations

The major strength of this study is the heterogeneous population, its size and national coverage. Because we included 245,363 acutely admitted Dutch trauma patients regardless of the type of injury, age or whether they were admitted to intensive care facilities, we are convinced that our population truly covers the entire clinical trauma population. Another strength of our study is the external validation in a population with 77,343 Dutch trauma patients admitted in 2018. Lastly, the development of a nomogram facilitates easy access to accurate mortality predictions in clinical practice. Nevertheless, our study also has several limitations that warrant discussion. First, as a primary outcome measure, we used in-hospital mortality. Any patient who died after hospital discharge was considered to have survived for the purposes of this study, which might yield an underestimation for those who die from late-onset symptoms or complications as a result of their injuries. Second, the mTRISS-NL model includes the ISS, which is still a fundamental component of trauma outcome research and quality improvement programs. However, due to its dependency on hospital diagnostics it cannot be used in pre-hospital triage and the inter-rater agreement in ISS coding remains moderate.[35–37] Third, the DNTR did not include other variables that define comorbidity in addition to the ASA classification; thus, we were not able to compare the discriminative value of ASA class with that of, for example, the Charlson Comorbidity Index (CCI),[38] which may be of interest because other studies showed that incorporating the Charlson Comorbidity Index (CCI) into the TRISS model resulted in similar improvements in outcome prediction as adding the ASA class.[39–41] Fourth, the mTRISS-NL model was developed and validated based on data from the Dutch Nationwide Trauma Registry, an external validation study is needed to confirm that the model performance is applicable to other populations or trauma systems. Finally, despite the excellent discriminative ability, the calibration plots show that the model slightly exaggerates the likelihood of death for severely injured patients, which may result in an overestimation of the quality of care (i.e., fewer deaths than predicted).

CONCLUSION

We developed an accurate model to predict mortality in all acutely admitted trauma patients based on seven predictors that can be obtained quickly and early in the care process—age, sex, Injury Severity Score, respiratory rate, systolic blood pressure, the best motor response, and comorbidities by the American Society of Anesthesiologists physical status classification. The final model showed good discrimination and was well calibrated in various subgroups of trauma patients within the Dutch trauma population. The presented nomogram enables easy use in clinical practice.

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APPENDIX

Supplemental Digital Content Table 1. mTRISS-NL formula

Predictor	formula	minimum	maximum
Gender=Gender (male)	f.male = I(gender=male)		
Age = Age (years)	f.age = (age – 60)/30	0	100
ISS = Injury Severity Score	f.ISS = LN(ISS)	0	75
RR = Respiratory rate (breaths/min)	f.RR = (MIN(MAX(RR,15),40)-15)/4	15	40
SBP = systolic blood pressure	f.SBP = (MIN(MAX(SBP,50),200)-140)/30	50	200
BMR = best motor response	f.BMR = BMR	0	6
ASA = Anesthesiologist Physical Status.	f.ASA2 = I(ASA=2) f.ASA3 = I(ASA=3) f.ASA45 = I(ASA=4 or ASA=5)	1	4

logodds = -4.4420 +
f.age * 2.0545 +
f.age^2 * 1.2226 +
f.age^3 * -0.3234 +
f.age ^4 * -0.3345 +
f.male * 0.0005 +
f.male * f.age * -0.5381 +
f.male * f.age^2 * -0.5349 +
f.male * f.age^3 * 0.2112 +
f.male * f.age ^4 * 0.1828 +
f.ISS * -0.6997 +
f.ISS^2 * 0.4738 +
f.RR * 0.3129 +
f.SBP * -0.3485 +
f.SBP^2 * 0.1046 +
f.MR * 0.3829 +
f.MR^2 * -0.1351 +
f.ASA2 * 0.6887 +
f.ASA3 * 1.4601
f.ASA45 * 2.3800

Probability (in-hospital death) = 1/(1+exp(-logodds))

E

CHAPTER 9

Funnel plots a graphical instrument for the evaluation of population performance and quality of trauma care: A blueprint of implementation

European Journal of Trauma and Emergency Surgery

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ABSTRACT

Background

Using patient outcomes to monitor medical centre performance a has become an essential part of modern health care. However, classic league tables generally inflict stigmatization on centres rated as “poor performers”, which has a negative effect on public trust and professional morale. In the present study, we aim to illustrate that funnel plots, including trends over time, can be used as a method to control the quality of data and to monitor and assure the quality of trauma care. Moreover, we aimed to present a set of regulations on how to interpret and act on underperformance or overperformance trends presented in funnel plots.

Methods

A retrospective observational cohort study was performed using the Dutch National Trauma Registry (DNTR).

Two separate datasets were created to assess the effects of healthy and multiple imputations to cope with missing values. Funnel plots displaying the performance of all trauma-receiving hospitals in 2020 were generated, and in-hospital mortality was used as the main indicator of centre performance. Indirect standardization was used to correct for differences in the types of cases. Comet plots were generated displaying the performance trends of two level-I trauma centres since 2017 and 2018.

Results

Funnel plots based on data using healthy imputation for missing values can highlight centres lacking good data quality. A comet plot illustrates the performance trend over multiple years, which is more indicative of a centre’s performance compared to a single measurement. Trends analysis offers the opportunity to closely monitor an individual centres’ performance and direct evaluation of initiated improvement strategies.

Conclusion

This study describes the use of funnel and comet plots as a method to monitor and assure high-quality data and to evaluate trauma centre performance over multiple years. Moreover, this is the first study to provide a regulatory blueprint on how to interpret and act on the under- or overperformance of trauma centres. Further evaluations are needed to assess its functionality.

INTRODUCTION

Monitoring the performance of medical centres based on patient outcomes has become an essential part of modern health care [1]. Classic league tables are an established technique for displaying the comparative performance ranking of organizations. Previous research suggests that these rankings aimed to generate a stimulus to initiate improvements [2]; however, they generally inflict stigmatization on centres rated as “poor performers”, which has a negative effect on public trust and professional morale [3,4].

The use of funnel plots has been suggested as a standard method for institutional comparisons using cross-sectional data [5–9]. Funnel plots are a graphical tool used to present centre comparisons, while avoiding ordering or ranking of centres [6]. Moreover, they clearly visualize the relationship between sample size and precision since the control limits and the distribution become narrower with higher volumes. The control limits indicate a range in which the values of the quality indicator would be expected to fall. Centres exceeding these control limits may be considered underperforming or overperforming, prompting an investigation into their practices. In addition, quality can be improved by learning from good performing centres (i.e., adopting best practice methods) and initiating improvement strategies.

The funnel plot methodology has been applied previously in a trauma setting to evaluate and compare mortality rates and hospital length of stay between centres [10,11]. However, there are two main issues that need to be addressed when evaluating trauma centre performance. First, the quality of the data needs to be assured, as mortality rate prediction is less accurate in cases of incorrectly entered or missing data. Second, because trauma populations can vary widely between centres, it is important to ensure that a centre’s performance is investigated rather than focus on differences in case variability. Indirect standardization can be used to overcome problems resulting from comparing centres with different degrees of injury severity [12]. However, individual centres are, even after standardization, not directly comparable because each centre’s’ own population is used to calculate the expected outcomes. The indicator thus shows how well a centre performs within its own population in comparison to the performance of the reference standard. In current practice, the comparison between centres is overemphasized when evaluating health care-related outcomes. We believe that assessing a centre’s performance trend for its designated trauma population over multiple years is extensively more interesting, assuming that the patient population remains relatively stable. Thus, the aim of the present study is to illustrate that funnel plots can be used as a method to control the quality of data and assure an optimal level of trauma care by evaluating centre performance trends over time. Moreover, a set of guidelines on how to interpret and act on results presented in funnel plots, including underperformance as well as overperformance trends, will be presented.

METHODS

Study population

A retrospective observational cohort study was performed using the Dutch National Trauma Registry (DNTR) [13]. The DNTR documents all injured patients directly admitted to a centre through the emergency department (ED) within 48 hours after trauma, regardless of their age, injury location and severity. Patients arriving at the ED without vital signs were excluded [13]. For this study, all patients recorded in the DNTR in 2020 were included. To illustrate trends in performance over multiple years, standardized mortality ratios of two level-I trauma centres between 2017 and 2019 were additionally calculated. Each dot in the comet plots shows the performance over one year, yet the time frame moves three months forward with each dot. In other words, from point to point, three quarter of the data is identical, and one quarter is new. By doing so, the points in the graph move slowly 'like a comet'. Without this feature (for example, if annual data were used without overlap), points would jump around more.

This study was exempted from ethics review board approval because the study used existing coded data from the DNTR, and patient anonymity was guaranteed. Neither patients nor members of the public were involved in the design, execution, reporting, or dissemination plans of our study. The DNTR dataset includes the Utstein template items for uniform reporting of data following major trauma and covers 100% of the trauma-receiving centres in the Netherlands [14].

The DNTR includes 86 trauma centres, 13 of which are designated level-I trauma centres [13,15]. Injuries are coded according to the Abbreviated Injury Scale (AIS) 2005, update 2008 [16]. The Injury Severity Score (ISS) is calculated from the three most affected body regions as the sum of squares of the respective AIS severity levels [17]. Patients with ISS scores of 16 or above are classified as severely injured.

Statistical analysis

In-hospital mortality was used as the main indicator of a centre's performance. To describe patient characteristics, centres were divided into two groups according to their level of expertise, following the ASCOT guidebook entitled *Optimal Resources for Care of the seriously Injured* [15]. Level-I trauma centres are fully equipped to deliver the highest level of emergency and surgical care for the most severely injured, with 24/7 coverage of all specialities, including thoracic and neurosurgery. Lower-level trauma centres (i.e., level-II and level-III) provide optimal care for moderately and mildly injured patients in a cost-effective manner.

Missing values were imputed using multiple imputation, assuming missing values at random [18]. We used Multivariable Imputation by Chained Equations (R-package mice) for multiple imputation of missing case-mix variables [19,20]. To assess the value of complete data for evaluating funnel plots, we generated a second dataset where missing values were imputed with normal healthy values. For example, when the ISS is missing, the lowest possible score of 1 is recorded, and if the American Society of Anaesthesiologists (ASA) score for comorbidity is missing, a score of 1 (no comorbidity) is recorded. The number of missing values per variable is listed in Table 1 of the supplemental material.

The standardized mortality ratio (SMR) is the ratio of observed deaths to the expected number of deaths or the observed mortality rate to the expected mortality rate [12]. A ratio of 1 means that a particular centre performs exactly as was expected based on its population characteristics. A value above one indicates more deaths recorded than the reference model predicts, while a value less than one represents fewer deaths recorded than expected.

To account for differences in patient characteristics between centres, the expected in-hospital mortality rate was calculated with the use of a recently published modified Dutch version of the Trauma Injury Severity Score (mTRISS-NL) [21]. This mortality prediction model uses polynomial transformation of classic TRISS variables and is able to accurately predict mortality rates for all acutely admitted trauma patients. The model includes the variables sex, ASA class, nonlinear transformations of age, systolic blood pressure (SBP), respiratory rate (RR), Injury Severity Score (ISS) and best motor response (BMR) [17,22,23]. Using this mortality prediction model, the expected probability of in-hospital mortality after trauma is determined for each patient, and these SMRs can be added to encompass all patients treated at a specific centre over a specified period of time.

Control limits

The funnel plot is so named because of the funnel shape of the control limits or prediction intervals. The prediction interval is calculated around the SMR and is based on its precision. The precision of the SMR increases with sample size and injury severity. Therefore, wide prediction intervals occur with small patient numbers, and narrower prediction intervals occur with large patient numbers. The control limits for the funnel plots were set at 95% and 99.8% prediction intervals, corresponding to approximately 2 and 3 standard error widths, respectively. Centres that perform similarly to the reference population have a 5% chance of exceeding the limits, 2.5% at the upper limit and 2.5% at the lower limit. Estimates falling outside the control limits represent the centres showing wider deviation from the estimate than the deviation expected because of chance alone.

