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REVIEW AND PREDICTION OF TRAUMA MORTALITY

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Review and prediction of trauma mortality

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To my son, Caspian

ABSTRACT

Quality management principles stipulate that outcome after injury is dependent upon patient factors, injury severity, structures and processes of care in a trauma system. Structures refers to the context in which care is delivered, including material resources, equipment and competence of involved personnel. Processes refers to what is literally done by the personnel involved in patient care. In this thesis, we examine the different aspects of this conceptual model with outcome as the main focus.

Historically, trauma mortality has been the standard quality outcome measure. However, non-trauma related deaths and patients that are dead on arrival (DOA) in registries, complicates the interpretation of trauma mortality statistics. In Paper I, we demonstrated by clinical review of all deaths during 2007-2011 in a Level I trauma centre (Karolinska University Hospital – Solna [KUH]), that 30-day trauma mortality included 10.5% of non-trauma related deaths and the exclusion of DOAs significantly reduced the mortality rate. We concluded that review of all trauma deaths was necessary to correctly interpret trauma mortality.

Analysis of preventable death (PD) is another quality outcome measure. The World Health Organization (WHO) has defined PD by the use of survival prediction models which calculates a probability of survival (Ps): non-PD with a Ps <25%, and potentially PD with a Ps >50%. In Paper II, we used a multidisciplinary peer review during 2012-2016, to identify the proportion of potentially PD and errors committed at KUH, and to evaluate the use of the WHO's Ps cut-offs as a tool to identify the right patients to review, i.e., exclude non-PD from review or to focus review on potentially PD. We used the North American Trauma and Injury Severity Score (TRISS) and the Norwegian Survival Prediction Model in Trauma (NORMIT) to calculate the Ps. When applying the cut-off limits to the groups of non-PDs and potentially PDs for review, both models missed cases that otherwise needed to be reviewed. We concluded that peer review of all trauma deaths is essential in preventability analysis.

Survival prediction models, which adjust for case-mix, have been developed to allow comparisons of the quality of trauma care between centres and over time. In Paper III, we used TRISS based risk-adjusted survival to compare two Scandinavian Level I trauma centres (KUH and Oslo University Hospital – Ullevål) during 2009-2011 and concluded that the model had its shortcomings when applied in a Scandinavian setting. The model lacks adjustments for age as a continuous variable and does not include comorbidity which, if included, could improve survival prediction in Scandinavian trauma populations.

In Paper IV, we tested the accuracy of NORMIT and its later update (NORMIT 2), in regards to survival prediction, in two Swedish trauma populations; one national population including all hospitals admitting trauma patients in Sweden and one subpopulation of patients admitted to a single designated Level I trauma centre (KUH) during 2014-2016. We concluded that NORMIT 2 can be used to predict survival in a Swedish trauma centre population, but both NORMIT models performed poorly in a more heterogeneous national trauma population.

LIST OF SCIENTIFIC PAPERS

This thesis is based on the following papers, which will be referred to by their Roman numerals as indicated below:

I. Ghorbani P, Falkén M, Riddez L, Sundelöf M, Oldner A, Strömmer L
Clinical review is essential to evaluate 30-day mortality after trauma
Scand J Trauma Resusc Emerg Med. 2014;22(1):18

II. Ghorbani P, Strömmer L
Analysis of preventable deaths and errors in trauma care in a Scandinavian trauma level-I centre
Acta Anaesthesiol Scand. 2018;00:1–8

III. Ghorbani P, Ringdal KG, Hestnes M, Skaga NO, Eken T, Ekbom A, Strömmer L
Comparison of risk-adjusted survival in two Scandinavian Level-I trauma centres
Scand J Trauma Resusc Emerg Med. 2016;24(1):66

IV. Ghorbani P, Troëng T, Brattström O, Ringdal KG, Eken T, Ekbom A, Strömmer L
External validation of the Norwegian survival prediction model in trauma – NORMIT 1 and 2 – in two Swedish trauma populations
Unpublished manuscript

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LIST OF ABBREVIATIONS

DOA	Dead on arrival
ICU	Intensive care unit
CPR	Cardiopulmonary resuscitation
GCS	Glasgow Coma Scale
TRISS	Trauma and Injury Severity Score
Ps	Probability of survival
ISS	Injury Severity Score
RTS	Revised Trauma Score
NORMIT	Norwegian Survival Prediction Model in Trauma
NISS	New Injury Severity Score
T-RTS	Triage-RTS
KUH	Karolinska University Hospital - Solna
OUH	Oslo University Hospital - Ullevål
TRK	Trauma Register - Karolinska
CDR	Cause of Death Register
SweTrau	Swedish National Trauma Registry
HEMS	Helicopter emergency medical service
AIS	Abbreviated Injury Scale
AAAM	Association for the Advancement of Automotive Medicine
TTA	Trauma team activation
TBI	Traumatic brain injury
NBWH	National Board of Health and Welfare
WHO	World Health Organization
ICD	International Classification of Diseases
MPRC	Multidisciplinary peer review committee
ROC	Receiver operating characteristic
AUC	Area under curve
ASA-PS	American Society of Anesthesiologists Physical Status

1 INTRODUCTION

Judging this book by its cover, it seems like yet another trauma work highlighting mortality. Hopefully, there is more to it than meets the eye.

Since the introduction of the concept of a system approach to the care of trauma patients, in particular the designation of major trauma centres, mortality after injury has been reduced[1]. One might debate, that it has reached levels that are difficult to surpass. As compelling this idea seems, the journey does not end here. The establishment of a continuous performance improvement protocol for the management of the injured patient still remains. Therefore, in order to continue to improve quality in trauma care, work has to be devoted to refine current measures (such as mortality) and develop new tools. Major trauma centres have to take on this task and demonstrate dedication to high standards of care.

For a better understanding of the future, we need to look at the past. One of the prominent figures of public health, Avedis Donabedian introduced in his classical, and today extensively cited seminal paper of 1966 the concept of structure, process and outcome. He suggested that health care quality can be evaluated in terms of structure (characteristics of the health care setting), process (clinical processes performed in the health care setting), and outcome (ultimate status of the patient following a given set of interventions)[2-4]. This concept remains to our day as the dominant paradigm for the evaluation of the quality of health care[4]. His conceptual model has laid the foundation of the work presented in this thesis.

In details, the four included papers address several aspects of Donabedian's principle, such as the outcome measures: crude mortality (Paper I), risk-adjusted survival (Paper III), preventable death rate and trauma management errors (Paper II). Different reviewing processes of trauma mortality (Paper I and II) as well as survival prediction models and risk-adjustment methods are also being tested (Paper II-IV). Structural aspects of Scandinavian trauma centres are evaluated and processes of care are being explored and compared between centres (Paper III).

Few studies have previously focused on these subjects in a Scandinavian setting. Thus, this thesis may be of interest to healthcare personnel in Scandinavian countries, but several aspects may also attract the broader trauma society, not the least provide an understanding of trauma panorama of part of the world which has low criminality, strict gun legislation, renowned road safety and a different trauma population compared to major trauma centres around the world.

2 BACKGROUND

2.1 PRINCIPLE OF QUALITY MANAGEMENT

Donabedian’s principle of quality management suggests that outcome is dependent on structures and processes of care, i.e., advancements in the structure of health care system will result in improvements in clinical processes, which in turn should improve the outcome for the patient[3]. Structures, also referred to as structural quality indicators, focus on the different attributes of health care environment including organizational framework, material resources and competence of the health care personnel. Process quality indicator relates to what is indeed done by the personnel involved. Outcome is, in addition to injury severity and patient factors, the consequence of the provided healthcare, such as specific complications and trauma deaths.

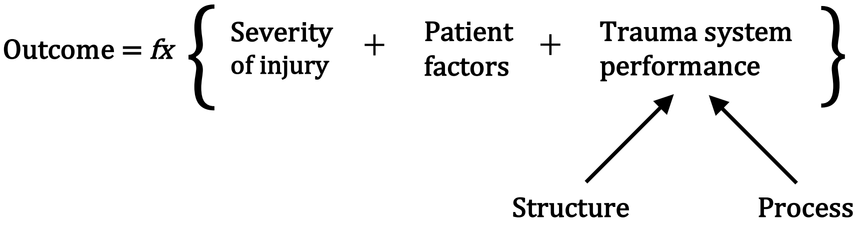

Figure 1. Principle of quality management according to Avedis Donabedian.

This model has since its introduction in the late 1960s been widely adopted by the trauma community but it was not until recently that Moore et al. showed that it indeed is a credible model for evaluating trauma performance[5]. The authors concluded that it is likely that trauma centres which perform well in regards of structures also perform well in terms of clinical processes, consequently causing a favourable influence on patient outcomes. In this thesis, we will look on the different aspects of this model with the emphasis on outcome.

2.2 MORTALITY AS AN OUTCOME MEASURE

Mortality has historically been the standard method for measuring and comparing trauma centre performance. Death is easily measurable with an undisputable consequence for the patient. Its validity as a dimension of quality is hard to question[2]. Most scoring systems for trauma quality assessment are based solely on whether patients are dead or alive at the end of their hospital admission[6].

However, although mortality is influenced by many variables, it is overwhelmingly a consequence of the injuries sustained. Therefore, the absolute effect of the designated major trauma centres on mortality may be small in massively injured patients[6]. Conversely, some injuries may produce suboptimal health or crippling conditions, but carry little mortality[6, 7]. Further, trauma deaths occur in different phases, i.e., before reaching the hospital, during inter-hospital transfer, during rehabilitation or after discharge; thus, in-hospital deaths represent only part of the overall picture. In addition, variations of the definitions and methodologies used may have consequences for the interpretation of trauma mortality. For instance, variations of the definition and exclusion of patients that are dead on arrival (DOA) may distort interpretation of mortality outcomes[8, 9].

2.2.1 In-hospital vs. 30-day mortality

The use of inpatient outcome measures (such as in-hospital mortality) is inadequate for a number of reasons. The severely injured patients rarely achieve a steady state by the time of discharge from hospital[10]. Furthermore, in-hospital vs. 30-day mortality data may differ substantially due to discharge practices such as discharge to another intensive care unit (ICU), availability of rehabilitation beds and patient case mix[11].

In recent years, 30-day mortality has become the European standard[12, 13] of how outcome is measured. Studies in support of that have shown that death later than 30 days after injury is more related to comorbidities rather than to the injury as such[14]. Additionally, studies has demonstrated that up to 20% of trauma deaths occur after discharge from hospital, therefore, suggesting that in-hospital mortality may be a poor indicator of outcomes for some injuries[15, 16].

Because of the mentioned reasons, one could argue that the usefulness of mortality as an indicator of the quality of care and performance of a trauma system has diminished. However, should we take these concerns into consideration and address them accordingly, mortality can once again be a robust and reliable quality outcome measure[17-19].