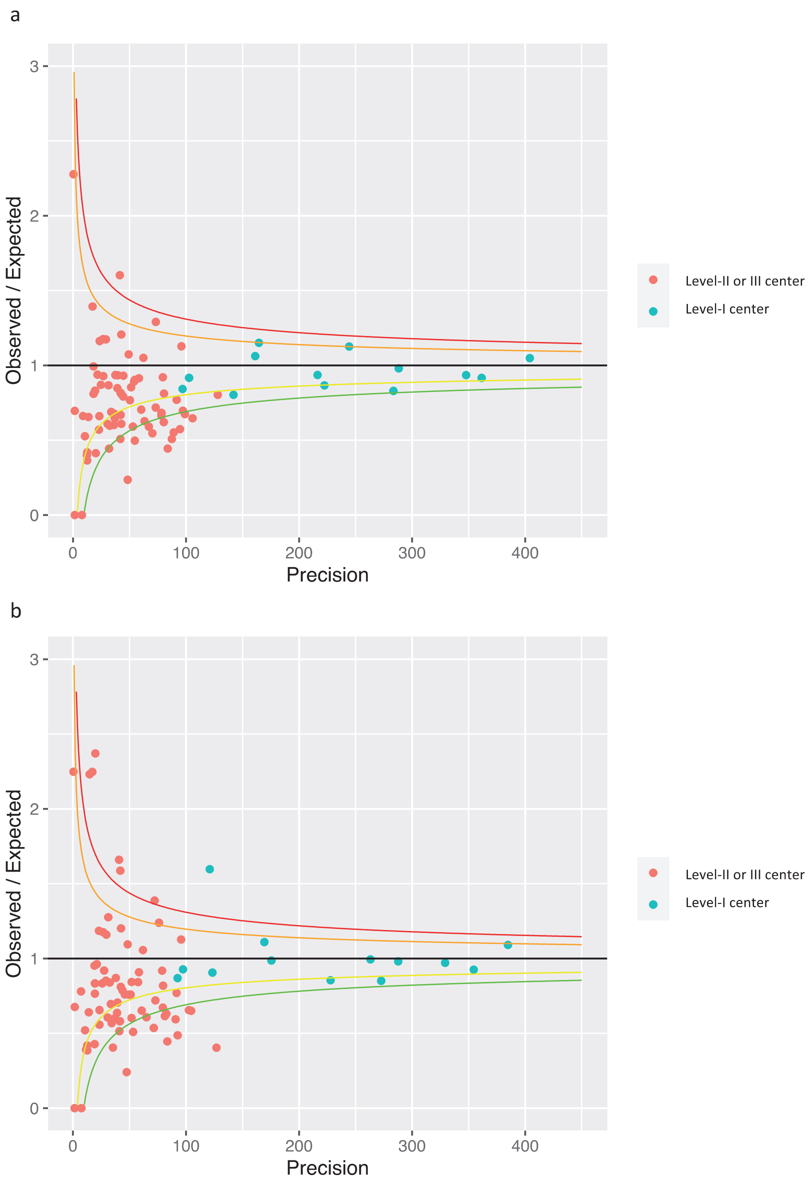

Figure 1. Funnel plot showing the standardized mortality ratio for all trauma-receiving centres in the Netherlands, a) for the healthy imputed dataset and b) for the multiple imputed data set. The inner orange and yellow lines are the 95% and the outer red and green lines are the 99.8% confidence intervals. Note that several underperforming centres in a) are corrected in b).

RESULTS

A total of 71,613 acutely admitted patients were included in this study. Most (n=54,483 (76.1%)) of these patients were admitted to a level II or III trauma centre (Table 1). A total of 4671 severely injured patients (ISS>15) were included, and 3299 (70.6%) were treated at one of the 13 level-1 trauma centres, with a range of 76 to 452 severely injured patients per centre per year. The average mortality rate for all trauma-receiving hospitals was 2.7%, varying from 2.0% for level-II and level-III trauma centres and 5.0% for level-I trauma centres.

Table 1. Patient characteristics in the dataset set using healthy imputations, for patients treated at level-I and level-II/III trauma centres.

	All centres	Level-I	Level-II/III
Number of cases (%)	71,613 (100)	17,130 (23.9)	54,483 (76.1)
Median age (IQR)	66.1 (30,5 - 81.7)	55.5 (24.6 -75.2)	69.4 (34.7 -83.0)
Male gender, n (%)	35,229 (49.2%)	9,997 (58.4%)	25,232 (46.3%)
Blunt injuries, n (%)	69131 (96.5%)	16,127 (94.1%)	53,004 (97.3%)
Median ISS (IQR)	6 (4 - 9)	9 (4 - 12)	5 (4 - 9)
Median RR	14 (11 - 18)	16 (14 - 20)	14 (11 - 18)
Median SBP	135 (109 - 157)	139 (120 - 158)	136 (109 - 158)
Median BMR	6 (6 - 6)	6 (6 - 6)	6 (6 - 6)
ASA, n (%)			
I	32,546 (45.4%)	8624 (50.3%)	23,922 (43.9%)
II	24,054 (33.6%)	5452 (31.8%)	18,602 (34.1%)
III	14,153 (19.8%)	2897 (16.9%)	11,256 (20.7%)
IV	839 (1.2%)	149 (0.9%)	690 (1.3%)
V	21 (0.0%)	8 (0.0%)	13 (0.0%)
ICU admission, n (%)	3706 (5.2%)	2438 (14.2%)	1268 (2.3%)
Mortality, n (%)	1963 (2.7%)	859 (5.0%)	1104 (2.0%)

Abbreviations: ISS; Injury Severity Score, RR; respiratory rate, SBP; systolic blood pressure, BMR; best motor response, ASA; American Society of Anesthesiologists, ICU; Intensive Care Unit.

Funnel plot

Two funnel plots showing the standardized mortality ratio for all trauma receiving centres in the Netherlands are shown in Figure 1. The funnel plot derived from the dataset with multiple imputations (Figure 1a) shows a clear distribution of level-I, level-II and level-III trauma centres. Precision increases when a centre has a high patient volume or treats a large number of more severely injured patients. As level-I trauma centres treat a higher volume of severe patients, the precision of level-I trauma centres is generally higher than level-II and III centres, and is thus positioned at a narrower location between the prediction intervals of the funnel plot. In the upper prediction intervals (PI), there are three underperforming level-II or level-III centres and one at the 95% PI that warrant attention. Furthermore, there are eleven (15%) overperforming level-II or level-III centres positioned outside of the 99.8% PI, and twenty-one (28.8%) in between the 95% and 99.8% PI. Of the level-I trauma centres, two (15.4%) are on the upper 95% PI line, and three are positioned between the lower 95% and 99.8% PI intervals. Comparing Figure 1a and 1b (i.e., comparing funnel plots derived from multiple and healthy imputed data) shows some interesting deviations. Figure 1b shows that six level-II or level-III centres and one level-I centre are positioned outside the upper 99.8% PI, indicating a worse performance than expected. By comparing the patient characteristics from the dataset using healthy imputations (Table 1) with those using multiple imputations (Table 2), we can see that the median systolic blood pressure and the ASA score for comorbidities vary between the datasets. Lower ASA scores (i.e., fewer preinjury comorbidities) as a result of using healthy imputations due to the number of missing values. The derived prediction (expected mortality) is lower, while the observed mortality is the same. This will increase the SMR, indicating worse performance. Only if there were no cases with missing data, the points would be exactly the same.

Table 2. The pooled numbers and medians of patient characteristics using the five multiple imputation data sets, for patients treated at level-I and level-II/III trauma centres

	All centres	Level-I	Level-II/III
Number of cases (%)	71,613 (100)	17,130 (23.9)	54,483 (76.1)
Median age (IQR)	66.1 (30.5 - 81.7)	55.5 (24.6 - 75.2)	69.4 (34.7 - 83.0)
Male gender, n (%)	36527 (51.0%)	10015 (58.5%)	25713 (47.2%)
Blunt injuries	69008 (96.4%)	16126 (94.1%)	52980 (97.2%)
Median ISS (IQR)	6 (4 - 9)	9 (4 - 12)	5 (4 - 9)
Median RR	16 (14 - 20)	16 (14 - 20)	16 (14 - 20)
Median SBP	140 (120 - 159)	136 (120 - 156)	140 (121 - 160)
Median BMR	6 (6 - 6)	6 (6 - 6)	6 (6 - 6)
ASA, n (%)			
I	27325 (38.2%)	7826 (45.7%)	19518 (35.8%)
II	27403 (38.3%)	5997 (35.0%)	21405 (39.3%)
III	15924 (22.2%)	3150 (18.4%)	12773 (23.4%)
IV	928 (1.3%)	169 (1.0%)	769 (1.4%)
V	25 (0.0%)	9 (0.1%)	16 (0.0%)
ICU admission, n (%)	3709 (5.2%)	2439 (14.2%)	1270 (2.3%)
Mortality, n (%)	1963 (2.7%)	859 (5.0%)	1104 (2.0%)

Abbreviations: ISS; Injury Severity Score, RR; respiratory rate, SBP; systolic blood pressure, BMR; best motor response, ASA; American Society of Anesthesiologists, ICU; Intensive Care Unit.

Comet plot

A performance trend over multiple years gives additional insight into a centre's performance compared to a single measurement. Figure 2 shows the performance trend of a level-I trauma centre since 2018. The increasing dot size indicates its direction, with larger dots indicating more recent performance. Note that each dot in the SMR performance trend shows the performance over one year, yet the time frame moves three months forward with each dot. From this comet plot, we learn that this particular centre's precision is increasing (i.e., indicating more patients or more severely injured patients), while overall performance remains relatively stable. The comet shown in Figure 3 illustrates an unfavourable performance trend of a level-I trauma centre. The evaluation at the time revealed a problem in the care of a specific trauma patient subgroup. After assessment and change in policy, the trend reverted.

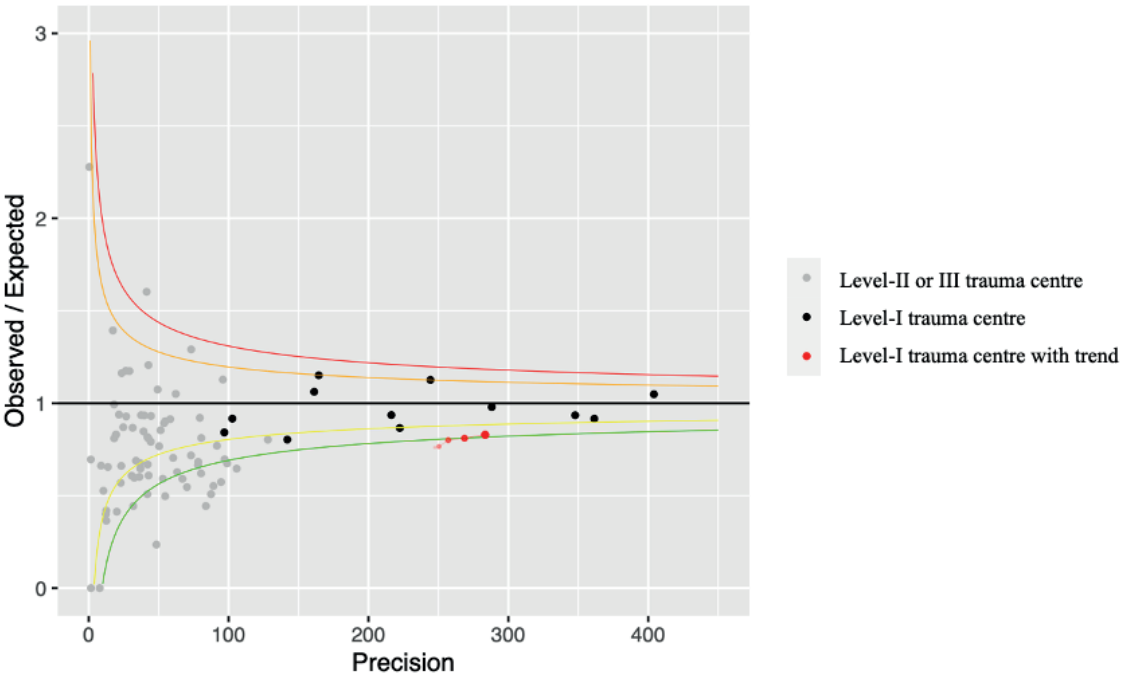

Figure 2. Funnel plot showing the standardized mortality ratio for all trauma-receiving centres in the Netherlands. The inner orange and yellow lines are the 95% and the outer red and green lines are the 99.8% confidence intervals. Note that for one level-1 trauma centre the trend since 2018 is shown.

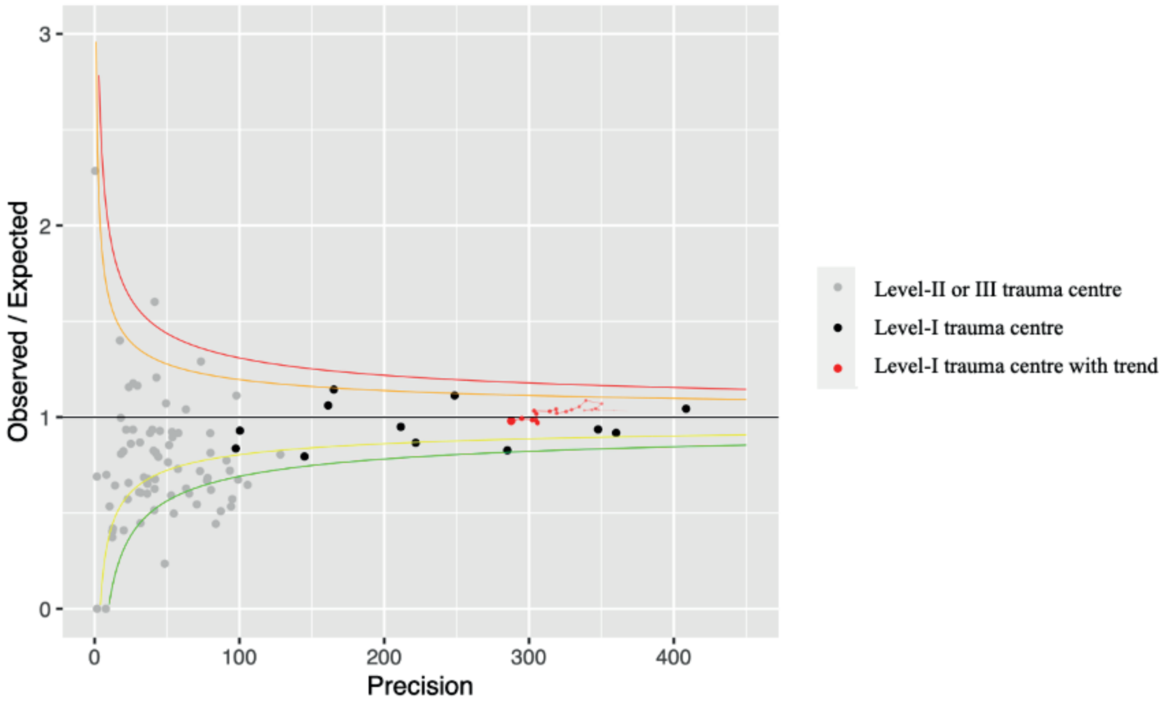

Figure 3. Funnel plot showing the standardized mortality ratio for all trauma-receiving centres in the Netherlands, highlighting the trend for one level-1 trauma since 2017. The inner orange and yellow lines are the 95% and the outer red and green lines are the 99.8% confidence intervals.

DISCUSSION

This national retrospective observational study illustrates how funnel plots can be used to closely monitor the quality of data and trauma care. Moreover, by following and comparing standardized mortality trends in comet plots, we can identify both favourable and unfavourable effects that changes in, for example, a centres' organizational structure have on patient outcomes. Funnel and comet plots facilitate an independent evaluation of a centre's trauma performance, moving away from hierarchical intercentre comparison rankings.

Regulations

We must strongly emphasize that crossing the upper or lower prediction interval does not directly indicate lower or higher "quality" of trauma care. Nevertheless, it should serve as a warning sign that prompts an investigation into the possible causes that could inflict this deviation. To successfully implement and regulate the use of funnel plots, an independent party should be appointed. In the example of the Dutch trauma system, this leading party is the Dutch Network for Emergency Care (Landelijk Netwerk Acute Zorg, in Dutch (LNAZ)). The LNAZ is an organization charged with overseeing and coordinating acute care within the Netherlands. Moreover, it is the overarching network organization of the eleven trauma regions in the Netherlands. Each trauma region has at least one level-I trauma centre. The leading trauma surgeons from the eleven trauma networks (Dutch Trauma Council of the LNAZ) authored a regulatory flowchart on how to manage trauma centres whose performance deviates from expectations (Figure 4). This flowchart has been adopted by the board of the LNAZ, and the funnel and comet plots are generated based on DNTR data and distributed in a yearly report. If necessary, according to the flowchart, a centre has to investigate and clarify its SMR in case of underperformance.

Importance of complete data

The evaluation of trauma care is highly dependent on the quality of the data. The accuracy of a funnel plot is as reliable as the data supporting it. For this reason, funnel plots were generated based on both multiple and healthy imputations. The dataset using healthy imputations is intended to expose centres that might have an issue in their registration. The imputation process using healthy scores can lead to an increased underestimation of expected mortality in the case of missing values. This becomes clear after comparison with funnel plots based on multiple imputations for missing values. In the dataset used for this study, the evaluation process showed that the ASA score (the variable for comorbidities) was missing for several centres. Healthy imputations resulted in SMRs above the upper prediction intervals in the

funnel plot. However, if there were no cases with missing data, the points for multiple and healthy imputations would be exactly the same.
After the initial evaluation of funnel plots using healthy imputation designed to filter out poor performance due to missing values, funnel plots using multiple imputation were generated and distributed to the individual trauma regions. Similar to the process in the first step, the centres that significantly deviate from what is expected are notified of the possibility of lacking data, giving them the opportunity to review and improve the quality of their supplied data. The accuracy of in-hospital mortality rate predictions can be assessed by evaluating if the data on the deceased are entered correctly, for example, if the AIS- or ASA-scores are accurately registered. After this quality control step, new funnel plots were generated. Moreover, in addition to evaluating the performance of a particular year, the general trend over multiple years is assessed.

There are two situations in which a centre is asked to self-conduct a local investigation to assess whether any intentional or unintentional organizational changes have been made that could have either led to an improvement in or deterioration of trauma care. This will be initiated in cases, where after carefully reviewing the data, a centre is positioned below the lower 95% prediction interval of the funnel plot and the general performance trend shows an unfavourable path (trend 03 in Figure 5), or the centre is positioned above the 95% prediction interval and the trend shows a favourable path (trend 04 in Figure 5).

In the unfortunate scenario where a hospital finds itself positioned above the 95% prediction interval and the general performance trend shows an unfavourable path (trend 06 in Figure 5), an independent party (such as the LNAZ) is asked to investigate the locally-delivered trauma care. During such an investigation, the injury characteristics of the deceased, as well as the surgical interventions executed and admission descriptions, need to be evaluated. Any organizational changes made in the previous years that might have impacted patient outcomes need to be reported and reassessed based on their initial targets. In this way, any unfavourable effects can be detected at an early stage, and transparent reporting will serve as a learning opportunity for other centres. Moreover, the funnel plot works both ways, overperforming centres with descending favourable trends (trend 02 and 05 in Figure 5) on the comet plots are asked to assess what organizational or quality improvement changes might have led to the improved outcomes for their patients.

Generally, a hospital's performance will be positioned between the 95% prediction intervals. However, this does not mean there is nothing that can be achieved or questioned. The particular case presented in Figure 3 of this study is an excellent example of this. This hospital was situated within the 95% prediction intervals, just slightly above the midline. However, when assessing the trend of the funnel plot, an unfavourable deviation was found. Their internal evaluation revealed that an increased number of deaths among patients admitted after sustaining a hip fracture caused the centre's performance to deviate from its trend. After carefully evaluating the situation, an improved postoperative care path was established. As illustrated, this initiative quickly reversed its unfavourable trend in the following years.

Future perspectives

The funnel plot methodology is currently being tested in the Netherlands. Knowledge on how to interpret and act upon a specific position and trajectory in the funnel plot is essential in order to successfully implement and regulate the use of funnel plots. This paper will serve as a guideline for surgeons, data-managers and others involved. The next step after implementation will be creating a transparent platform that facilitates users to ask questions, browse existing content, and exchange results.

Funnel plots provide centres with insight into their performance on a specific outcome variable within their own patient population. Moreover, funnel plots clearly visualize the relation between sample size and precision, i.e., the control limits and the distribution of centre outcomes decrease with increased patient volume. The presentation of volume on the x-axis also provides the opportunity to observe an association between volume and outcome. Currently major trauma patient volumes in the Netherlands are too low to demonstrate an allegedly beneficial effect of volume on mortality. Future analysis are needed to assess whether there is an volume effect on mortality or functional outcomes [24].

Even though approximately 95% of the Dutch trauma population survive their injury, mortality remains the main outcome measure [13]. Other outcomes, such as the Glasgow Outcome Scale [25] or the patient-reported outcome measure (PROM), would be interesting options to use to measure trauma care quality. However, several obstacles remain. First, when selecting a PROM, the purpose of healthcare quality evaluation must be taken into account. It is possible that a PROM serves as an important measure on an individual level, but it is not suitable for comparing health-related quality of care. To evaluate healthcare quality, PROMs should be selected for situations where an association with healthcare quality is plausible or established [26]. Second, adequate adjustment for case-mix correction is needed, as multiple influential factors, such as age, sex, educational level, type of injury, injury severity, frailty, comorbidity and duration of hospital stay, are relevant in predicting health status after injury [27,28].

Ideally, a case-mix model is developed, enabling comparison between observed outcome and preinjury health status [26]. Previous efforts to develop such prediction models in trauma care resulted in models with an explained variance of almost 50 percent [27]. Third, PROMs can be more challenging to obtain than clinical outcomes. Because PROMs can only be observed and registered by the patients themselves, it is more difficult and time-consuming to collect complete data on fixed time points. Moreover, predictors such as education levels, preinjury health status and frailty are generally not routinely assessed in trauma registries.