2.2.2 Dead on Arrival (DOA)

DOA, is a familiar term in the medical profession. It has been used for many years by the trauma community to imply that a trauma patient arrived at the hospital is already dead[8]. However a uniform definition of DOA has never been adopted in the trauma community nor defined in scientific terms and therefor the different definitions and variation in exclusion in registries may distort interpretation of mortality outcomes[8, 9]. Consequently, as stated by Pasquale et al[8], “its wide use in registries, death certificates, government statistics, insurance companies, and quality review organizations, has financial, ethical, and quality implications”.

Previous studies based definitions for DOA on mechanism of injury (blunt vs. penetrating), whether or not pre-hospital cardiopulmonary resuscitation (CPR) were performed, the lengths of performed CPR, or interventions performed in the emergency department (e.g. resuscitative thoracotomy)[8, 9, 20, 21]. These definitions are problematic, with great inter-variations and many patients defined as DOA had times to death more than 30 minutes after arrival[20]. Therefore, there is a need for a single reliable and well defined criterion for the unsalvageable patient.

Addressing this problem, Byrne et al.[22] proposed in 2015 a definition based on physiological status of the patient upon admission, defined as the following: Emergency department (ED) heart rate = 0, ED systolic blood pressure (SBP) = 0, and Glasgow Coma Scale (GCS)[23] score motor component = 1. This definition demonstrated an excellent predictive validity to identify patients who will go on to die, with less than 1% of patients meeting the criteria surviving. The authors concluded that this definition should be used to exclude unsalvageable patients from performance improvement endeavours.

2.3 PEER REVIEW OF PREVENTABLE DEATH

Another quality outcome measure in trauma care is the preventable death rate. A detailed understanding of the causes, timing and patterns of trauma death and the identification of the root causes of preventable deaths in particular, has been critical for improving the delivery of optimal care[24]. Preventable deaths have been used not only as a marker of the global quality of trauma care delivery[25, 26], but specifically, as an assessment tool for the evaluation of trauma protocols[27-32]. In addition to that, evaluation of preventable death through peer review has been identified as a quality indicator of trauma care[33]. It is believed that the peer review process not only helps determining preventability but also helps identify potential fields of improvement[24, 34, 35].

However, the critiques of the peer review model argue that there is a wide disparity among methods creating a lack of comparability among results[31, 36]. Sample selection methods have varied: many studies focused primarily on motor vehicle crash patients[28, 29, 37, 38] whereas others included only paediatric injuries[26]. In some instances, death occurring in a short period in a given area have been studied[29], whereas in others, longitudinal stratified samples have been drawn[39]. Some studies have focused on hospital deaths[40], and others have included pre-hospital deaths[37]. The size of panels deciding on preventability has varied (from 3 to 35) and, although most have included only surgeons, the mix of specialities represented has varied. Definitions of “preventability” have also differed. Data sources have varied from the use of all hospital and pre-hospital records, to the inclusion of only hospital or only autopsy records[41]. The definition of consensus among panel members has differed; one study required agreement between two of six panel members[42], whereas most required a simple majority[31].

If preventable death review were to be standardized with regard to several of the above-mentioned parameters, its usefulness as an evaluative and quality improvement tool within and among centres over time would be enhanced greatly[36].

Recognizing some of these challenges, The World Health Organization (WHO) proposed guidelines for the preventable death panel review procedure[43], in which mortality risk-prediction models are suggested to be used as a tool in the peer review process. It is suggested that risk-prediction models can increase objectivity and at the same time help identify right patients to review, i.e., exclude non-preventable deaths (probability of survival [Ps] <25%) from review or to focus review on potentially preventable deaths (Ps >50%). Peer review requires time and competence and with a high number of annual deaths it consumes large clinical resources. Therefore, a standardized method to select the patients who are the most important to review may be more productive and save resources.

2.4 QUALITY MEASUREMENT USING RISK-ADJUSTMENT METHODS

2.4.1 Trauma and Injury Severity Score (TRISS)

To improve the quality of care, the performance data (for instance mortality) of a trauma centre should be continuously registered, analysed and compared with data from other institutions or against a recognized standard[44]. In order to make such comparisons, the data must be risk-adjusted (i.e., adjusting for patient factors and injury severity) to reduce the effects of case-mix (i.e., actual differences in patient factors [for instance age, and health status] and injury severity in a population) at different centres. In the 1980's, the most commonly applied outcome prediction tool, the North American Trauma and Injury Severity Score (TRISS), based on a large trauma population in the United States and Canada, was described[45]. Through this method an outcome analysis, i.e., a Ps for a trauma patient, was estimated[45-48]. Since its introduction, this method has been the cornerstone in performance analysis in trauma care. TRISS enables users to identify and review systematically unexpected outcomes, i.e., patients whose death were considered to be unexpected, defined by Boyd et al.[45] as death that occurs when the Ps exceeds 0.5 (i.e., >50% survival chance). Conversely a death in patients with Ps below 0.25 (<25% survival chance) should be considered unavoidable[43] (see discussion in section 2.2). TRISS attempts to predict probability of patient survival based on the physiological status of the patient on hospital admission, overall anatomic injury severity, age, and type of injury.

Shortcomings of the model are well known[44, 48-50]. The critiques include the inappropriate exclusion of patients with missing physiologic data (e.g. respiratory rate) on hospital admission and the inability to account for multiple injuries to a single body region. Furthermore, the model uses in-hospital mortality, which excludes post-hospital trauma-related deaths[51] (see discussion in section 2.2.1). In addition, comorbidity in trauma patients is being disregarded. This will have a substantial effect in geriatric trauma patients who die after trauma. This group generally have a higher level of comorbidity, injuries due to low fall producing relatively low Injury Severity Score (ISS)[52] values, high Revised Trauma Score (RTS)[49] values and thus high Ps, yielding a high unexpected death rate[50]. But the most important limitation may be the application of this prediction model to datasets other than the one from which the model was derived. If the distribution of certain cases and risk factors varies between the studied centre and the reference population (i.e., the data from which the model was developed), a selection bias has to be ruled out. Additionally, we know that there are differences in health care organization between countries in Europe and North America (particularly in the pre-hospital system), possibly leading to selection differences.

2.4.2 Norwegian Survival Prediction Model in Trauma (NORMIT)

Acknowledging some of these problems, a Norwegian study suggested that risk difference calculation based on ISS stratification should complement the TRISS method when benchmarking performance in the Norwegian trauma population[44]. Further, a novel Norwegian survival prediction model that includes adjustment for comorbidity was introduced (NORMIT 1)[53] and recently updated (NORMIT 2)[54], and could be a better choice of prediction model in the Scandinavian trauma populations.

The NORMIT 1 model was developed based on trauma data from Oslo University Hospital Ullevål (OUH) in Norway from a 6-year period (2000-2006) and validated in a 2-year data set from 2006-2008. In NORMIT 2, the original NORMIT model coefficients were updated in a derivation dataset with patients admitted 2005-2009 and evaluated in a validation dataset with patients admitted 2010-2013, also to OUH.

In NORMIT, the anatomic injury is represented by the New Injury Severity Score (NISS)[55]. It has been demonstrated that NISS has predictive benefit in trauma mortality compared to ISS[55-58], in particular in patients with several severe injuries in a single body compartment, such as penetrating injuries towards the torso, and in both blunt and penetrating traumatic brain injury[36]. In contrast to TRISS, NORMIT also accounts for the patient´s pre-injury health status (American Society of Anaesthesiologists Physical Status [ASA-PS] Classification System[59]), incorporates age as a continuous variable, includes an unweighted physiological scoring (Revised Trauma Score for Triage [T-RTS])[49], defines rules that allow inclusion of intubated patients, and utilises mortality at a fixed time 30 days after injury as end point[53].

An external validation of NORMIT 1 in a population of severely injured patients in Finland showed good ability to separate survivors and non-survivors, but poor agreement between predicted and observed outcome amongst severely injured patients (NISS >15). The authors suggested that the NORMIT 1 should be re-calibrated[60], and the model has since than been updated (NORMIT 2).

3 AIMS

The general aim of the thesis was to investigate the importance of clinical review of trauma mortality and to evaluate survival prediction models as a risk-adjustment tool in clinical review, as well as in comparison of mortality between trauma centres.

The specific aims of this thesis were:

I. To, through clinical review, examine the proportion of trauma patients dying within 30 days from causes not related to the injury and the impact of exclusion of patients dead on arrival on 30-day trauma mortality.

II. To, through multidiciplinary peer review, identify preventable death and errors committed in a Level I trauma centre, and explore the use of TRISS and NORMIT based risk-adjustment methods as a help to identify right patients to review, i.e., exclude statistically defined non-preventable deaths (Ps <25%) from review or to focus review on statistically potentially preventable deaths (Ps >50%).

III. To compare TRISS based risk-adjusted survival in two Scandinavian Level I trauma centres and indentfiy characteristics explaining differences in trauma mortality.

IV. To validate NORMIT 1 and 2 with regards to their accuracy in survival prediction in two Swedish trauma populations.

4 PATIENTS AND METHODS

4.1 STUDY OBJECTIVE, DESIGN, SETTING AND POPULATION

Table 1. Overview of the PhD studies with aims, design, setting, population, sample size and time-period.

Paper	**I**	**II**	**III**	**IV**
Aims	Examine the proportion of trauma patients dying within 30 days from non-trauma related causes and the impact of exclusion of DOA patients on 30-day trauma mortality	Identify preventable death and errors committed in a Level I trauma centre through multidisciplinary peer review process, and explore the use of TRISS and NORMIT risk-adjustment methods as a complement for patient selection	Compare TRISS risk-adjusted survival between KUH and OUH, and identify patient factors and trauma care processes of relevance for outcome in comparison between the two trauma centres	Compare NORMIT 1 and 2's accuracy in regards of survival prediction in two Swedish trauma populations
Design	Observational retrospective cohort study	Observational retrospective cohort study	Observational retrospective cohort study	Observational retrospective cohort study
Setting	Clinical review was conducted at KUH	Multidisciplinary peer review was conducted at KUH	Comparison of KUH and OUH	Comparison of Swedish national trauma population (NT) and trauma centre (TC) subpopulation at KUH
Population	Prospectively collected data from trauma patients ≥15 years who died within 30 days after trauma fulfilling the registry inclusion criteria	Prospectively collected data from trauma patients ≥15 years who died within 30 days after trauma fulfilling the registry inclusion criteria	Prospectively collected data from trauma patients ≥15 years at KUH and OUH fulfilling the registry inclusion criteria	Prospectively collected data from trauma patients ≥15 years registered in SweTrau. Eligible were all patients which were primarily admitted to the reporting hospital
Sample size	343	298	KUH: 4485 OUH: 3591	NT: 21554 TC: 3972
Time-period	2007-2011	2012-2016	2009-2011	2014-2016
Registry used	TRK and CDR	SweTrau	TRK and OUH trauma registry	SweTrau

DOA: Dead on arrival; TRISS: Trauma and Injury Severity Score; NORMIT: Norwegian survival prediction model in trauma; KUH: Karolinska University Hospital-Solna; OUH: Oslo University Hospital-Ullevål; TRK: Trauma Register – Karolinska; CDR: Cause of Death Register; SweTrau: Swedish National Trauma Registry.

4.2 SETTINGS

The scientific papers in this thesis is primarily based upon data originating from the trauma centre at Karolinska University Hospital – Solna (KUH). A description of this setting will follow in the coming section. In Paper III, a comparison was made between KUH and OUH. Section 4.2.1 gives a description of the healthcare system at OUH. In Paper IV, a comparison was made between KUH and a Swedish national trauma population, which is detailed in section 4.4.

4.2.1 Trauma centre at Karolinska University Hospital – Solna (KUH)

The trauma system in the Stockholm region consists of seven acute-care hospitals, of which KUH has since 2007 served as the only primary trauma care facility. During the time period, which the different studies have been conducted, from 2007 an onwards, the catchment population[61] at KUH has increased from 1.9 million inhabitants to 2.2 million from an area of 6,526 km^2. The pre-hospital transport system that served KUH consisted of one helicopter emergency medical service (HEMS) base with one helicopter operational 24 hours per day during the entire year and an additional helicopter available during daytime in the summer. Physicians were not available in the helicopters, but an anaesthesiologist staffed ground ambulance was operational during daytime on weekdays. Trauma trained surgeons and consultant specialists are located within the hospital and the trauma centre is equivalent to a Level I trauma centre[1].

4.2.2 Oslo University Hospital – Ullevål (OUH)

The trauma care infrastructure is similar between KUH and OUH, and both centres are equivalent to a Level I trauma centre. Trauma registries are available in both centres, and trauma registry datasets are based upon the same European core dataset. OUH was the major trauma centre in Oslo and the trauma referral centre for 2.7 million inhabitants (2016) in the South-Eastern Norway Regional Health Authority region, with an area of 111,000 km2. The regional trauma system consisted of 19 acute-care hospitals located outside Oslo[62-64] (1-3). In the South-Eastern Norway Regional Health Authority region there were five HEMS bases with a total of six anaesthesiologist-staffed helicopters, all operating 24 hours per day[65-67]. The HEMS-bases also operated rapid-response cars. Additionally, there was an anaesthesiologist-manned rapid-response car operating in Oslo during daytime.

4.3 TRAUMA REGISTRY AT KAROLINSKA UNIVERSITY HOSPITAL (TRK)

The trauma registry at KUH (TRK) was established in 2004. It holds information on pre-hospital as well as in-hospital care, admission time, trauma mechanism, physiological derangement, trauma care processes and outcome variables. The trauma registry is based on a European core dataset[13]. The trauma registrars/coders are registered nurse anaesthetists, formally certified in injury coding (Abbreviated Injury Scale [AIS])[68-70] by the Association for the Advancement of Automotive Medicine (AAAM)[71].

4.3.1 Inclusion and exclusion criteria at TRK

All trauma patients ≥15 years admitted with trauma team activation (TTA), irrespective of ISS, and patients without TTA but retrospectively found to have injuries with ISS >9 who were admitted to the hospital directly or transferred from a local hospital within 24 hours after injury were included. Patients transferred to the trauma centres more than 24 hours after injury were included only if the trauma team was activated upon patient arrival. Drowning, predominant burn injuries, and hypothermia without concomitant trauma were excluded.

4.3.2 Criteria for trauma team activation (TTA)

TTA criteria were based on specific anatomical injuries, mechanism of injury (high energy or penetrating trauma) and physiologic derangement such as circulatory or respiratory instability or reduced level of consciousness, or other situations with a high index of concern. Patients with an isolated fracture of a single extremity were excluded unless the trauma team was activated.

4.4 NATIONAL TRAUMA REGISTRY - SWETRAU

In 2011, a national trauma registry was introduced in Sweden. The registry is based on a European core dataset[13]. To date, it includes more than 50 000 trauma patients from 48 out of 52 Swedish hospitals with emergency surgical units that admit trauma patients of all ages, 24/7, 365 days a year, including KUH[72]. The inclusion criteria in SweTrau are (a) all trauma patients admitted with prior TTA irrespective of injury severity, (b) all patients with anatomical injury of NISS >15 who did not receive TTA, and (c) all patients who were transferred from another hospital (secondary admissions) to the reporting hospital within 7 days after trauma who had a NISS >15. Exclusion criteria are (a) patients with isolated subdural hematoma, and (b) patients with TTA who were not exposed to a prior traumatic event[72].

4.5 DEFINITION OF CAUSES OF DEATH

The following definitions of causes of death were used: Traumatic brain injury (TBI) was defined as a cerebral, brainstem or high spinal injury incompatible with life. Haemorrhage was clinically documented and led to a complete loss of blood volume or hypovolemic arrest. Death was attributed to organ dysfunction (OD) when clinical documentation or the Sequential-related Organ Failure Assessment (SOFA)[73] score supported organ failure (alone or in combination). Other (O) deaths were those where there were other causes of death, and Unknown death (U) were, where the cause of death could not be established.

4.5.1 The Cause of Death Register (CDR)

The causes of death of the study population in Paper I were extracted from The Cause of Death Register (CDR), managed by the Swedish National Board of Health and Welfare (NBHW), Stockholm. The physician that determines death is responsible that a cause of death is submitted to NBHW, in line with WHO standards and according to International Classification of Diseases (ICD) coding. ICD version 10 has been used in Sweden since

1997. The immediate cause of death which is defined as the final disease or condition that resulted in death is registered as primary cause of death. The conditions that lead up to the primary cause of death is subsequently listed, with the underlying cause of death defined by WHO as “the disease of injury which initiated the train of morbid events leading directly to death, or the circumstances of the accident or violence which produce the fatal injury”[74]. Misclassification of the underlying cause of death have been estimated to approximately 20% overall[75].

4.6 MORTALITY REVIEW

4.6.1 Peer review

In Paper I, the reviewing process was performed by two independent surgeons; disagreements were discussed with a third party and consensus reached. The cause of death was based on the ICD-10 code and the clinical review. ICD-10 codes were, as previously stated, extracted from the CDR at the NBWH. A trauma death was defined as (1) an ICD-10 trauma code based on an autopsy; or (2) an ICD-10 trauma code without an autopsy in which the clinical review supported a trauma death; or (3) an ICD-10 non-trauma code in which clinical review supported a trauma death or could not rule out that trauma contributed to death. A death not directly related to the injury was defined as (1) an ICD-10 non-trauma code based on an autopsy; or (2) an ICD-10 non-trauma code without an autopsy in which the clinical review supported a death not directly related to the injury. If clinical review was not possible because of missing medical records, it was classified as a trauma related death in the Other/Unknown category if the ICD-10 code was trauma code. If the ICD- 10 code was non-trauma code, the death was classified as a death not related to the injury.

4.6.2 Multidisciplinary peer review

In Paper II, a multidisciplinary peer review committee (MPRC) was put together in 2012 at KUH. The committee consisted of health care providers involved in the management, i.e. emergency and trauma surgeons, vascular surgeons, orthopaedic surgeons, neurosurgeons, anaesthesiologists, intensivists, radiologists, emergency medicine specialists and nursing. A senior trauma surgeon chaired the MPRC and the secretary (senior surgical resident) prepared the meeting by summarizing registry as well as clinical data relating to trauma deaths (pre-hospital emergency medical system notes, emergency room documentation, operative reports, imaging, electronic labs, injury severity and autopsy reports) using a predefined structure. Delivered trauma care was divided into 5 phases: pre-hospital care, resuscitation, operative measures/interventions, ICU/postoperative ward and ward. All data was presented to the MPRC which then, confirmed a trauma related death, decided on DOA, the cause of death and preventability. Additionally, errors in trauma management were identified and categorized.

4.6.3 Criteria for DOA

In Paper I and II, DOA patients were identified through autopsy reports and clinical review by using the explicit criteria for DOA according to Powell et al.[21]. The criteria suggest that the patient is DOA when (1) blunt trauma patient arriving with no signs of life (defined as pupillary response, respiratory effort, or motor activity) and pre-hospital CPR >5 min, or (2) penetrating trauma with no signs of life or asystole without the possibility of cardiac tamponade and pre-hospital CPR >15 min.

4.6.4 Preventability and errors in management

Preventable death was defined in accordance with the classification by MacKenzie et al.[76], meeting the 3 criteria: (1) the injury must be survivable, (2) the delivery of care is suboptimal, and (3) the error in care must be directly or indirectly implicated in the death of the patient. Errors in care were categorized using a modified version of O'Reilly[35] and Teixeria et al.[24]. DOA patients were analysed regarding in-hospital errors (such as an emergency department thoracotomy in a futile patient) but were not assessed for preventability.

4.6.5 Prediction models – a tool in the peer review process

In Paper II, Preventable and non-preventable deaths judged by peer review were compared with the statistically defined non-preventable deaths (Ps <25%) and potentially preventable deaths (Ps >50%) according to the WHO classification. The agreements between the MPRC's judgements and the statistically defined cut-off limits were evaluated and the validity of the WHO classification examined. Ps was calculated according to both the TRISS[45-47, 77] and the NORMIT methods[53, 60].

4.7 DIFFERENT SURVIVAL PREDICTION MODELS

4.7.1 TRISS

TRISS is a weighted combination of patient age, overall anatomic injury severity (ISS) and physiological status of the patient on hospital admission (Revised Trauma Score [RTS][49]). The age variable is coded in two categories for adults: 15-54 years as 0 and ≥55 years as 1. The model has also two separate specification for injury mechanism with different subset of coefficients for blunt and penetrating injuries.

$$Probability\ of\ survival\ (Ps) = \frac{1}{1+e^{-b}}$$

$$\begin{aligned} b_{blunt} &= c_1 + (c_2 \times RTS) + (c_3 \times ISS) + (c_4 \times Age\ code) \\ b_{penetrating} &= c_5 + (c_6 \times RTS) + (c_7 \times ISS) + (c_8 \times Age\ code) \end{aligned}$$

Figure 2. The TRISS model equation for adult blunt and penetrating trauma. Probability of survival (Ps) is calculated by inserting RTS value, Age code, and NISS in the equation. The coefficients from the 2009 revision by Schluter et al. was used[77]. c: coefficient; RTS: Revised Trauma Score; ISS: Injury Severity Score.

4.7.2 NORMIT

In NORMIT, the anatomic injury is represented by the NISS. The model accounts for the patient´s pre-injury health status (measured as the ASA-PS Classification System), incorporates age as a continuous variable and includes an unweighted physiological scoring (T-RTS).

The ASA-PS Classification System divides health status in different categories: ASA-PS 1 represents a normal healthy patient, ASA-PS 2 mild systemic disease, ASA-PS 3 severe systemic disease, ASA-PS 4 severe disease that is a constant threat to life, ASA-PS 5 a moribund patient and ASA-PS 6 a declared brain-dead patient. The latter two categories were disregarded in this thesis due to lack of relevance for the trauma population. The T-RTS (range 0–12) is defined as the sum of the clinical category values (RTS) of GCS score, SBP and respiratory rate (RR).

$$Probability\ of\ survival\ (Ps) = \frac{1}{1+e^{-b}}$$

$$b = (c_1 \times T\text{-}RTS) - c_2 \times \left(\frac{age+1}{100}\right)^3 + \begin{cases} ASA\text{-}PS\ 1: (c_3 \times NISS) + c_4 \\ ASA\text{-}PS\ 2: (c_5 \times NISS) + c_6 \\ ASA\text{-}PS\ 3: (c_7 \times NISS) + c_8 \\ ASA\text{-}PS\ 4: (c_9 \times NISS) + c_{10} \end{cases}$$

Figure 3. The NORMIT (2) model equation. Probability of survival (Ps) is calculated by inserting T-RTS, age, and NISS in the equation. The latter is selected depending on the patients ASA-PS classification. c: coefficient; T-RTS: Revised Trauma Score for Triage; ASA-PS: American Society of Anaesthesiologists Physical Status; NISS: New Injury Severity Score.