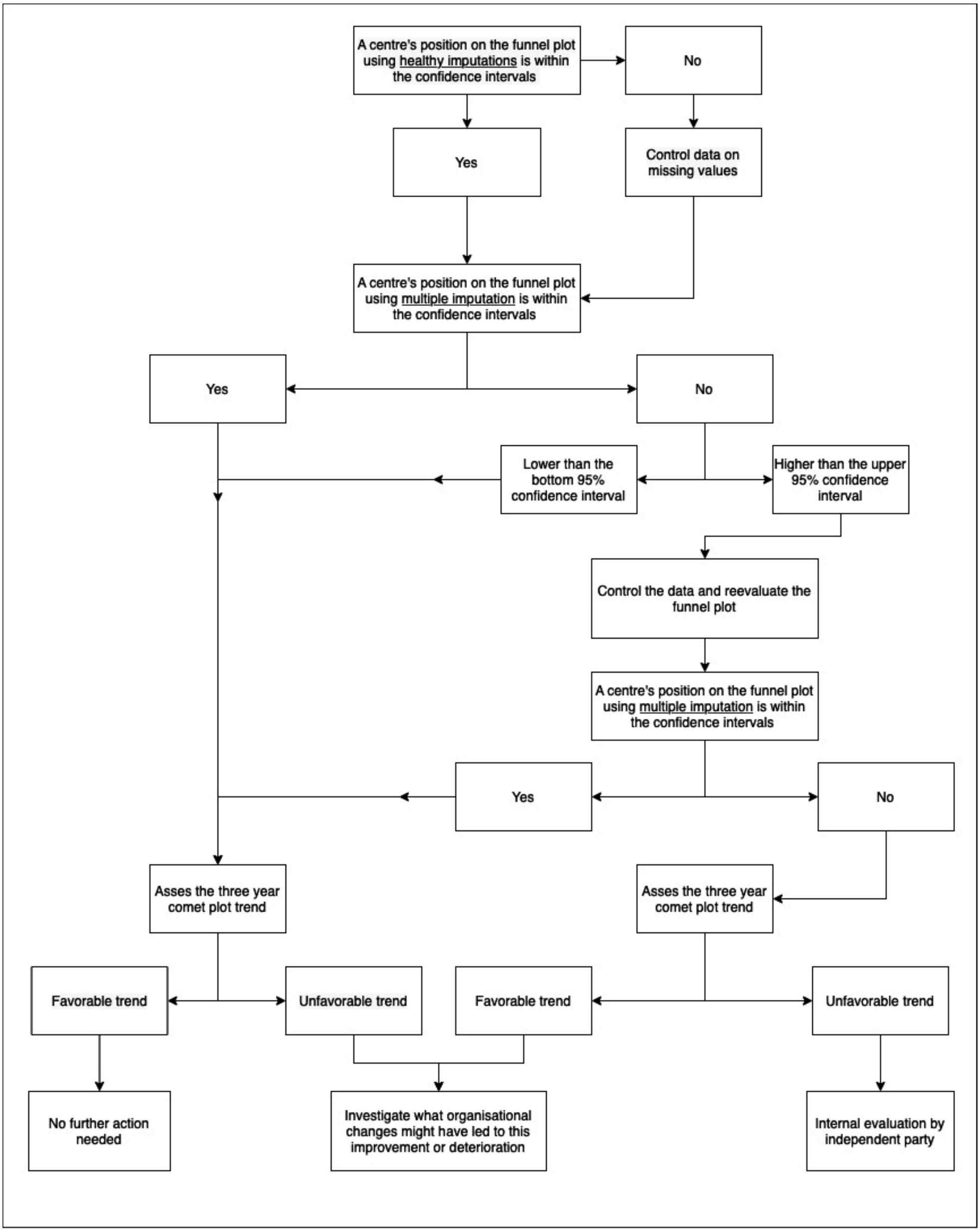

Figure 4. Dutch regulatory flowchart

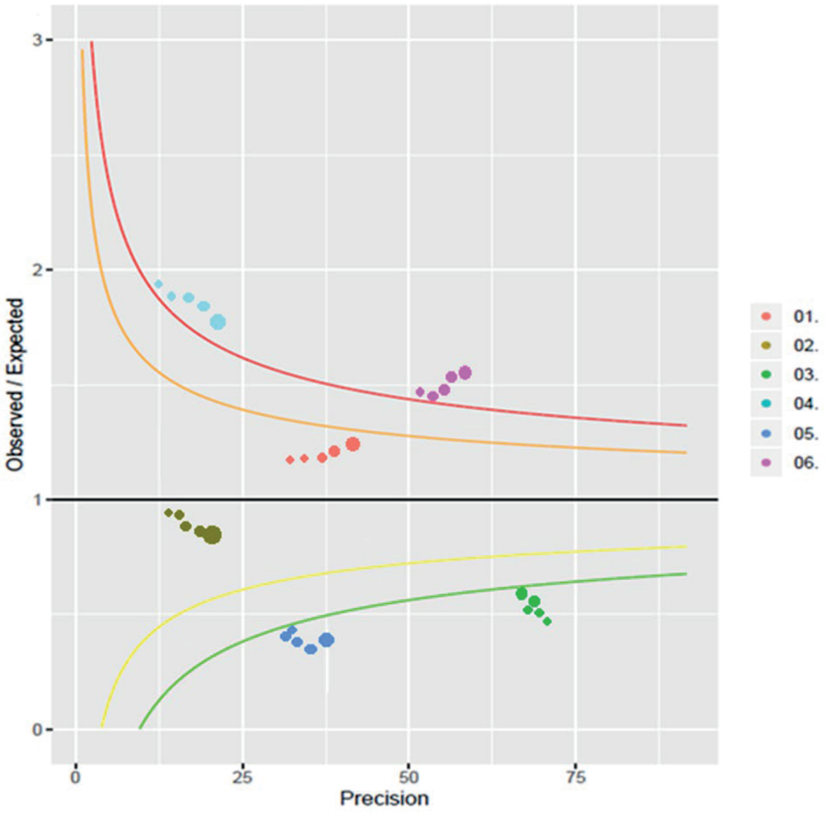

Figure 5. Six possible hospitals' standardized mortality ratio performance trends, based on fictive data. The inner orange and yellow lines are the 95% and the outer red and green lines are the 99.8% confidence intervals.

Strengths and limitations

This study has several strengths. First, we used data from the national trauma registry, which includes detailed data on all acutely admitted trauma patients in all Dutch centres registered by trained data managers [13]. By imputing missing values using "normal" healthy scores, we aimed to increase the quality of our data and avoid the presentation of overly optimistic results by punishing those who failed to deliver complete data. Third, the method of indirect standardization enables centres to reflect on the quality of trauma care given to the population they were designated to treat. This offers the opportunity to directly evaluate initiated improvement strategies. Fourth, to the best of our knowledge, this is the first study that describes regulatory proceedings related to a centre's performance illustrated in a funnel plot using trends over multiple years.

This study also has limitations. Although the model used for case-mix correction has good accuracy, it does slightly overestimate mortality for severely injured individuals, possibly showing a more positive centre performance [21]. Second, because this study presents the initial blueprint of the regulations yet to be fully implemented in the Netherlands, experiences or flaws in the system have not yet been reported. Further evaluations are needed to assess its functionality. Third, lower-level trauma centres with a low number of cases may not observe a trauma related death. The SMR makes their position within the funnel plot more susceptible for volatility. In these particular cases the difference between observed and predicted mortality would be the preferred method to be used. However, further studies are needed to show whether the performance of any centre will be significantly divergent and whether any serious repercussions are needed. Fourth, a more detailed alternative to illustrate individual hospital performance could be achieved with the use of risk-adjusted cumulative sum charts. However, we deliberately chose to use funnel plots because they illustrate the position of an individual centre among other centres. Although centres cannot be compared due to differences in case types, it is of interest to observe a centre's position within the acute care landscape.

Conclusion

This study describes the use of funnel and comet plots as a method to assure high-quality data and to monitor and evaluate trauma centre performance over multiple years. Moreover, this is the first study to provide a regulatory blueprint on how to interpret and act on the under- or overperformance of trauma centres.

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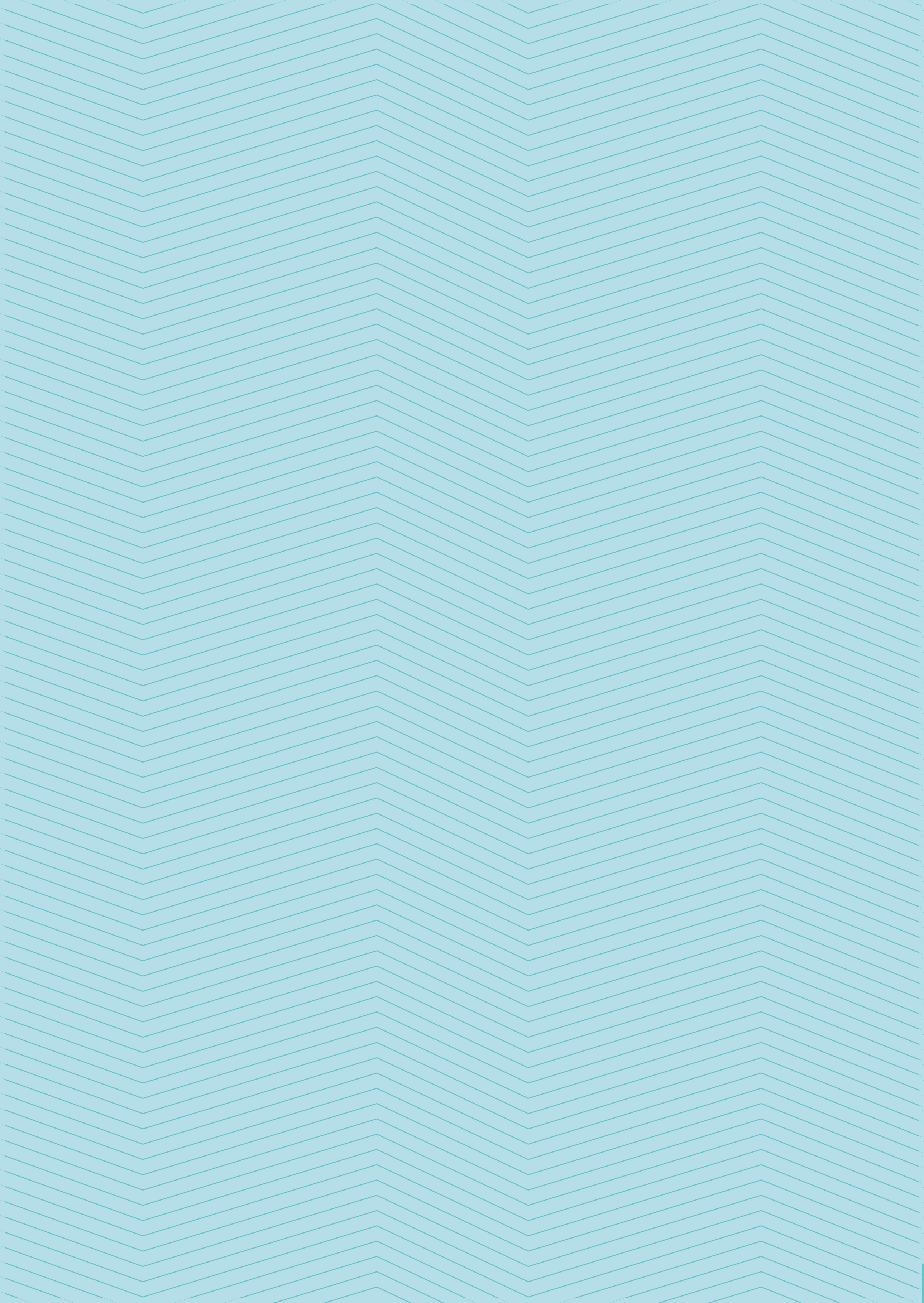

CHAPTER 10

General discussion and future perspectives

Table 1. The study questions and answers in this thesis

CHAPTER	Research question
2	To what degree do Dutch trauma system succeed in centralising the treatment of severely injured patients (ISS > 15) at level-I trauma centres and non-severely injured (ISS 1-15) patients at level-II or III trauma centres? *The rate of severely injured patients that received appropriate specialized care varied between the trauma networks (36.8% – 88.4%). Approximately 79.2% of the non-severely injured patients were treated at level-II or III trauma centres.*
2	Which patient characteristics are associated with emergency medical services undertriage of severely injured patients to a major trauma centre? *Severely injured patients of the female sex, older age, ground-level falls, and severe thoracal or abdominal injuries were associated with undertriage.*
3	What is the added value of registering all acute trauma admissions? *Registering all acutely admitted trauma patients enables the opportunity to assess the total burden of injury and to evaluate the quality and efficiency of the entire trauma system.*
4	Did the SARS-CoV-2 pandemic change the epidemiology of the Dutch trauma population? *The nationwide volume of acute trauma admission was significantly reduced, least affecting the number of hip fracture and severely injured patients.*
4	How have the periods of social lockdown affected the mechanisms of injury? *In response to the imposed social restrictions, the prevalence of sports and traffic-related injuries decreased significantly. However, an increase in the prevalence of self-harm was recorded.*
5	Could access and specialized care for severely injured trauma patients be guaranteed to the same level of trauma care during the pandemic as in the pre-COVID-19 era? *Trauma care could not for all patients be guaranteed to the same level as in the pre-COVID-19 era. In particular at the expense of patients with minor to moderately severe traumatic brain injuries.*
5	To what extend did the COVID-19 induced intensive care pressure affect trauma patient outcomes? *Trauma patients were significantly less frequent admitted to ICU facilities, this has likely resulted in an increased number of deaths for patients with minor to severe traumatic brain injury.*

Table 1. Continued

CHAPTER	Research question
6	How well does the Berlin polytrauma definition (BPD) perform in identifying patients with a high risk of resource use and mortality? *By combining anatomical injury characteristics with physiological risk factors the BPD succeeds to improve the identification of severely injured trauma patients with a high risk of resource use and mortality.*
6	Are physiological risk factors present during emergency department resuscitation indicative of mortality for patients with multiple injuries? *The physiological risk factors: age, Glasgow coma score, systolic blood pressure, base excess and coagulopathy are all associated with an increased risk of death in patients with injuries in multiple body regions.*
7	Are severe isolated injuries entities to be reconned with? *Severe isolated injuries were found to have an equally high mortality rates and medical resources usage as there polytrauma counterparts.*
7	Are physiological risk factors present during emergency department resuscitation indicative of resource use or mortality for patients with severe isolated injuries? *The physiological risk factors age, Glasgow coma score, systolic blood pressure, base excess and coagulopathy are all associated with a higher resource usage and higher risk of death in patients with severe isolated injuries.*
8	Can we develop a prediction model that accurately predicts the mortality of all acutely admitted trauma patients using only widely available variables? *Yes, by using polynomial transformation of existing TRISS variables, replacing Glasgow Coma Scale with best motor response and the addition of the variables gender and ASA score for comorbidities. This prediction model performed well for all eight tested trauma population subgroups.*
9	Can funnel plots be used to evaluate and regulate quality trauma care? *Funnel plots can be used as a method to ensure a high quality of data and combined with comet plots a hospitals' population specific performance trend can be evaluated and regulated.*

CONCLUSIONS AND IMPLICATIONS FOR PRACTICE AND FUTURE PERSPECTIVES

Trauma registries have been established to collect comprehensive data for quality assessment, quality improvement and research purposes. The Dutch Nationwide Trauma Registry (DNTR) forms the cornerstone of the research presented in this thesis.

This thesis was designed based on an alternative version of the ABCDE-methodology used in trauma resuscitation. The primary aims were:

- Assessing the Accuracy of centralizing severely injured patients in the Dutch trauma system
- Benchmarking the all-inclusive regime of the DNTR
- Evaluating trauma care during a medical Catastrophe
- Evaluating and improving Definitions to describe the severely injured patient
- Developing tools to monitor and Evaluate trauma centre performance

The following sections provide an overview of our conclusions, implications of our findings and future perspectives.

PART I: EVALUATION OF THE DUTCH TRAUMA SYSTEM

Our first study assessed the accuracy in which the Dutch trauma systems succeeds in the centralization of the severely injured. This study revealed that even in a highly urbanized country, such as the Netherlands, with good access to emergency care, approximately one third of all severely injured patients end up in a suboptimal hospital. Adequate prehospital trauma triage of patients is imperative for optimal trauma care. In an inclusive trauma system, patients with severe injuries are ideally transported to a level-I trauma centre and patients with minor injuries to a level-II or III hospital.[1,2] The Dutch triage scheme should offer guidance to the emergency medical services, to help define the patients destination. Currently, the Dutch triage scheme correctly identifies approximately one third of the severely injured patients.[3,4] The results of our multivariable regression analysis, revealed that the following patient characteristics are directly related to undertriage of severely injured patients: female sex, older age, ground-level falls, and severe thoracic or abdominal injuries. Moreover, undertriage rate was negatively correlated with longer transport times to a level-I trauma centre. These factors should be accounted for in the development of triage protocols, in order to increase the percentage of severely injured patients that receive primary level-I trauma centre care.