4.7.3 Injury scoring – ISS and NISS

ISS and NISS provide a description of the severity of anatomical injuries (e.g. an overall score) in trauma patients. Each individual injury is given an AIS score according to its relative importance on a six-point grading scale, in which 1 is minor injuries and 6 is almost certain death. The injuries are then appointed to six body regions defined as (1) head and neck, (2) face, (3) thorax, (4) abdomen, (5) extremities and (6) external.

In ISS, only the highest AIS score in each body region is used. The sum of the squares of the highest AIS score, in each of the three most severely injured body regions represents ISS, ranging from 1-75 (1 = minor severity and 75 = fatal injury)[52].

In contrast to ISS, NISS is the sum of the squares of the AIS scores of each of the patient's three most severe injury *independent* of the body region in which they appear[55].

4.8 RISK-ADJUSTED SURVIVAL

In Paper III, to calculate risk-adjusted survival we used Ps calculated according to the TRISS model. Risk-adjusted survival per patient was calculated by assigning every patient a value corresponding to gained or lost fractional life, where survivors were given a value of 1 and those patients who died a value of 0. Each survivor thus contributed a reward of 1–Ps and each death a penalty of –Ps. The sum of penalties and rewards, corresponding to the difference between expected and actual mortality[62, 78] was compared between the centres. Data was presented as excess survivors per 100 trauma patients, which is equivalent to the W statistic[49].

4.9 MODELL ACCURACY

In Paper IV, we used the same methodology as Raj et al.[60], to evaluate the performance of NORMIT 1 and 2 by measuring their discrimination and calibration capabilities. The discrimination of a survival prediction model refers to its ability to distinguish between survivors and non-survivors. Discrimination was assessed for each model by calculating the area under the receiver operating characteristic (ROC) curve (AUC)[79] with 95% confidence interval (CI). Random guess produces an AUC of 0.5, whereas 1.0 represents perfect model performance. AUCs ≥0.90 are considered excellent, AUCs ≥0.80 good, and AUCs <0.70 poor[80]. The discrimination capabilities of two models were not considered to be significantly different if their 95% CIs overlapped.

The calibration of a survival model refers to the agreement between predicted and observed survival[79]. To assess calibration, we used the GiViTI (Gruppo Italiano per la Valutazione degli Interventi in Terapia Intensiva) calibration belt, using its R-package (©Nattino & Finazzi)[81, 82]. The GiViTI test demonstrates visually the relationship between observed and predicted outcomes, in this case survival, by fitting a polynomial function between the two and calculating the 80% and 95% confidence intervals (CI), respectively[81]. Statistically significant deviations occur when the diagonal bisector line is not contained within the 95% CI. Hence, by using the GiViTI calibration belt, it is possible to identify specific risk intervals with over- and under prediction of survival by the model[82]. Wider CIs are seen with a higher degree of uncertainty, primarily caused by a lower number of patients at the specific risk interval.

4.10 STATISTICS

For categorical variables, data are resented as numbers and proportions (%). Normally distributed data are presented as means with standard deviations (SD), and data that are not normally distributed are presented as medians with quartiles. Normality was tested using the Shapiro-Wilk test and continuous variables were non-normally distributed. In Paper III, continuous data was also presented as means with SD. This was to facilitate comparison with previous literature and to explore the discrepancy between median and mean values. Comparisons of continuous data were performed using the Mann-Whitney U test or the Wilcoxon Signed Ranked test as appropriate. For comparisons of continuous data between more than two groups, analysis of variance was followed by Dunn's test for multiple comparisons. Differences between categorical variables were evaluated primarily using the chi-square test (two-tailed). When the expected number was lower than five, we used the Fischer's exact test. Statistical significance was assumed for 2-sided $P < 0.05$. Data were analysed with SPSS (Statistical Package for the Social Sciences, Version 21.0.0; SPSS, Inc., Chicago, IL) in papers I-II and with Version 23.0.0 in Papers III-IV.

4.11 ETHICAL CONSIDERATIONS

All studies were approved by the Regional Ethical Review Board in Stockholm, Sweden. Since all studies were purely retrospective in nature, informed consent from the included patients was not required according to the Regional Ethical Review Boards. In Paper III, which involved a comparison between KUH and OUH, appropriate approvals were obtained locally as well as in Norway. The Data Privacy Ombudsman for research at OUH deemed that the study was exempt from a requirement for informed consent because of the anonymity of the extracted data and the absence of any treatment study protocol.

5 RESULTS

5.1 CLINICAL PEER REVIEW OF TRAUMA MORTALITY

5.1.1 Overall mortality

During 2007-2011, 7422 trauma patients were admitted to KUH, of which 1626 were severely injured defined as having an ISS greater than 15. A total of 343 patients were registered dead, yielding a crude mortality of 4.6% (343/7422). Mortality amongst the severely injured was 17.5% (285/1626). The reviewing process is presented in Figure 4. The final number of trauma deaths and deaths not related to the injury was 307 and 36 respectively.

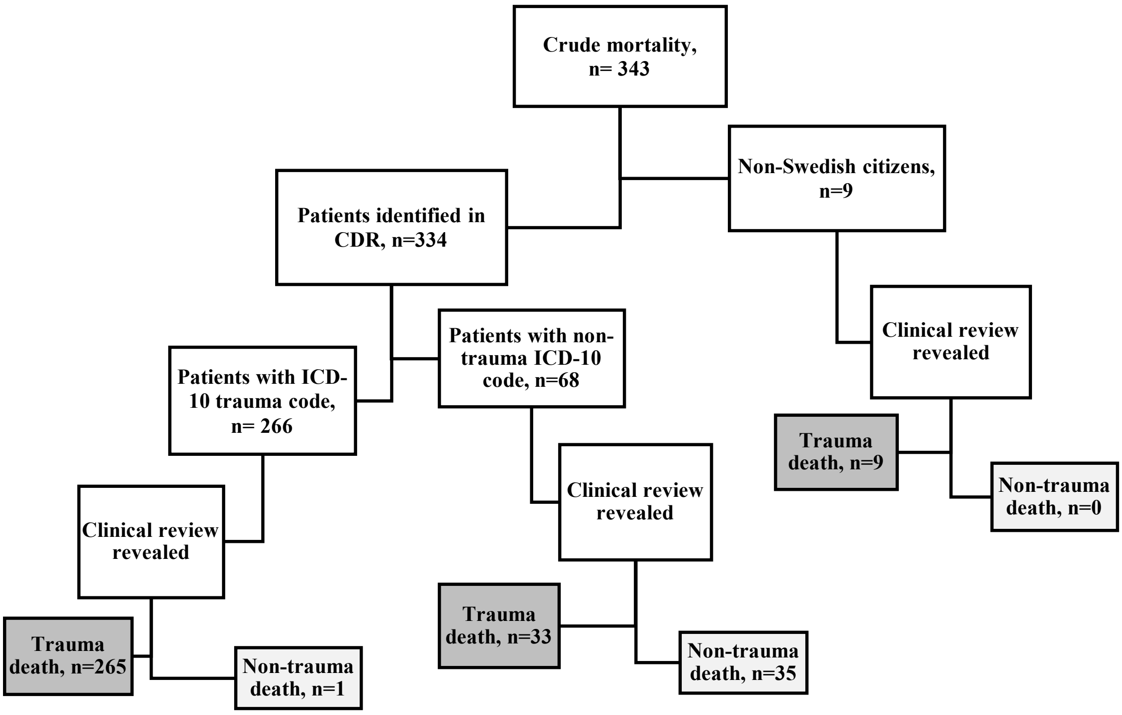
Crude mortality, n= 343
Non-Swedish citizens, n=9
Patients identified in CDR, n=334
Patients with non-trauma ICD-10 code, n=68
Patients with ICD-10 trauma code, n= 266
Clinical review revealed
Clinical review revealed
Clinical review revealed
Trauma death, n=9
Non-trauma death, n=0
Trauma death, n=33
Non-trauma death, n=35
Trauma death, n=265
Non-trauma death, n=1

Figure 4. The reviewing process revealed 307 (265+33+9) trauma related death and 36 (1+35+0) non-trauma related death. CDR: Cause of Death Register; ICD-10: International Classification of Diseases-10.

5.1.2 Trauma related death vs. non-trauma related death

The patient characteristics of the 307 trauma related death are presented in Table 2. The review of the 36 non-trauma related death (10.5%, 36/343) revealed their non-trauma related causes of death, which were the following: Non-traumatic intracerebral bleeding n = 16, stroke n = 3, ischemic heart disease n = 6, cancer death n = 4, intoxication n = 2, pneumonia n = 1, bleeding stomach ulcer n = 1, terminal kidney disease n = 1, convulsions and asystole of unknown cause n = 2. The non-trauma related death had a median age of 78 (62–88) years and the median ISS was 2 (1–6) representing minor injuries such as scalp wounds, hematomas or skin abrasions. The deaths occurred predominantly in hospital. Only two patients died outside the hospital after recovering from their injuries.

Table 2. Patient characteristics subdivided by causes of death.

	TBI	Haemorrhage	Organ dysfunction	Other/Unknown
Death	180	50	46	31
Autopsy	86 (47.8%)	50 (100%)	11 (23.9%)	29 (93.5%)
Penetrating: Blunt trauma	5:175	16:34	1:45	1:30
DOA	17 (9.4%)	22 (44.0%)	0 (0%)	15 (48.4%)
Age, years	69 (50–81)[a]	33 (24–50)	83 (70–88)[b]	53 (38–75)
Sex, male	65%	82%	72%	87%
ISS	27 (25–41)[a]	56 (39–75)	25 (17–30)[b]	38 (29–66)
Time to death, hours	28 (7–120)[c]	1 (0.3–3)	180 (72–312)[b]	0.8 (0.3–96)

Categorical data are presented as numbers and proportions (%) and continuous data as medians and quartiles. ISS: Injury Severity Score; DOA: Dead on arrival; [a]P <0.01 vs. Haemorrhage; [b]P <0.0001 vs. Haemorrhage and Other/Unknown; [c]P vs. Haemorrhage, Organ dysfunction and Other/Unknown.

5.1.3 DOA and its impact on mortality statistics

Out of the 307 trauma related death, clinical review classified 54 (17.6%) of the patients as DOA. Forty-nine (90.7%) of these 54 patients met the criteria set for DOA by Powell et al.[21]. The remaining five patients did not fulfil the criteria of DOA since there were no pre-hospital CPR performed. All patients were subject to autopsy. The causes of death were the following: TBI (n = 17), Haemorrhage (n = 22) and Other/ Unknown (n = 15). The median time to the patient being declared dead from admission was 17 (10–26) minutes. After exclusion of DOA patients, mortality dropped from 4.2% (307/7422) to 3.4% (253/7368) ($P < 0.05$). The majority of DOA patients were severely injured (only 2/54 had ISS <15). Mortality in patients with ISS >15 showed a trend to a reduction from 17.5% to 14.8% (233/1574) when patients DOA were excluded ($P = 0.084$). Additionally, the exclusion of patients DOA resulted in an increase of median age from 64 (38–81) to 71 (47–84) years ($P < 0.01$) and a decrease of median ISS from 29 (25–50) to 27 (25–41) ($P < 0.05$). The causes of death were not affected by excluding DOA patients. The median time to death in all trauma deaths almost doubled from 24 hours (3 hours-6 days) to 43 hours (12 hours-7 days) ($P < 0.001$) when patients that were DOA were excluded.

5.2 MULTIDISCIPLINARY PEER REVIEW OF TRAUMA MORTALITY

5.2.1 Preventability analysis

Figure 5 gives an overview of patient selection, the reviewing process and the MPRC's judgment, during the period of 2012-2016. 6204 patients were admitted to the hospital with 30-day mortality in 298 cases (4.8%). Forty-three deaths (14.4%) were non-trauma related. Of the remaining 255 (4.1%) deaths, 3 were excluded due to missing data, leaving 252 deaths to review. One death (0.4%) was classified as preventable and 9 (3.6%) deaths as potentially preventable. From here on potentially and "frankly" preventable are presented and referred to as potentially preventable deaths as due to the low number of "frankly" preventable deaths.

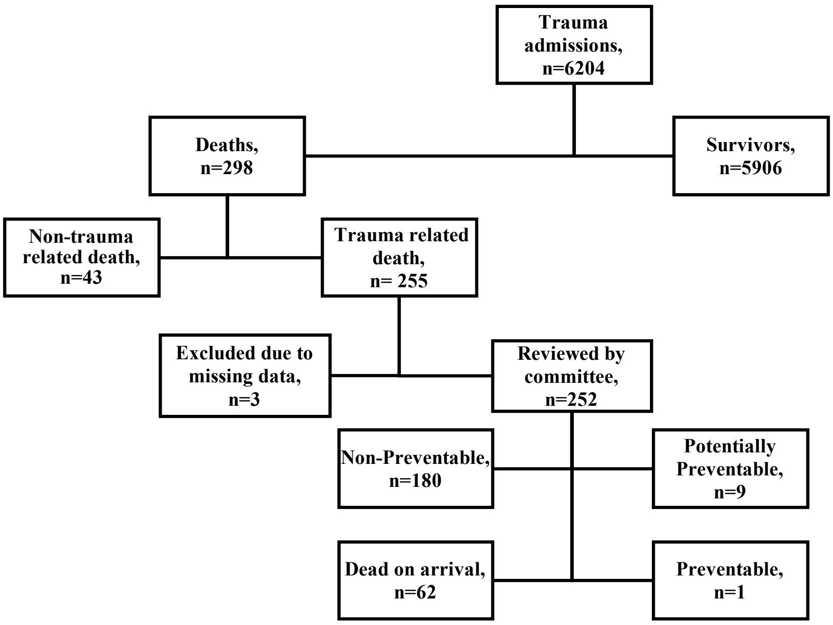
Trauma admissions, n=6204
Deaths, n=298
Survivors, n=5906
Non-trauma related death, n=43
Trauma related death, n= 255
Excluded due to missing data, n=3
Reviewed by committee, n=252
Non-Preventable, n=180
Potentially Preventable, n=9
Dead on arrival, n=62
Preventable, n=1

Figure 5. The review process by the multidisciplinary peer review committee (MPRC) regarding preventability.

5.2.2 Patient demography

In Table 3 we present mortality statistics over the two time-periods which the separate reviews were conducted in; Period 1 (2007-2011): clinical peer review by two separate surgeons; and period 2 (2012-2016): Multidisciplinary peer review consisted of all relevant healthcare providers involved in the management of the trauma patient.

Table 3. Mortality statistics over time.

	Clinical peer review	**Multidisciplinary peer review**
Time period	2007-2011	2012-2016
Trauma admissions	7422	6204
Crude mortality	343 (4.6%)	298 (4.8%)
Non-trauma related death	36 (10.5%)	43 (14.4%)
Trauma related mortality	307 (4.1%)	255 (4.1%)
DOA	54 (17.6%)	62(24.3%)

Data are presented as numbers and proportions (%). DOA: Dead on arrival.

Descriptive statistics for all deaths, DOA patients and deaths after admission for 2012-2016, are presented in Table 4. DOA patients were almost half the age, were to a greater extent male (85.5%), had better pre-injury health status, were subject to a higher extent to penetrating injuries (45.2%), and were more severely injured (ISS 54 vs 26 and NISS 66 vs 43) compared to patients that died after admission (P < 0.001-0.01). Exclusively all DOA patients were subject to clinical autopsy and the most frequent cause of death was haemorrhage (66.1%). The most common cause of death in patients dying after admission was TBI (61.6%) followed by organ dysfunction (14.7%). The median time to death was approximately 2 days when excluding DOA patients. Time to death was also categorized in time intervals and the majority of patients died between 1 and 7 days (Figure 6).

Table 4. Patient demography amongst the different dead populations, during 2012-2016.

	All deaths n=252	**DOA n=62**	**Deaths after admission n=190**	**P**[a]	**Missing data**[b]
Age, years	63 (34-83)	37 (25-55)	73 (46-86)	<0.001	
Male	178 (70.6%)	53 (85.5%)	125 (65.8%)	<0.01	
ASA-PS	2 (1-3)	1 (1-2)	2 (1-3)	<0.001	4
Penetrating trauma	42 (16.7%)	28 (45.2%)	14 (7.4%)	<0.001	
ISS, median	26 (21-45)	54 (29-75)	26 (19-34)	<0.001	2
NISS, median	48 (33-66)	66 (48-75)	43 (27-57)	<0.001	3
Autopsy	146 (59.8%)	62 (100%)	84 (46.2%)	<0.001	8
Time to death, min	1453 (61-6979)	17 (10-29)[c]	2904 (805-9172)	<0.001	2
Causes of death:					
TBI	126 (50.0%)	9 (14.5%)	117 (61.6%)	<0.001	
Haemorrhage	54 (21.4%)	41 (66.1%)	13 (6.8%)	<0.001	
Organ dysfunction	28 (11.1%)	0 (0%)	28 (14.7%)	<0.001	
Other	37 (14.7%)	10 (16.1%)	27 (14.2%)	<0.001	
Unknown	7 (2.8%)	2 (3.2%)	5 (2.6%)	<0.001	

Categorical data are presented as numbers and proportions (%) and continuous data as medians and quartiles.
DOA: Dead on arrival; ASA-PS: American Society of Anaesthesiologists Physical Status; ISS: Injury Severity Score; NISS: New Injury Severity Score; TRISS: Trauma Score-Injury Severity Score; NORMIT: Norwegian survival prediction model in trauma; TBI: Traumatic brain injury; [a]DOA vs. Deaths after admission; [b]In total death population; [c]Time spent on futile resuscitation.

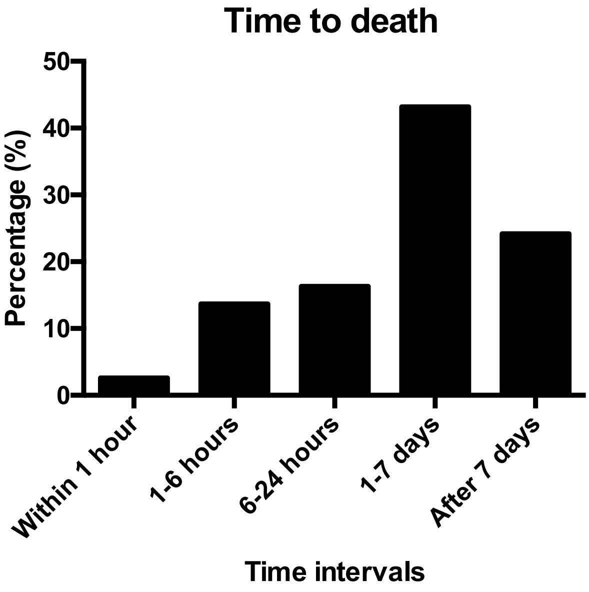

Figure 6. Time to death in patients dying after admission (n=190), dead on arrival (DOA) is excluded.

5.2.3 Errors in trauma management

Sixty-seven errors were identified and categorized (Table 5) by the MPRC. In all death, the most frequent error was inappropriate treatment (for instance, violation of the emergency department thoracotomy protocol according to Powell et al.[21]) presented in 29 of 67 errors, and the second most frequent error was delay to computer tomography (CT) presented in 9 of 67 errors. In potentially preventable deaths, the most common error was inappropriate treatment, found in 5 of 13 errors. Clinical characteristics of the ten deaths deemed potentially preventable and their associated errors are shown in Table 6.

Table 5. Categorized errors in trauma management, both in all death and in death deemed as potentially preventable (PP).

		Errors in all deaths, n=67	**Errors in PP deaths, n=13**
1. Delay in treatment	a. Delay to surgery/intervention	7 (10.4%)	1 (7.7%)
	b. Delay to other treatment	3 (4.5%)	1 (7.7%)
2. Clinical judgement error	a. Procedural error	8 (11.9%)	2 (15.4%)
	b. Inappropriate treatment	21 (31.3%)	5 (38.4%)
3. Missed diagnosis	a. Delay to CT	9 (13.4%)	0
	b. Imaging not complete or inappropriate	2 (3.0%)	1 (7.7%)
	c. Delay to diagnosis/missed diagnosis	2 (3.0%)	1 (7.7%)
4. Technical errors		0	0
5. Other	a. Personnel or resources unavailable	1 (1.5%)	0
	b. Inappropriate prehospital triage or delay in transport to trauma centre	5 (7.5%)	1 (7.7%)
	c. Error in inter-hospital communication	5 (7.5%)	0
	d. Inappropriate monitoring in ward	4 (6.0%)	1 (7.7%)

Data are presented as numbers and proportions (%). PP: Potentially Preventable; CT: Computer Tomography.

Table 6. Patient specifics of potentially preventable (patient numbers 1-9) and frankly preventable death (patient number 10).