Trauma Registries

The inclusion criteria of trauma registries vary around the world. Clinical experts disagree on which patients should be included. This has precipitated into trauma registries that do not include trauma patients that were not admitted to intensive care facilities, patients with an injury severity score (ISS) below 12, or frail patients admitted with isolated fractures.[5–7] A comparison of three large European national trauma registries showed that the implementation of limited inclusion criteria such as those of the German trauma registry, reduces the total number of recorded trauma patients by 95%. Moreover, 50% of the severely injured patients and 68% of in hospitals deaths are missed. These results show that including all acutely admitted trauma patients gives us the opportunity to assess the total burden of injury and to evaluate the quality and efficacy of the entire trauma system. For the DNTR it was a conscious choice to focus only on those who are acutely admitted. Even though the DNTR serves as an example for other existing and trauma registries to be, one could still argue whether or not trauma patients that receive primary treatment in the emergency department and undergo semi-elective orthopaedic surgery a few days later should also be included. As these patients require a different approach of care and outcome evaluation, they are currently not registered.

The pandemic

The catastrophe inflicted by the SARS-CoV-2 virus hit the world in beginning of 2020. The uncertainty and fear for the spread of this virus led to social, medical and economic derangement of extreme proportions. Yet, it also turned out to be a unique opportunity to evaluate the choices that were made in a time of extreme pressure on the acute care chain. Given the obliged social restriction it is not surprising that, compared with the years prior to the pandemic, the number of acute trauma admissions in the Netherlands was reduced by approximately 20% during the first and 11% during the second infectious wave. Yet, our study showed that the case load of elderly admitted with a hip fracture remained the same. A quite concerning finding was the 41% and 26% increase in the frequency of minor (ISS <16) self-harm-related injuries during the respective first and second infectious waves and a 37% increase in violence-related severe injuries during the summer period when restrictions were partially lifted. Similar behavioral patterns have been registered around the world.[8–15] Implying that in preparation for indefinite periods of social restrictions that may lie ahead, policy-makers need to take precautionary measures to identify and protect those that pose the highest risk of self-harm or domestic abuse. Moreover, it could be wise to at least consider additional funding towards mental health services to meet the growing demand. Another concerning secondary effect that we measured, is the fact that severely injured trauma patients admitted during the COVID-19 peak were 11% less likely to be admitted to an intensive care facility. In particular, patients with minor to moderate traumatic brain injuries did not receive the same level of care as in the pre-pandemic period, which resulted in a 2.5 times higher odds ratio of death. Considering the results of this study recorded during a time of overwhelming pressure on the Dutch intensive care facilities, we believe that close monitoring of these patients at an intermediate care unit could offer some solace.

Findings in this part of this thesis demonstrate the clear benefits of an all-inclusive trauma registry. We were able to analyse the epidemiological changes and some of the secondary effects of the COVID-19 pandemic, which would be nearly impossible without an all-inclusive trauma registry. Due to this research, we are able to be better prepared for future potential crises. We have illustrated the need for improved efforts to get the right patient at the right hospital, making clear suggestions on patients that are vulnerable of undertriage. Comparison of our findings with the currently available literature, shows that contemporary triage tools are ineffective and are outperformed by the clinical judgement of emergency medical services.[4] Healthcare providers and policymakers need to prioritise on the improvement of the prehospital triage of severely injured patients. Their efforts should focus on improving field triage, the awareness of factors that affect undertriaging, interfacility transfer guidelines, and the provision of resources to overcome longer transport times to a level-I trauma centre.

PART II: CHANGING THE BOUNDARIES

Trauma systems were introduced to improve and facilitate cost-effective trauma care. The accuracy of the centralization of severely injured patients is one of the variables used to evaluate trauma system performance. The inadequate performance of the Dutch triage scheme, described in *Part I*, is likely associated with the use of its reference standard. The anatomical ISS is widely implemented and therefore of interest for many. However, it should not be used as a system target. The arbitrary threshold level used to determine whether a patient is severely injured, is usually set at an ISS of 16 or higher. This threshold was adopted following evaluation of mortality rates in the North American Major Trauma Outcome Study in the 1980s.[16] The mortality rate for this patient population used to be 20% or greater.[17] Today, it is considered to be considerably lower and ranges between 9% and 16%.[18,19] The studies presented in this part of the thesis, confirm that contemporary major trauma definitions should be based on the combination of both anatomical injury scores and physiological risk factors. Moreover, such definition should focus on both resource usage and mortality as outcome markers. We illustrated that severe isolated anatomical injuries are equally associated with the chance of death and resource use as those having multiple injuries. Additionally, we confirmed that the physiological factors defined in the Berlin polytrauma definition, i.e. age, Glasgow Come Scale for consciousness, systolic blood pressure, base excess (as a measure for acid-base disturbances) and International Normalized Ratio (as a measure for the time it takes for blood to cloth), are associated with increased risk of mortality.[20] Although, we argue that the high mortality for severe isolated injuries (SII) could be correlated with the level of undertriage in this particular group, which consequently receive suboptimal trauma care. We would still advise to incorporate patients with severe isolated injury in future major trauma definitions and ascribe a higher value to physiological derangements. In our opinion a more optimal major trauma definition combines the criteria described in the Berlin definitions with those for severe isolated injuries. By replacing the ISS of 16 and higher with this new definition, the annual number of patients designated for level-I trauma centre care will be reduced by approximately 20%. Yet, available resources will be used more efficiently, as mortality for this population currently ranges between 27% and 32%. Future evaluation studies are needed to assess whether there was a causal relation between undertriage and high mortality in this particular group of trauma patients.

Outcome

In order to evaluate the quality of delivered trauma care, observed outcome is compared with the predicted outcome. Currently the Trauma and Injury Severity Score (TRISS) method is a well-known standardized method to predict a trauma patients' risk of mortality.[21] Unfortunately previous research revealed also shortcomings.[22] The classic TRISS model showed a high misclassification rate for severely injured patients, and the coefficients were drifting out of calibration when applied to other trauma registries' populations.[23–25] Several factors can cause the loss of predictive power. Plausible reasons are the introduction of trauma systems,[1] medical advancements and the fact that the classic TRISS model was derived from an American trauma population in the late 1980s.[17,26] The lack of power led to the development of multiple new models, that incorporated new or restructured variables.[27] Unfortunately, a lot of these newly developed models were (over)fitted on a specific trauma registry or population. This resulted in a significant loss of predictive power when being cross-validated in another setting.[28] As advocated in part I, worldwide uniformity of inclusion criteria for trauma registries would probably resolve these issues. Because the DNTR is an all-inclusive trauma registry, we were able to develop a statistically optimized TRISS model for all acutely admitted trauma patients. Moreover, as different registries tend to include different variables, we aimed to develop a model that only includes those variables that are easily assessed and are widely available. Because of the previously mentioned strengths the newly developed mTRISS-NL model is seemingly less susceptible to inter-registry differences and is thus transferable to other trauma registries. However, an external validation study is needed to determine its actual performance in another registry. International or intercontinental differences in patient characteristics, injury patterns or prehospital times might change predicted outcomes, leading to a deceivable variance in trauma system performance.

Performance

Historically, league tables are an established technique for displaying the comparative ranking of organizations in terms of their performance. Some data suggest that these rankings generate a stimulus to initiate improvements,[29] however they can also inflict stigmatization on "poor performers" which has a negative effect on public trust and professional morale. The funnel plot methodology has been applied previously in a trauma setting to evaluate and compare mortality and hospital admission data between hospitals.[30,31] However, one of the main goals is to ensure that a hospitals' performance is investigated rather than differences in case-mix.[23] Indirect standardization can be used to overcome problems when comparing hospitals with different injury severity case mixes.[32] But, even after standardization, individual hospitals are not directly comparable because each hospitals' own population is used to calculate the expected outcomes. Moreover, with the use of comet plots the performance trend over multiple years can be assessed. Yet, as demonstrated in our study, a hospitals' position in the funnel plot is highly reluctant to the completeness of data. A significant number of missing values can cause a hospital to be listed as a "poor performer". The regulatory flowchart presented in our study, yet to be implemented in daily practice, is ought to systematically assess, control and improve the quality of DNTR data and trauma care. It will be of interest to see whether organizational changes in for example personnel, appliances or in-hospital rehabilitation will have a directly visual impact on outcomes. The funnel plot methodology is in our opinion an excellent way to evaluate a hospitals true performance for its designated population. Transparency could be a major pitfall, as reporting of both favorable and unfavorable effects will be crucial to increase the overall Dutch trauma system performance.

FUTURE PERSPECTIVES AND RECOMMENDATIONS

After being founded in 2007, the Dutch National Trauma Registry has raised the hospital participation rate to 100% in 2015. Since 2015 the Dutch National Trauma Registry registered over 500,000 acutely admitted trauma patients, averaging 78,726 patients a year. This immense amount of data illustrates the collective effort that is delivered on a daily basis, by data managers, doctors and nurses all across the Netherlands. This thesis proves that the DNTR is of invaluable importance as a tool to monitor and improve the quality of trauma care.

However, it does not stop there. The DNTR offers the unique capability of a signalling and control function for other fields of interest. Over the past few years, the Dutch government has implemented relentless cutbacks in mental healthcare which, as previously described, resulted in an increase in self-inflicted trauma. Moreover, data from the DNTR can be used to assess if the freeway speed limitation leads to less motor vehicle accidents or whether the mandatory use of helmets on an (electric) bicycles leads to less traumatic brain injuries.

Despite the fact that the DNTR has already demonstrated its added value for multiple purposes, further development is required. The DNTR records data from the entire acute care chain, starting at the site of injury until hospital discharge or assessment of the 30-day mortality. However, personal patient data is required in order to follow a patient through the chain (pre-hospital and hospital). Previously, the DNTR data was pseudonymised at a regional level and uploaded in the DNTR database, making it practically impossible to link data from different health care providers to a specific patient. Gladly, new Dutch legislations allow the DNTR to include the required citizen service numbers. This recent development offers new opportunities to present individually collected data on an aggregated level, assess the weaknesses, strengths and make substantiated decisions on the future direction of the acute care chain.

Besides this recent development, there is room for improvement in the efficacy, accessibility and in the methods used to evaluate the Dutch trauma system performance. Future efforts and research endeavours should aim to address the items described in the following paragraphs. These items are intended to improve the quality of the Dutch trauma registry's data and enhance (global) collaborations in order to obtain a higher standard of trauma care.

Enhancing the (future) DNTR

Currently, the percentages of missing values show that there is room for improvement on completeness and consistency of the trauma registry in the Netherlands and registries in general.[18,33] To address these issues in the future, the DNTR and other trauma registries need to transition from labour-intensive and inefficient data entry and strive for more automated techniques based on electronic health record data and other existing platforms. This will reduce the number of missing values, lower the workload and expand datasets.

Enforcing the completeness and reliability of pre-hospital DNTR data can be also be realised by strengthening the collaboration with regional Emergency Medical Services (EMSs,) Mobile Medical Teams and rehabilitation clinics. This collective approach would greatly improve our understanding of the decisions made in a prehospital setting, and their effect on a patient's outcome. This data facilitates improvements in triage protocols and offers the opportunity to initiate EMS feedback loops on whether the patient was transferred to the most appropriate hospital. Most importantly, these developments will lead to better functioning trauma systems and less secondary transport. This will eventually lead to improved patient outcomes and more cost-effective trauma care.

Another suggestion is to include a new set of biochemical markers. Because trauma diagnostics, and especially prognostics, are becoming less reliant on clinical information and several haematological and biochemical markers have been associated with injuries and worsening outcomes after trauma.[34,35] For example, prehospital lactate measurement can indicate the need for immediate interventions for correcting haemostasis.[36] Lastly, data obtained from laboratory results is less influenced by subjective assessments of vital signs, which are less reliable in case of intubation, sedation, or intoxication. Structural testing of predefined laboratory diagnostics sets for different trauma patient subpopulations could increase the understanding of the physiological changes that occur after trauma, which in turn could serve as the cornerstone in optimizing patient resuscitation and consequently their outcome.