Patient	Age	Sex	ASA -PS	ISS /NISS	Ps, TRISS	Ps, NORMIT	Cause of death	Error	Time to death
1*	71	F	3	9/34	0.74	0.45	Other; Cardiac arrest	2b, 5d	1-7 days
2*	42	M	2	41/41	0.76	0.77	Haemorrhage	1b	1-6 h
2*	69	F	3	38/57	0.78	0.71	TBI	5b, 1b	>7 days
4†	32	M	1	75/75	0.03	0.12	Other; Hypoxia	2a, 2b	1-7 days
5†	61	M	2	5/9	0.81	0.92	Other; Haemorrhage + drug intoxication	2b	1-6 h
6*	22	M	1	24/34	0.98	0.99	Other; Pulmonary embolism	3b	1-7 days
7*	74	M	3	38/75	0.16	0.02	Other; Neurogenic shock	2b	1-6 h
8*	33	F	1	25/54	0.80	0.53	TBI	3c	1-7 days
9*	55	M	2	26/43	0.43	0.64	TBI	2b	1-7 days
10*	69	M	4	25/34	0.62	0.35	Other; Hypoxia due to dislocation of tracheostomy	2a	>7 days

ASA-PS: American Society of Anaesthesiologists Physical Status; ISS: Injury Severity Score; NISS: New Injury Severity Score; Ps: Probability of survival; TRISS: Trauma Score-Injury Severity Score; NORMIT: Norwegian survival prediction model in trauma; F: Female; M; Male; TBI: Traumatic brain injury; 1b: Delay to other treatment; 2a: Procedural error; 2b: Inappropriate treatment; 3b: Imaging not complete or inappropriate; 3c: Delay to diagnosis/missed diagnosis; 5b: Inappropriate prehospital triage or delay in transport to trauma centre; 5d: Inappropriate monitoring in ward; †Penetrating injury mechanism; *Blunt injury mechanism.

5.2.4 The use of survival prediction model as a tool

The numbers of deaths with Ps <25% were 29 (TRISS) and 67 (NORMIT) (P <0.001). Using the WHO cut-off limit for non-preventable deaths (n = 169, 11 missing), 17.2% (29/169, when using TRISS) and 39.6% (67/169, when using NORMIT) of patients could have been excluded from the peer review process. Two clinically judged preventable deaths with Ps <25% (patients 4 and 7, Table 6) would have been missed with both models. The numbers of deaths with Ps >50% were 118 (TRISS) and 68 (NORMIT) (P < 0.001). Using the WHO Ps cut-off limit to identify potentially preventable deaths (n = 10, judged by peer review) for review, 7 of 10 deaths when using TRISS, and 6 of 10 deaths when using NORMIT, had a Ps >50%. Hence, 3 and 4 clinically judged preventable deaths respectively would have been missed if using this cut-off (Table 6).

5.3 USE OF RISK-ADJUSTED SURVIVAL IN COMPARISON BETWEEN TRAUMA CENTRES

5.3.1 Patient characteristics and injury severity

In Paper III, we used TRISS risk-adjusted survival to compare KUH and OUH and identify patient related factors and trauma care processes of relevance for survival between the two trauma centres. An overview is given of the two study populations in Table 7. During the period 2009-2011, KUH had 4485 trauma admissions and OUH 3591. Compared with KUH, OUH had a greater proportion of elderly trauma patients, defined as age >65 years ($P <0.01$) and a greater proportion of patients with higher levels of comorbidity pre-injury, defined as ASA-PS ≥3 ($P <0.001$). The proportions of patients stratified in different ISS intervals are presented in Figure 7. Compared with KUH, OUH had a lower proportion of patients with minimal injuries (ISS 1) (16.6 % [n =596] at OUH vs. 25.6 % [n =1147] at KUH, $P <0.001$) and minor injuries (defined as ISS <9) (41.8 % [n =1500] at OUH vs. 57.9 % [n =2598] at KUH, $P <0.001$).

Table 7. Patient demography, injuries, admission and mortality.

	KUH **n=4485**	**OUH** **n=3591**	**P**	**U/M KUH**	**U/M OUH**
Age (years)	39 (25-55)	40 (26-57)	<0.05		4
Age >65 years	603 (13.4%)	576 (16.0%)	<0.01		4
Pre-injury ASA-PS	1 (1-1)	1 (1-2)	<0.001	15	6
Pre-injury ASA-PS ≥3	308 (6.9%)	522 (14.6%)	<0.001	15	6
Pre-injury ASA-PS ≥3 for age >65 years	204 (34.1%)	294 (51.3%)	<0.001	4	3
Male	3113 (69.4%)	2618 (72.9%)	<0.001		
Blunt trauma	4139 (92.3%)	3202 (89.2%)	<0.001		
ISS	5 (1-13)	10 (4-18)	<0.001		
NISS	6 (3-17)	12 (4-27)	<0.001	71	
Injury mechanism					30
Transport accidents	1977 (44.1%)	1474 (41.1%)	<0.01		
Fall	1671 (37.2%)	1124 (31.6%)	<0.001		
Other	837 (18.7%)	963 (27.1%)	<0.001		
Injury intention				31	33
Self-inflicted	223 (5.0%)	138 (3.9%)	<0.05		
Assault	563 (12.6%)	481 (13.5%)	0.256		
Secondary admission	290 (6.5%)	1236 (34.4%)	<0.001	9	
Crude mortality	143 (3.2%)	202 (5.6%)	<0.001		
DOA	39 (21.4%)	26 (11.4%)	<0.01		

Categorical data are presented as numbers and proportions (%) and continuous data as medians and quartiles. KUH: Karolinska University Hospital-Solna; OUH: Oslo University Hospital-Ullevål; U/M: Unknown/Missing ASA-PS: American Society of Anaesthesiologists Physical Status; ISS: Injury Severity Score; NISS: New Injury Severity Score; DOA: Dead on arrival, as fraction of total deaths.

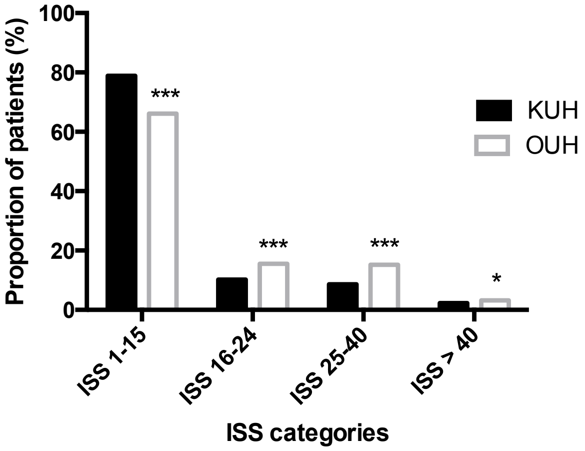

Figure 7. Proportions of patients in different ISS intervals at KUH and OUH. ISS: Injury Severity Score; KUH: Karolinska University Hospital-Solna; OUH: Oslo University Hospital-Ullevål; *P <0.05; ***P <0.001 vs. KUH.

5.3.2 Primary vs. secondary admissions

Secondary admissions were more than five times more frequent at OUH compared with KUH (34.4 % vs. 6.5 %). At both centres, secondary admitted patients were almost ten years older than in primary admitted patients. The secondary admissions were also more severely injured, measured both by ISS and NISS, and had a slightly higher pre-injury ASA-PS at both institutions (all P <0.001) (Table 8).

Table 8. Comparison of age, comorbidity and injury severity in primary and secondary admissions at KUH and OUH.

	KUH			**OUH**		
	Primary n=4185	**Secondary n=290**	**P**	**Primary n=2355**	**Secondary n=1236**	**P**
Age, years	38(25-54)	48(29-61)	<0.001	37(25-53)	46(27-64)	<0.001
ASA-PS	1(1-1)	1(1-2)	<0.001	1(1-2)	1(1-2)[a]	<0.001
ISS	5(1-11)	17(12-26)	<0.001	8(2-17)	14(8-22)	<0.001
NISS	6 (2-17)	27 (17-34)	<0.001	9 (2-22)	17 (10-29)	<0.001

Data are median and quartile. KUH: Karolinska University Hospital-Solna; OUH: Oslo University Hospital-Ullevål; ASA-PS: American Society of Anesthesiologists Physical Status; ISS: Injury Severity Score; NISS: New Injury Severity Score. [a]Higher ASA-PS in secondary admissions at OUH.

5.3.3 Trauma care processes

The characteristics of trauma care processes are presented in Table 9. The dispatch frequency of pre-hospital anaesthesiologist to the scene of injury was more than eight times higher for OUH patients than for KUH patients, and the pre-hospital intubation was performed 2.8 times more often in OUH patients. The higher pre-hospital intubation rate for OUH patients was only observed in primary admitted patients transported with helicopter (33.7 % [n = 227] vs. 7.7 % [n =53], P <0.001). Trauma patients were more often admitted to ICU and stayed there for a longer period of time at OUH than at KUH. Patients with less severe injuries (ISS 1-15) were admitted to ICU more frequently at OUH compared with KUH (17.0 % [n =403] vs. 8.3 % [n =294], P <0.001). There was no difference in ICU admissions amongst the most severely injured (ISS >40) between the two hospitals.

Table 9. Comparison of trauma care processes at KUH and OUH.

	KUH (n=4485)	OUH (n=3591)	P	U/M KUH	U/M OUH
Prehospital time (min)				123	300
Primary admissions[1]	46 (37-58)	37 (24-57)	<0.001		
Ground ambulance missions[1]	45 (36-57)	33 (22-52)	<0.001		
Helicopter ambulance missions[1]	52 (43-62)	65 (48-90)	<0.001		
Prehospital transportations					23
Ground ambulance missions	3393 (75.7%)	2552 (71.5%)	<0.001		
Helicopter ambulance missions	697 (15.5%)	984 (27.6%)	<0.001		
Other	395 (8.8%)	32 (0.8%)	<0.001		
Prehospital anaesthesiologist at scene of injury	149 (3.7%)	1088 (30.5%)	<0.001	452	27
Prehospital intubations	126 (2.8%)	280 (7.8%)	<0.001		3
Emergency room intubations[2]	297 (6.8%)	362 (10.9%)	<0.001		
CT scans	4029 (89.8%)	2901 (80.8%)	<0.001		
CT for primary admissions	3788 (90.5%)	2068 (87.8%)	<0.01		
Key emergency interventions	327 (7.3%)	326 (9.1%)	<0.01		
ICU admissions	844 (18.8%)	986 (27.5%)	<0.001		
ICU LOS[3] (days)	3 (1-7)	3 (2-10)	<0.01		
Hospital LOS (days)	1 (1-6)	3 (2-7)	<0.001	27	

Categorical data are presented as numbers and proportions (%) and continuous data as medians and quartiles. KUH: Karolinska University Hospital-Solna; OUH: Oslo University Hospital-Ullevål; U/M: Unknown/Missing; Prehospital time: Time from alarm (prehospital) to arrival to hospital; CT: Computer Tomography; ICU: Intensive Care Unit; LOS: Length of stay; [1]KUH: n=4185, OUH: n=2355; [2]KUH: n=4359, OUH: n=3308; [3]KUH: n=844, OUH: n=986.

5.3.4 Mortality and DOA

The unadjusted mortality proportion was lower at KUH (3.2%) than at OUH (5.6%). The relation was the opposite when considering the proportion of DOA patients, in which KUH had almost twice as many compared with OUH (21.4% vs. 11.4%). DOA patients were excluded in risk-adjusted survival analysis in the following section. Mortality in the different ISS interval is presented in Figure 8.

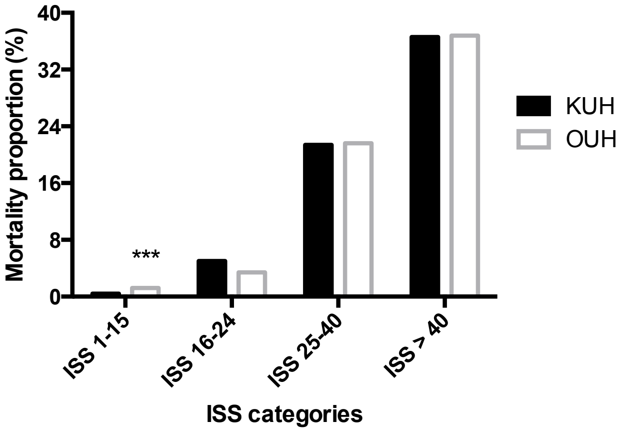

Figure 8. Mortality proportions for ISS intervals at KUH and OUH. DOA is excluded. KUH: Karolinska University Hospital-Solna; OUH: Oslo University Hospital-Ullevål; ISS: Injury Severity Score; DOA: Dead on arrival; ***P <0.001 vs. KUH.

5.3.5 Risk-adjusted survival between two trauma centres

TRISS risk-adjusted survival is presented in Table 10. In the population of primary admitted patients and the total populations, median risk-adjusted survival was higher at OUH than at KUH. This relation was the opposite when considering mean risk-adjusted survival which was higher at KUH. In contrast, both median and mean risk-adjusted survival was higher at KUH for secondary admitted population. The discrepancy between median and mean could be explained by different distributions of risk-adjusted survival between the two centres. Therefore, we examined the proportion and characteristics of patients with high Ps (defined as Ps ≥80%) who went on and died, consequently causing major penalties to total risk-adjusted survival (Table 11). The proportion of patients in this subgroup was larger at OUH compared with KUH and consisted of high number of secondary admissions with high age and comorbidity.

Table 10. Trauma Score-Injury Severity Score (TRISS) risk-adjusted survival at KUH and OUH.

A	**KUH**	**OUH**	**P**
All patients	0.55 (0.32-1.88)	0.82 (0.40-2.94)	<0.001
Primary admissions	0.51 (0.32-1.58)	0.59 (0.34-2.07)	<0.001
Secondary admissions	2.85 (1.00-9.17)	1.41(0.55-3.99)	<0.001
B			
All patients	0.64 (14.8)	0.01 (19.7)	<0.001
Primary admissions	0.36 (1.4)	0.25 (1.8)	<0.001
Secondary admissions	4.49 (2.24)	-0.44 (0.63)	<0.001

Data are presented as excess survivors per 100 trauma patients compared to TRISS model predictions. A: median and quartile; B: mean and standard deviation (SD); KUH; Karolinska University Hospital-Solna; OUH: Oslo University Hospital-Ullevål.

Table 11. Characteristics of patients with probability of survival (Ps) ≥80% who died.

	KUH	**OUH**	**P**
Number of patients (proportion of total population)	54 (1.2%)	80 (2.2%)	<0.001
Secondary admissions	7 (13%)	42 (52.5%)	<0.001
Age (years)	83 (69-90)	72 (46-83)	<0.01
Pre-injury ASA-PS ≥3	21 (39.6%)	48 (60.8%)	<0.05
ISS	21 (16-26)	25 (14-16)	0.400
NISS	27 (22-38)	34 (20-50)	0.148

Categorical data are presented as numbers and proportions (%) and continuous data as medians and quartiles. KUH; Karolinska University Hospital-Solna; OUH: Oslo University Hospital-Ullevål; ASA-PS: American Society of Anesthesiologists Physical Status; ISS: Injury Severity Score; NISS: New Injury Severity Score.

5.4 VALIDATING NORMIT – A SCANDINAVIAN RISK-ADJUSTMENT METHOD

NORMIT 1 and 2 were compared with regards to their accuracy in survival prediction in two Swedish trauma populations containing of (1) a national trauma (NT) population consisting of all patients registered in SweTrau admitted to designated trauma centres and university hospitals as well as regional and local hospitals during the study period, and (2) a subpopulation consisting of patients registered in a designated trauma centre, referred to as the trauma centre (TC) subpopulation.

Figure 9 shows the inclusion and exclusion process in the study giving rise to the different populations. 26504 patients were included in the study. The proportion of missing data was 18.7% (n=4950) in the NT population and 2.6% (n=103) in the TC subpopulation. After exclusion of patients with missing data, the NT population consisted of 21554 patients, and the TC subpopulation consisted of 3972 patients.

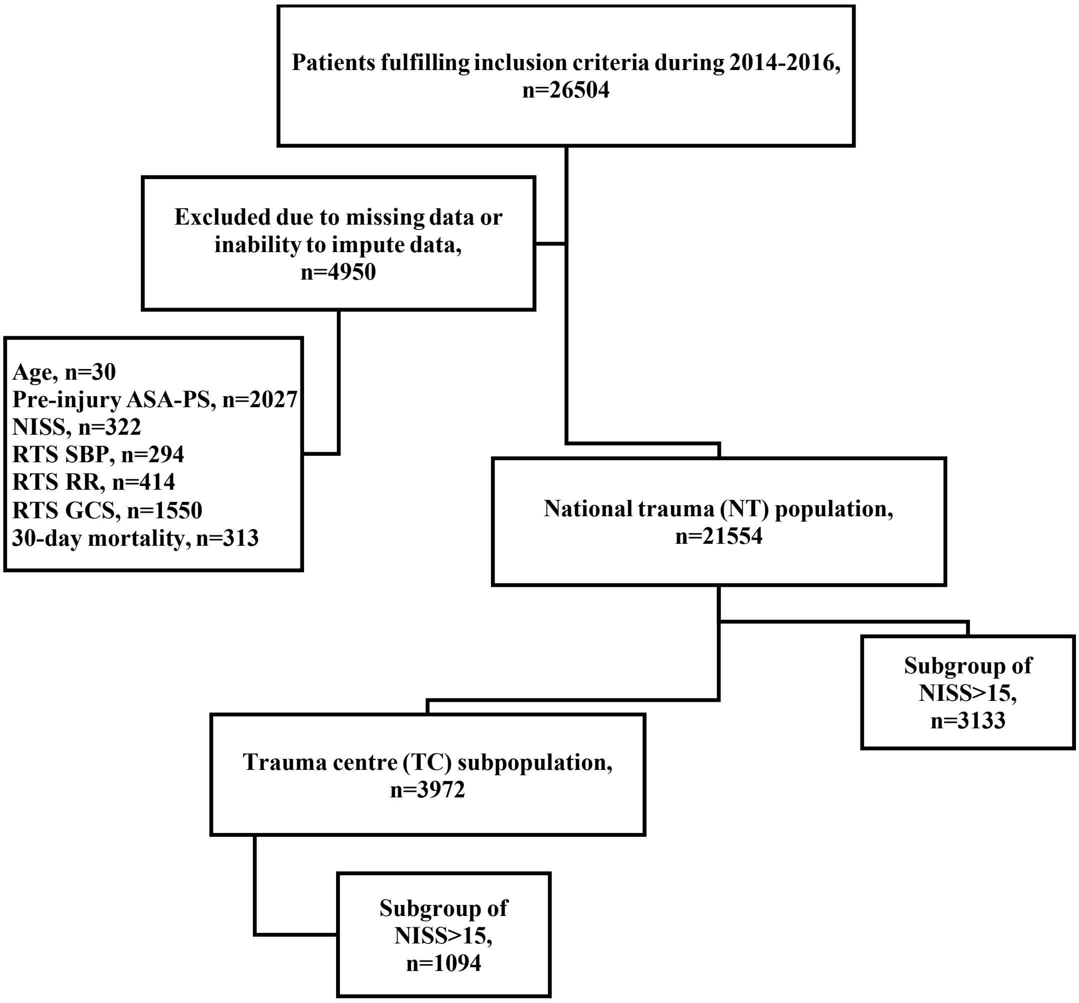
Patients fulfilling inclusion criteria during 2014-2016, n=26504
Excluded due to missing data or inability to impute data, n=4950
Age, n=30
Pre-injury ASA-PS, n=2027
NISS, n=322
RTS SBP, n=294
RTS RR, n=414
RTS GCS, n=1550
30-day mortality, n=313
National trauma (NT) population, n=21554
Subgroup of NISS>15, n=3133
Trauma centre (TC) subpopulation, n=3972
Subgroup of NISS>15, n=1094

Figure 9. Inclusion flowchart of the different populations and subpopulations. ASA-PS: American Society of Anesthesiologists Physical Status; NISS: New Injury Severity Score; RTS: Revised Trauma Score; SBP: Systolic blood pressure; RR: Respiratory rate; GCS: Glasgow Coma Scale.

5.4.1 Population characteristics

The characteristics of the two study populations are presented in Table 12. In comparison with the NT population, patients in the TC subpopulation were more severely injured (according to both ISS and NISS), had more deranged vital signs on admission (according to RTS), had poorer pre-injury health status (according to ASA-PS) and higher mortality.

Table 12. Patient baseline characteristics for the national trauma (NT) population and the trauma centre (TC) subpopulation.

	National trauma (NT) population, n=21554	**Trauma centre (TC) subpopulation, n=3972**	**P**
Age (years)	35 (21-56)	41 (26-59)	<0.001
Male gender	13531 (62.8)	2689 (67.7)	0.015
Penetrating injury	1498 (7.0)	457 (11.5)	<0.001
ISS	2 (1-9)	5 (1-12)	<0.001
NISS	3 (1-9)	6 (3-17)	<0.001
30-day mortality	652 (3.0)	172 (4.3)	<0.001
Pre-injury ASA-PS			
1	15595 (72.4)	2534 (63.8)	<0.001
2	4169 (19.3)	980 (24.7)	
3	1688 (7.8)	425 (10.7)	
4	102 (0.5)	33 (0.8)	
RR RTS Category			
4	20435 (94.8)	3716 (93.6)	<0.001
3	837 (3.9)	156 (3.9)	
2	110 (0.5)	47 (1.2)	
1	26 (0.1)	9 (0.2)	
0	146 (0.7)	44 (1.1)	
SBP RTS Category			
4	21139 (98.1)	3854 (97.0)	<0.001
3	175 (0.8)	37 (0.9)	
2	99 (0.5)	35 (0.9)	
1	34 (0.2)	9 (0.2)	
0	107 (0.5)	37 (0.9)	
GCS RTS Category			
4	20264 (94.0)	3489 (87.8)	<0.001
3	547 (2.5)	179 (4.5)	
2	268 (1.2)	115 (2.9)	
1	128 (0.6)	60 (1.5)	
0	347 (1.6)	129 (3.2)	
T-RTS	12 (12-12)	12 (12-12)	<0.001

Categorical data are presented as numbers and proportions (%) and continuous data as medians and quartiles. ISS: Injury Severity Score; NISS: New Injury Severity Score; ASA-PS: American Society of Anesthesiologists Physical Status; RR: Respiratory rate; RTS: Revised Trauma Score; SBP: Systolic blood pressure; GCS: Glasgow Coma Scale; T-RTS: Triage-RTS.