Our final suggestion concerns the implementation of a quantitative outcome measure. Although mortality serves as the primary performance indicator throughout this thesis, approximately 97% of the patients registered in the DNTR have a non-fatal outcome.[18] Recent studies have shown that trauma patients are significantly impaired on mobility, self-care and pain up to one year after trauma.[37–40] Moreover, two years after injury only 23% of the severely injured patients returned to their pre-injury level of function and 70% resumed prior employment status.[41,42] As a result, the socio-economic impact of trauma due to health care dependence and a partial or complete inability to work is extremely high.[43] Identifying prognostic factors associated with return to work or decreased health-related quality of life (HRQOL) after injury is crucial for quality of care provided to trauma patients. Previous research showed that comorbidities, lower educational level, a lower pre-injury health status, higher ISS and brain, spine or extremity injuries are associated with lower post-injury reported HRQOL.[44–46] Moreover, return to work is associated with an increase in the patient reported scores in every HRQOL domain.[40] Functional outcome assessment is becoming more and more important in the evaluation of trauma care. The EuroQoL-

5D is predominantly used as an instrument to measure HRQOL in the previous studies. The standardized addition of this patient reported outcome measures to all DNTR patients will generate valuable data for the evaluation and optimization of future trauma care. Considering the amount of work involved in this implementation, the DNTR should define certain patient subgroups of interest. A suggestion would be to start with patients that have a high socio-economic impact, for example those of working age (18-60 years) admitted with a lower extremity injury or a traumatic brain injury. Besides generating insight in the morbidity of these injuries, level II and III hospitals can monitor and evaluate their provided care by comparison with the reference standard, visualised with the use of funnel and comet plots.

The acute care system

Several weaknesses in the healthcare system discovered during the pandemic need to be analysed and acted upon. During the first pandemic phase, ICU resource scarcity in the Netherlands was not solely caused by the relentless demand. Capacity expansion was limited by shortages in workforce, but also in equipment such as mechanical ventilators and protective materials. Moreover, the restrictions in outpatient clinic consultations, the downfall of operative procedures and the lack of catch-up, suggests that SARS-CoV-2 has claimed secondary victims.[47,48] Now, that we know more about the resources needed to cope with a pandemic, we should act upon it and ensure an equipoise distribution of care facing similar challenges going forward.

Regaining a balanced environment for medical professionals needs to be the top priority. However, the current shortages in medical personnel and the recovering economy will lead to an even greater demand in the job market. Recruitment of trainees and retaining existing personnel will not be sufficient to ensure optimal care for everyone, let alone when a pandemic breaks loose. The acute care system needs to be reorganised in a more efficient manner. The following paragraphs contain examples and suggestions on how to do that.

The unintended redistribution of patients with minor to moderate brain injuries to relief the pressure on the ICU had a disastrous effect. In retrospect, these patients would have benefited from ICU care. One of the lessons learned is that the further utilization of intermediate care units (IMCU) could have prevented a substantial number of deaths. The IMCU expands the possibilities of providing critical care for severely ill patients. Providing a safe and cost-effective layer between the ward and the ICU. Previous research shows that IMCUs provide the tools for the identification of patients at risk of rapid deterioration, and facilitating timely transfer to the next level of care.[49] Adequate usage of IMCUs during the first SARS-CoV-2 surge could have prevented the deaths of patients with minor to moderate brain injuries.

An excellent example of proper redistribution of care was initiated during the SARS-CoV-2 pandemic. Oxygen dependent hospital admitted patients recovering from COVID-19 were released to receive respiratory support at their own home, supported by home care services and general practitioners. Another option is optimizing the efficiency of medical care. An analysis of the effects on outcomes inflicted by the forced reduction of approximately 450.000 surgical treatments during the pandemic might reveal certain patient subgroups that were previously being overtreated. We would suggest to perform a nationwide collaborative study with multiple population-based Dutch registries to identify patients whose outcome was not significantly affected without or after delayed treatment. Moreover, making more conscious choices on who to operate could lower patient volumes. The frail hip study serves as an example. This Dutch study showed that non-operative treatment can be a viable option for frail institutionalized patients with limited life expectancy.[50]

Furthermore, investing in innovative technologies that optimize the efficiency of medical care can make all the difference in maintaining acute care available in the near future. According to a recent report by Gupta Strategist,[47] an independent consultancy for organizations in the healthcare sector, optimal implementation of new medical technologies can reduce the total healthcare provider time with the equivalent of 110,000 employees. However, significant investments and high patient volumes are required to fully utilize the implementation of these innovative infrastructures.

Even though some of these initiatives are promising they are unlikely to fully resolve the medical workforce shortages. The government will have to take their directive role in this matter, showing their appreciation and make working in healthcare more attractive.

Regionalization

There is an ongoing discussion regarding the number of level-I trauma centres that are needed in the Netherlands. In regard to further centralization of trauma care in the Netherlands, we need to evaluate three interacting elements that affect outcome. These elements are prehospital transport times, costs and patient volumes. Studies on prehospital transport times conclude that with an exception for patients with severe traumatic brain injuries or shock that require critical intervention, there is no association between increased prehospital time (≥60 min) and increased mortality.[51–54] The current status of the Dutch infrastructure and distribution of trauma centres enables the opportunity of offering specialized level-I trauma care within a 1-hour proximity, with a small exception for the northern Wadden Islands. Level-I trauma centres are required participate in residency training, conduct trauma research and staff more specialized personnel with better access to technological resources.[55] These organisational advantages come at a significantly higher cost in level-I centres, which may be problematic in the current healthcare environment with the ever-increasing economic pressures. It is therefore of utmost importance for level-I centres to demonstrate that they provide better trauma care than the level-II centres. In current literature, supporting evidence for this advantage mainly originates from studies conducted in the United States, and many of these studies have significant limitations.[56] These studies suggest that very severely injured patients with an ISS of ≥25 or patient with specific severe injuries such as cardiac, vascular, liver and traumatic brain injuries treated at level-I trauma centres have significantly lower mortality rates, better functional outcomes and a shorter length of stay.[57]

It is difficult to assess whether any of the structural differences or differences in volumes between level-I and II trauma centres account for the observed differences in outcomes. Among the criteria for level-I trauma centre designation is the required volume of treating over 240 ISS ≥16 patients per year. This is the minimum volume that is believed to be adequate to support the education and research requirements of a level-I trauma centre. Currently approximately 71% of the Dutch patients with an ISS of ≥16 receive level-I trauma care, while level-I trauma centre volumes vary between approximately 76 and 452 patients a year.[58–60] Although a volume-outcomes association has been demonstrated for certain high-risk oncological operations,[61] an inverse relationship between higher volume and lower mortality rates for trauma patients remains unclear. [62–64]

Concluding, the 24 hours a day operating room availability, in-house surgical intensive care unit combined with a trauma-, neuro and cardio-thoracic surgeon might play a greater role in survival than (ISS ≥16) patient volumes. Since studies from other countries, that receive higher number of severely injured patients remain inconclusive.[65] We should question ourselves whether raising the volume cut-off is needed to improve patients' survival or functional outcomes. Moreover, it is seemingly more important to is specify and get those specific subgroups of severely injured patients with a high risk of mortality to the most appropriate hospital, rather than generating higher volumes of ISS ≥16 patients. A strategic reduction of trauma centres could be helpful to reduce costs, while the consequent increase in overall prehospital transport times will likely not have a significant impact on mortality. However, a costs reduction should not be the primary aim. Although, optimizing trauma care for the most severely injured is a noble cause, we should not forget that this only concerns approximately 6% of the acutely admitted trauma population in the Netherlands. We believe, there is much to be accomplished in the care for the 70.000 patients with minor to moderately severe injuries, primarily treated at level-II and III centres. Mortality might be lower for this group, yet the impact on quality of life due to (lifelong) morbidity is a factor that cannot be ignored. Due to the volumes, minor changes in the optimalization of regional collaboration or rehabilitation processes can have a huge impact.

Universal criteria

Registry studies are more and more relevant for evaluating trauma care. However, reports and scientific publications from these registries lack standardization and show a great deal of variation. The purposes of a trauma registry are 1) to enable analysis of all phases of trauma care, from prehospital care to rehabilitation; 2) to evaluate morbidity and mortality; and 3) clinical and epidemiologic surveillance.[66] To reach these goals, both contemporary national norms and population-based studies are necessary. Supported by multiple studies,[67–69] the results presented in this thesis underline the importance of registries to record accurate, uniform, and complete data on the entire trauma population and continuum of care. This includes prehospital triage and resuscitation, rehabilitation outcomes, and long-term quality of life.[67] Developing a comprehensive international guideline for trauma registries enables adequate standardized reporting of trauma patient and injury characteristics. Such guideline would be a major step towards standardized trauma registry research and international comparison studies, which would be extremely helpful in a global effort to optimize prehospital triage protocols and improve both survival and functional outcomes after trauma.

Implementation of a registry is both expensive and time consuming. Consequently, it is understandable that focusing only on the severely injured or those who were admitted to intensive care facilities might seem more alluring. Yet, one should keep in mind that trauma does not only impact the lives of the 5% of patients with severe injuries. In the Netherlands approximately 25% of the registered concern patients with a hip fracture. Despite improved operative techniques and rehabilitation protocols for patients with a hip fracture, the 1-year mortality of almost 20% shows only a marginal decrease over time.[70] These mostly elderly patients differ from the younger: they can incur life-threatening injuries from low-energy mechanisms, they have a higher prevalence of comorbid conditions and they more often take medications that mask the already different physiological responses to injury.[71] These factors are likely associated with the undertriage rate of elderly trauma patients and consequently to higher rates of mortality, disability and complications.[72] Considering the growing number of elderly in our society combined with the increasing interest in HRQOL after trauma underlines the need for all-inclusive trauma registries and the exploration new outcome variables.

Severely injured

As described in this thesis the definition of a severely injured patient in need of specialized trauma care is another sensitive subject, which is no way near consensus.[20,74] Current practices to identify severely injured patients tend to focus mainly on the presence of multiple anatomical injuries.[20,74] Supported by evidential data presented in this thesis, we want to state that a severe isolated injury poses an equal treat to life, and requires a substantial amount of medical resources compared to those with multiple injuries. Therefore, we strongly suggest to move away from the outdated dogma that a major trauma patient is a polytrauma patient. Consequently, we believe that particularly in the prehospital setting, the presence of physiological abnormalities after trauma are far more valuable indication whether the patient requires specialized trauma care, than estimating if the ISS could be 16 or higher.

Conclusion

This thesis presented clinical research on the evaluation and optimization of trauma system performance conducted between 2019 and 2022. The all-inclusive trauma registry proved its inestimable importance, as a pandemic was evaluated, new definitions were proposed and tools were revised. Yet, the implementation of these findings and enforcing compliance will be the next major challenge moving forward.

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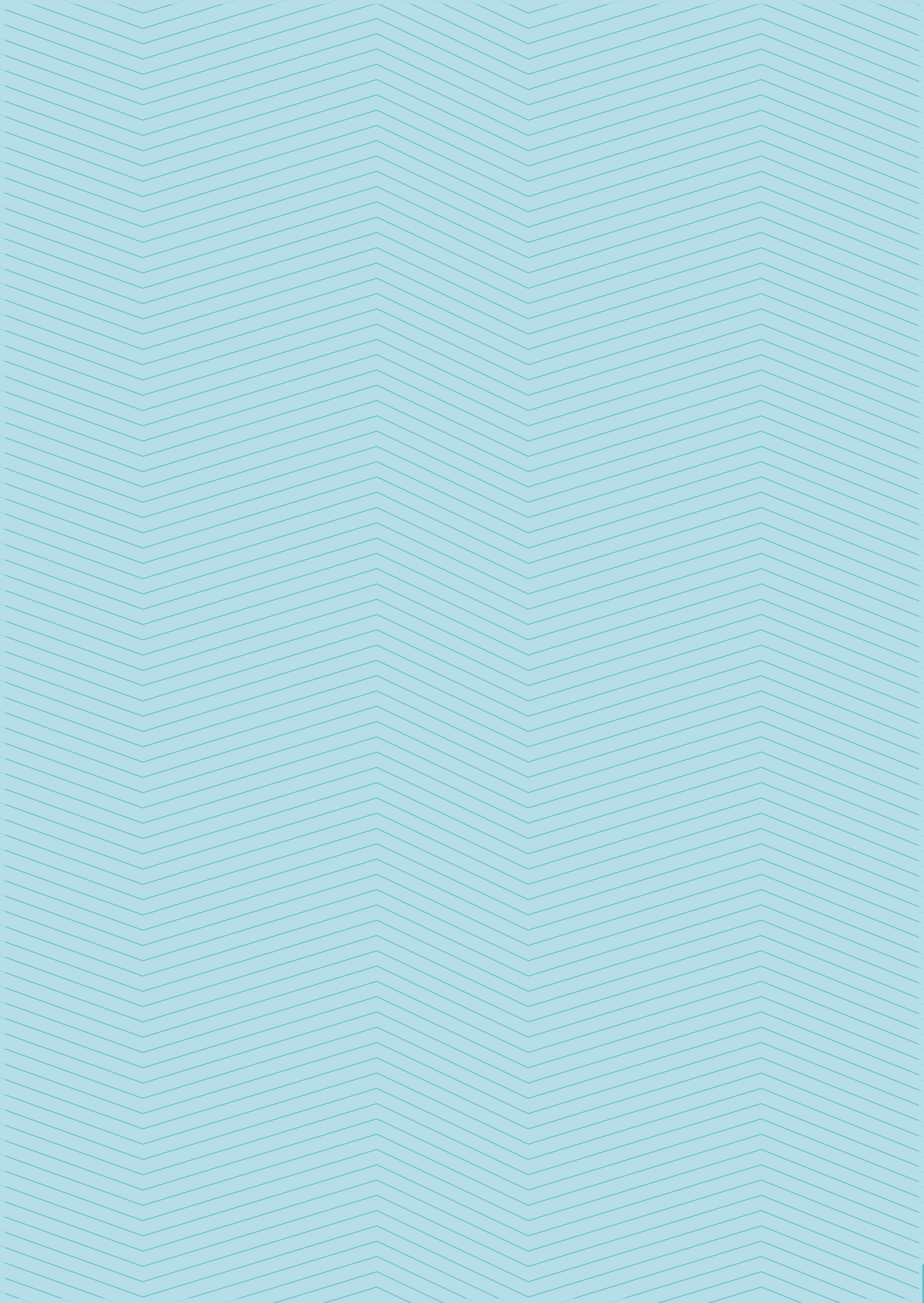


CHAPTER 11

Summary in Dutch (Samenvatting in het Nederlands)

Traumaregistraties zijn opgezet om gegevens te verzamelen over epidemiologische kenmerken en mogelijke veranderingen daarin waar te nemen, met als doel de kwaliteit van zorg te beoordelen, vergelijken en te verbeteren. De Nederlandse Trauma Registratie vormt de hoeksteen van het onderzoek dat in dit proefschrift wordt gepresenteerd. De opbouw van dit proefschrift is geïnspireerd op de bekende ABCDE-methodologie, gebruikt bij een trauma opvang, op de Spoed Eisende Hulp, volgens het Advanced Trauma Life Support (ATLS) principe. De belangrijkste doelstellingen van het onderzoek in dit proefschrift zijn:

- Het beoordelen van de nauwkeurigheid (Accuracy) waarmee ernstig gewonde patiënten in het Nederlandse traumasysteem getrieerd worden
- Het op internationale schaal vergelijken (Benchmarking) van de inclusiecriteria gebruikt in de Nederlandse trauma registratie
- Het evalueren van traumazorg tijdens een maatschappelijke ramp (Catastrophe);
- Het evalueren en zo nodig door ontwikkelen van definities (Definitions) die gebruikt worden om “de ernstig gewonde patiënt” te beschrijven
- Het ontwikkelen van nieuwe instrumenten om de kwaliteit van trauma zorg op ziekenhuisniveau te monitoren en te evalueren (Evaluation)

De volgende paragrafen geven een overzicht van de conclusies en de implicaties van onze bevindingen.

Trauma Registraties

Het onderzoek in **Hoofdstuk I**, evalueert de nauwkeurigheid waarmee ernstig gewonden patiënten in Nederland getrieerd en behandeld worden in één van de gespecialiseerde level-I traumacentra. Binnen een goed functionerend traumasysteem is het essentieel om patiënten met ernstig letsel naar een level-I centrum en patiënten zonder ernstig letsel naar ziekenhuizen van level-II of III te vervoeren. Dit is essentieel omdat level-I trauma volledig zijn uitgerust om de meest gespecialiseerde spoedeisende en chirurgische zorg te leveren met 24/7 dekking van alle specialismen, inclusief thoracale en neurochirurgie. Uit dit onderzoek bleek dat zelfs in een sterk verstedelijkt land met goede toegang tot acute zorg, ongeveer twee derde van alle ernstig gewonde patiënten naar een level-I traumacentrum wordt vervoerd. Momenteel is het Nederlandse triageprotocol in staat om ongeveer een derde van de ernstig gewonde patiënten correct te identificeren. Dit betekent dat de inschatting van het ambulancepersoneel momenteel beter is dan die van het triageprotocol. De resultaten van onze multivariabele regressieanalyse lieten zien dat er specifieke patiënt- of ongevalskenmerken direct gerelateerd zijn aan ondertriage. Zo wordt de ernst van letsel bij vrouwen, patiënten van oudere leeftijd, letsel ontstaan uit een val uit stand of van lage hoogte en verwondingen aan de borstkas of de buik vaker onderschat. Ondertriage houdt in dat de letselernst te laag wordt ingeschat, waardoor patiënten bijvoorbeeld naar een level-II of III ziekenhuis gaan in plaats van naar een level-I traumacentrum waar ten alle tijden alle faciliteiten en zorgverleners aanwezig zijn om een ernstig gewonde patiënt op te vangen. Bovendien was het percentage ondertriage negatief gecorreleerd met langere transporttijden naar een gespecialiseerd traumacentrum. Dit betekent dat in het geval van ondertriage het level-I traumacentrum dichterbij was. Met deze factoren moet rekening worden gehouden bij de ontwikkeling van nieuwe triageprotocollen. Om op deze manier het percentage ernstig gewonde patiënten dat de benodigde gespecialiseerde trauma zorg ook daadwerkelijk ontvangt te verhogen. Daarbij zal het verhogen van de aantallen ernstig gewonde patiënten die worden behandeld in een gespecialiseerd traumacentra resulteren in betere uitkomsten voor deze patiënten en leiden tot meer kosteneffectieve zorg.

Er is wereldwijd een enorme variatie in de inclusiecriteria van traumaregistraties. Experts zijn het niet eens over welke patiënten moeten worden geregistreerd. Dit heeft ertoe geleid dat er traumaregistraties zijn waarin enkel patiënten die zijn opgenomen op een intensive-careafdeling of enkel patiënten met een letsel score (ISS) hoger dan 12 worden geregistreerd. De Injury Severity Score (ISS) geeft op basis van anatomische letselkenmerken een score aan de totale letselernst per patiënt. Een letsel score van 16 of hoger wordt wereldwijd als drempelwaarde voor patiënten met een hoog overlijdensrisico gehanteerd. In Nederland worden alle patiënten die binnen 48 uur na een ongeval ter behandeling van het opgelopen letsel moeten worden opgenomen in het ziekenhuis geregistreerd. In **Hoofdstuk II** hebben we de patiëntenpopulatie die geregistreerd is in de Nederlandse trauma registratie vergeleken met de populaties uit de Engelse en Duitse traumaregistratie. Hieruit kwam naar voren dat als we de beperkte inclusie van bijvoorbeeld het Duitse traumaregistratie zouden gebruiken voor de Nederlandse registratie dit het totaal aantal geregistreerde traumapatiënten met 95% reduceert. Bovendien zouden hierdoor 50% van de ernstig gewonde patiënten en 68% van de patiënten die in het ziekenhuis komen te overlijden worden gemist. Deze resultaten laten zien dat het registreren van alle acuut opgenomen traumapatiënten de mogelijkheid biedt om de totale letsellast in kaart te brengen en daarbij de kwaliteit en efficiëntie van het gehele traumasysteem te evalueren.

De pandemie

Het SARS-CoV-2-virus, trof de wereld in het eerste kwartaal van 2020. De onzekerheid en de angst voor de verdere verspreiding van dit virus leidde tot sociale, medische en economische ontregeling van extreme proporties. Toch bood deze pandemie ons ook een unieke kans om de primaire en secundaire effecten van de gemaakte keuzes in een tijd van extreme druk op de acute zorgketen te evalueren. Dit vormde dan ook het doel van de studies in **Hoofdstuk III** en **IV.** Gezien de ingestelde sociale en maatschappelijke beperkingen is het niet verwonderlijk dat in vergelijking met de jaren voorafgaand aan de pandemie het aantal ongevallen is afgenomen. Zo nam het aantal acute trauma-opnames in Nederland met circa 20% af tijdens de eerste en 11% tijdens de tweede golf. Deze afname gold niet voor alle patiëntengroepen. Uit ons onderzoek naar voren dat het aantal ouderen dat werd opgenomen met een heupfractuur relatief gelijk bleef. Een verontrustende bevinding was de toename van respectievelijk 41% en 26% in de frequentie van matig ernstige zelfverwondingen (ISS ≥16) tijdens de eerste en tweede golf. Daarnaast zagen we een toename van 37% in het aantal geweld gerelateerde ernstige verwondingen ten tijde van de versoepelde maatregelen in de zomer van 2020. Soortgelijke patronen zijn over de hele wereld geregistreerd. Voor landelijke beleidsmakers zijn dit belangrijke gegevens als toekomstige problemen wederom vragen om beperkende sociale maatregelen. Het is raadzaam om in dit of dat geval voorzorgsmaatregelen te nemen en degenen te identificeren en te beschermen die het grootste risico op zelfbeschadiging of huiselijk geweld lopen. Bovendien is het wenselijk om aanvullende financiering voor geestelijke gezondheidszorg te verstrekken om aan de stijgende vraag te voldoen.

Een andere zorgwekkende bevinding beschreven in **Hoofstuk IV**, is het feit dat ernstig gewonde traumapatiënten tijdens de eerste COVID-19 golf minder frequent op een intensive care afdeling werden opgenomen. Vooral ernstig gewonde patiënten met licht tot matig traumatisch hersenletsel ontvingen niet dezelfde zorg als in de pre-pandemische periode. Dit heeft voor deze specifieke groep patiënten mogelijk geresulteerd in een 2,5 keer hogere kans op overlijden.

De ernstig gewonde patiënt

Het Nederlandse traumasysteem werd geïntroduceerd om kosteneffectieve en betere traumazorg mogelijk te maken. De mate waarin we er in slagen de juiste patiënt op de juiste plek te krijgen is één van de manieren om de prestaties van het traumasysteem te evalueren. De gebreken van het Nederlandse triageprotocol hangen waarschijnlijk samen met het gebruik van de referentiestandaard. Hoewel de letsel score van 16 of hoger breed wordt toegepast zou het niet als een zichzelf staand doel moeten worden gebruikt. Nieuwe initiatieven voor definities, zoals de Berlijn Polytrauma definitie, bevatten naast anatomische letselkenmerken ook fysiologische risicofactoren. Door het combineren van anatomische en fysiologische kenmerken wordt beoogd een meer specifieke patiëntengroep met een grotere zorgvraag en hoger risico op overlijden te identificeren.

De studies in **Hoofstuk V** en **VI** van dit proefschrift, bevestigen dat hedendaagse definities gebaseerd moeten zijn op de combinatie van zowel anatomische letselscores als fysiologische risicofactoren. Bovendien zou een dergelijke definitie zich naast de kans op overlijden ook moeten concentreren op de medische zorgvraag van de patiënt. Waar de Berlijn Polytrauma definitie zich uitsluitend toelegt op patiënten met meervoudige letsels, hebben we in **Hoofstuk VI** aangetoond dat geïsoleerde verwondingen een even sterke associatie met zowel een hoge medische zorgvraag als een hoge kans op overlijden hebben. Verder bevestigden we dat fysiologische kenmerken zoals leeftijd, de Glasgow Coma Scale als maat voor bewustzijn, de systolische bloeddruk, base-exces als maat voor verstoringen in de zuur-base huishouding en de International Normalised Ratio (INR) als maat voor de tijd die nodig is voor bloed om te stollen, geassocieerd zijn met een verhoogd risico op overlijden. We veronderstellen dat de hoge mortaliteit voor ernstige geïsoleerde verwondingen mogelijk gecorreleerd zou kunnen zijn aan de ondertriage van deze groep, die daardoor suboptimale traumazorg hebben verkregen. We bepleiten daarom patiëntenmet ernstig geïsoleerd letsel op te nemen in toekomstige definities. Op deze manier kunnen we verzekeren dat deze patiënten optimale zorg krijgen en toekomstige evaluatiestudies de kans geven om de kwaliteit van zorg voor deze groep opnieuw in kaart te brengen en te beoordelen of er een causaal verband was tussen ondertriage en de hoge mortaliteit.

Uitkomsten voorspellen

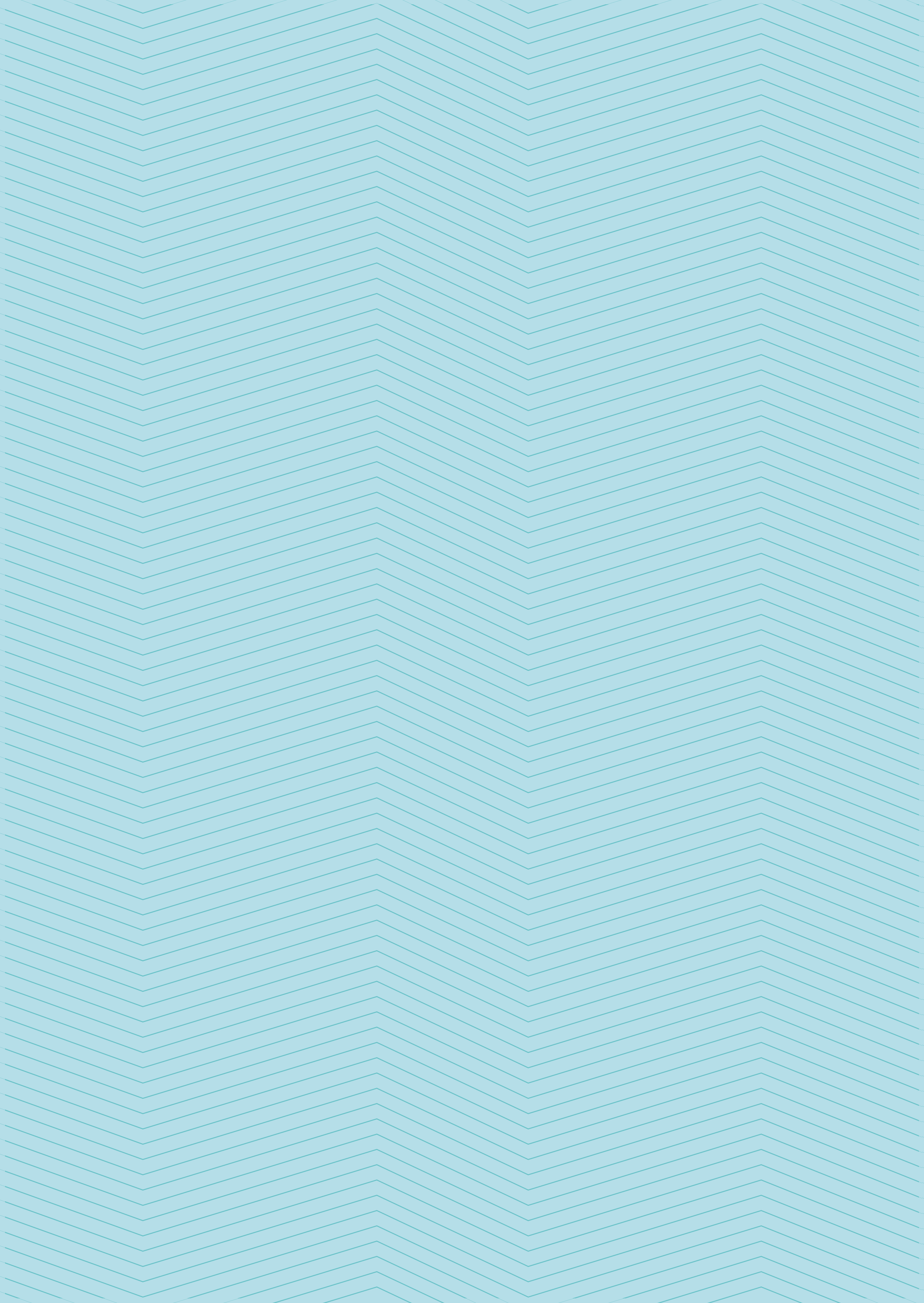
Om de kwaliteit van geleverde traumazorg te evalueren, wordt een voorspelling van de kans op overlijden vergeleken met de het daadwerkelijk aantal overleden patiënten. Momenteel is de Trauma Injury Severity Score (TRISS)-methode een bekende gestandaardiseerde methode om het risico op overlijden van een traumapatiënt te voorspellen. Dit predictie model uit de jaren tachtig zou ons in staat kunnen stellen de prestaties van traumacentra op nationaal en internationaal niveau te vergelijken. Na ruim 30 jaar is er echter nog geen internationale richtlijn om vergelijkende studies tussen internationale instellingen uit te voeren. Wellicht omdat meerdere studies tekortkomingen van het TRISS-model aan het licht brachten. Zo laat het TRISS-model een hoog percentage misclassificaties zien voor ernstig gewonde patiënten, en werden de voorspellingen minder accuraat wanneer ze werden toegepast op de populaties van andere traumaregistraties. Deze gebreken luidden de ontwikkeling van meerdere nieuwe modellen in, welke veelal nieuwe of herstructureerde variabelen incorporeerden. Helaas waren veel van deze nieuw ontwikkelde modellen voornamelijk geschikt voor de specifieke patiëntengroep waarop deze ontwikkeld was. Dit resulteert in een minder accurate voorspelling van de mortaliteit wanneer het model in een andere traumapopulatie werd toegepast. Zoals bepleit in **Hoofstuk II**, zou wereldwijde uniformiteit van inclusiecriteria voor traumaregistraties deze problemen waarschijnlijk verhelpen. Omdat de LTR een zogenaamde “all-inclusive” traumaregistratie is, hebben we een TRISS-model kunnen ontwikkelen dat de mortaliteit van alle acuut opgenomen traumapatiënten nauwkeurig voorspelt. Om het model zo breed mogelijk toepasbaar te maken, beoogden we een model te ontwikkelen dat enkel en alleen variabelen bevat die gemakkelijk kunnen worden bepaald en mede daardoor bij de meeste registraties algemeen beschikbaar zijn. Vanwege deze punten is het nieuw ontwikkelde mTRISS-NL-model minder gevoelig voor verschillen tussen traumaregistraties en daarmee ook toepasbaar in traumaregistraties uit andere landen. Er is echter een externe validatiestudie nodig om de werkelijke prestaties in een andere traumaregistratie te bepalen.

Prestaties

Historisch gezien zijn ranglijsten een gevestigde methode om de prestaties van organisaties weer te geven. Sommige studies suggereren dat deze ranglijsten een stimulans vormen om verbeteringen in gang te zetten, maar ze kunnen ook leiden tot stigmatisering van 'slechte presteerders', wat een negatief effect heeft op het vertrouwen van de patiënt en het professionele moreel.

Wij zijn van mening dat de prestaties van een individueel ziekenhuis voor haar aangewezen traumapopulatie, en het beoordelen van de trend over meerdere jaren, veel interessanter zijn. De funnel plot methode ofwel trechterplots in het Nederlands, biedt deze mogelijkheid. Funnel plots zijn een grafisch hulpmiddel om vergelijkingen weer te geven, zonder dat de centra worden geordend of gerangschikt. Bovendien visualiseren ze duidelijk de relatie tussen steekproefomvang en precisie: de betrouwbaarheidsintervallen en de spreiding worden kleiner naarmate het volume groter is. De betrouwbaarheidsintervallen geven een bereik aan waarbinnen de waarden van de kwaliteitsindicator naar verwachting zouden moeten vallen.

Gebruik makend van het m-TRISS-NL predictie model uit **Hoofstuk VII** zijn we in staat accuraat de verwachte mortaliteit voor een ziekenhuis specifieke populatie te berekenen. De ratio tussen deze voorspelde mortaliteit en de geobserveerde mortaliteit wordt als de Standarized Mortality Ratio (SMR) in de funnel plot uitgezet. In het geval dat een centra deze betrouwbaarheidsintervallen overschrijdt, kan dit worden beschouwd als een ondermaatse of juist als een buitengewoon goede prestatie, in beide gevallen kan dit een aanleiding zijn tot een onderzoek naar deze centra. Naast deze controlerende functie, kan de kwaliteit worden verbeterd door te leren van goed presterende centra of door zelf verbeterstrategieën te initiëren. In **Hoofstuk VIII** wordt aan de hand van enkele voorbeelden de toepassing en controle van funnel plots in Nederland beschreven. De kometen staart geeft de prestatie trend weer, die kan ondersteunen bij het meten van de kwaliteitseffecten van bijvoorbeeld een lokaal initiatief of om van elkaar te leren. Naleving van het gepresenteerde stroomdiagram ten behoeve van het gebruik van de funnel plots in Nederland beoogt zowel de kwaliteit van data als de kwaliteit van zorg in de toekomst te verbeteren.



APPENDICES

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List of publications

Acknowledgements (Dankwoord)

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LIST OF PUBLICATIONS

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Driessen MLS, Sturms LM, Bloemers FW, ten Duis HJ, Edwards MJR, den Hartog D, de Jongh MAC, Leenhouts PA, Poeze M, Schipper IB, et al. The Dutch nationwide trauma registry: The value of capturing all acute trauma admissions. *Injury*. 2020;Nov(11)(51):2553-2559. DOI: 10.1016/j.injury.2020.08.013.

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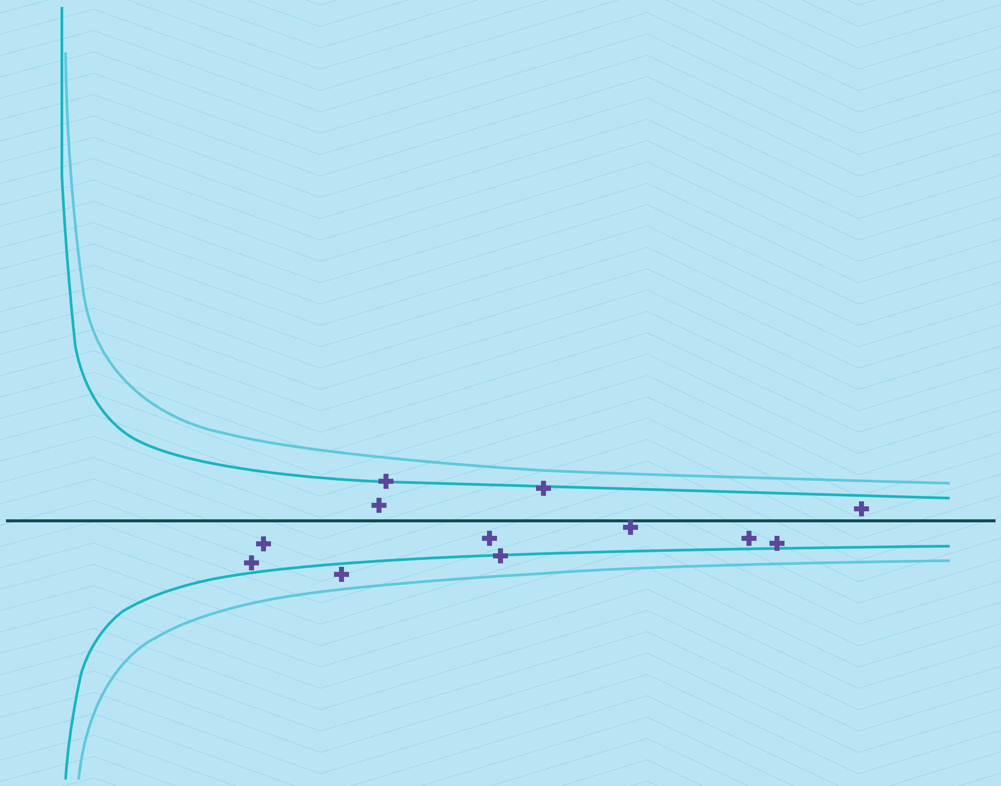
CURRICULUM VITAE

Mitchell Driessen was born on June 11th, 1990 in in Geleen, the Netherlands. He grew up as an only child. Although, he set his first steps in Elsloo, close to his grandparents, he spent most of his childhood and teens living in Sittard. Where in 2009 he graduated from the Trevianum college. During his college years, he was active on the soccer pitch and at the local Albert Heijn.

He left Sittard to study biomedical sciences at the Radboud university in Nijmegen, but switched to medical school in 2010. After finishing his bachelor's degree, he decided to go on a 3-month, medical internship in Kumasi, Ghana. During his fourth year he decided to do a research internship in the orthopedics department. Although, this led to his first scientific publication, his field of interest shifted to the department of surgery. After working on a systematic review on radiographic imaging techniques for monitoring esophageal cancer, he started building a database of patients with calcaneal fractures. The latter has evolved in a multicenter research group, currently working on multiple projects, including a randomized controlled trial. Besides clinical rotations and scientific research, Mitchell was either working at Albert Heijn Daalseweg, in Nijmegen, or providing first aid at music festivals for Event Medical Services. He concluded medical school in Leon, Nicaragua, where he completed his final rotation in the department of surgery.

After working as a surgical resident not in training at Gelre Hospital in Apeldoorn, Mitchell joined the Dutch Network for Emergency Care and started working on this thesis, under the supervision of Prof. Dr. L.P.H. Leenen. In September 2022 Mitchell started working as a resident not in training at Elisabeth Two Cities hospital in Tilburg. He is currently still pursuing a career in surgery combined with continuation of scientific research in the field of trauma surgery.



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