Median Ps values for survivors and non-survivors in the NT and TC subpopulations, calculated by the two NORMIT models, are shown in Table 13. Median Ps for non-survivors was higher with NORMIT 2 than with NORMIT 1 in both populations. Both NORMIT 1 and 2 produced higher median Ps values for non-survivors in the NT population than in the TC subpopulation.

Table 13. Predicted survival in survivors and non-survivors in the national trauma (NT) population and the trauma centre (TC) subpopulation.

	National trauma (NT) population, n=21554		Trauma centre (TC) subpopulation, n=3972		
	Survivors n=20902	**Non-survivors n=652**	**Survivors n=3800**	**Non-survivors n=172**	**P***
NORMIT 1 Ps	0.9994 (0.9961-0.9997)	0.6004 (0.2450-0.8689)	0.9983 (0.9889-0.9996)	0.3464 (0.0838-0.6983)	<0.001
NORMIT 2 Ps	0.9984 (0.9954-0.9991)	0.6647 (0.3139-0.9051)	0.9973 (0.9902-0.9989)	0.4881 (0.1245-0.7671)	<0.001
P†		<0.001		<0.001	

Data are presented as medians and quartiles. NORMIT: Norwegian survival prediction model in trauma; Ps: Probability of Survival; *P measured between non-survivors in the two populations in each model; †P measured between non-survivors in the two models in each population.

5.4.2 Accuracy of NORMIT 1 and 2

5.4.2.1 *Discrimination*

Both models displayed excellent discrimination in all populations and subgroups when evaluated with area under receiver operating characteristic curve (Figure 10), with no significant differences between AUCs in any group (Table 14).

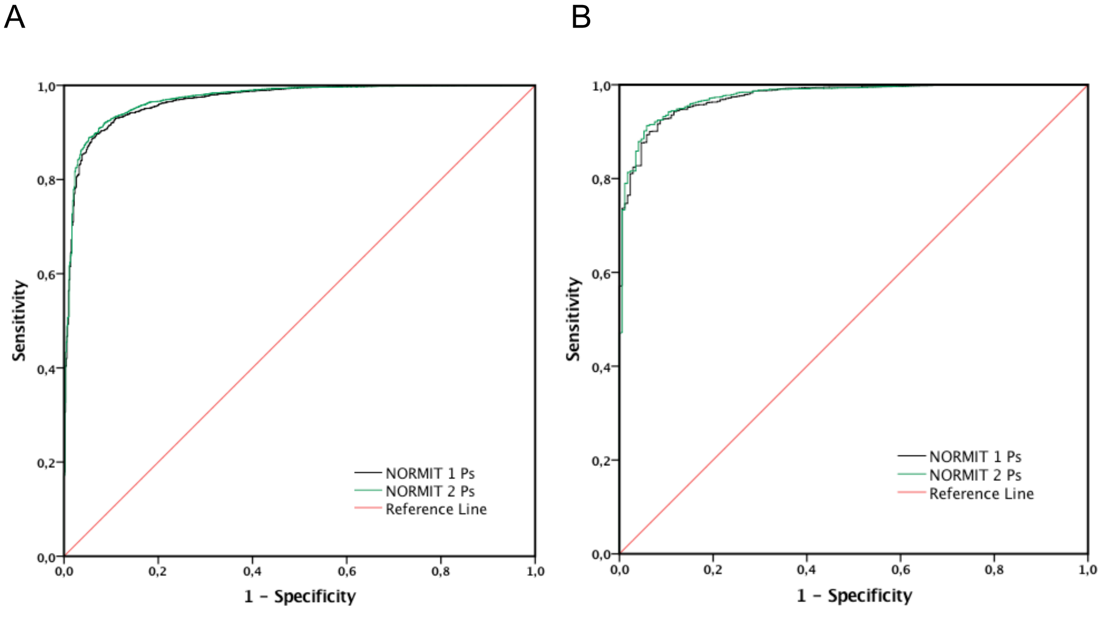

Figure 10. Receiver operating characteristic (ROC) curves for NORMIT 1 (black line) and NORMIT 2 (green line). A, National trauma (NT) population; B, Trauma centre (TC) subpopulation. The red reference (diagonal) line represents the performance of a model that is no better than a random guess, i.e., AUC = 0.5. See Table 14 for numeric values regarding AUC. NORMIT: Norwegian survival prediction model in trauma; AUC: Area under the receiver operating characteristic (ROC) curve.

Table 14. Area under the receiver operating characteristic curve (AUC) for NORMIT 1 and 2 in the two trauma populations.

	NORMIT 1	**NORMIT 2**
National trauma (NT) population	0.968 (0.962-0.974)	0.971 (0.965-0.977)
NISS >15 subgroup	0.933 (0.922-0.945)	0.937 (0.926-0.948)
Trauma centre (TC) subpopulation	0.974 (0.965-0.983)	0.976 (0.967-0.985)
NISS >15 subgroup	0.964 (0.952-0.976)	0.965 (0.954-0.977)

Data are presented with 95% confidence intervals. The discrimination capabilities of the two models were not considered to be significantly different if their 95% CIs overlapped. NORMIT: Norwegian survival prediction model in trauma; NISS: New Injury Severity Score.

5.4.2.2 Calibration

Both models displayed a poor calibration in the NT population (Figure 11) with lower observed than predicted survival, in particular for NORMIT 2 which overestimated survival through the Ps interval of 0.23-0.98 (Figure 11B, 95% confidence level).

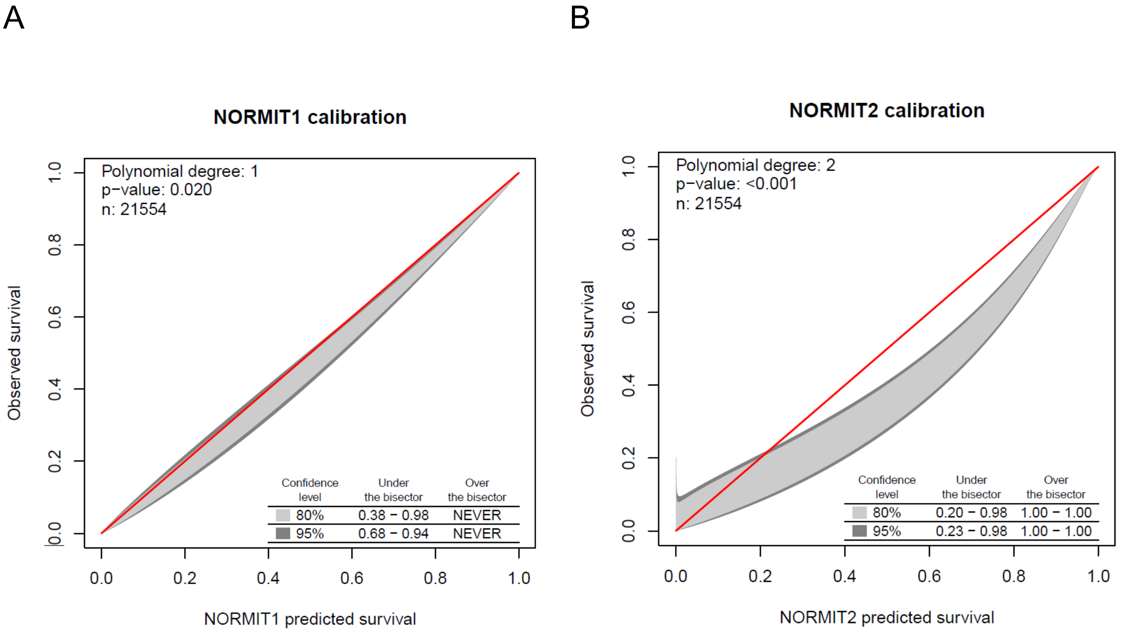

Figure 11. GiViTI calibration belt for NORMIT 1 (A) and NORMIT 2 (B) in the national trauma (NT) population. The bisector (red reference line) represents identity between predicted and observed survival rate. The calibration belt (grey area) depicts the estimated relationship between the model predictions and the probabilities of the true response, with 80% (light grey) and 95% (dark grey) confidence levels. The bottom-right table reports the ranges of the predicted probabilities where the calibration belt deviates significantly from the bisector, i.e., where observed survival is significantly different from what the model predicts. NORMIT: Norwegian survival prediction model in trauma.

Similar relationships were demonstrated in the severely injured (NISS >15) subgroup of the NT population (Figure 12), where NORMIT 2 overestimated survival through the entire Ps interval (Figure 12B).

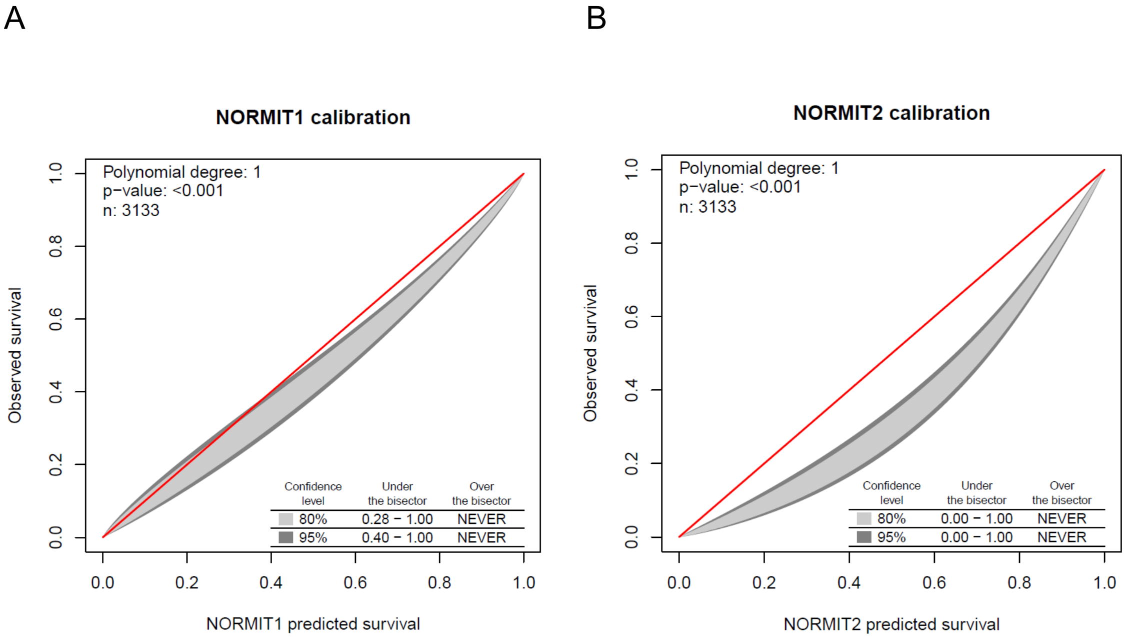

Figure 12. GiViTI calibration belt for NORMIT 1 (A) and NORMIT 2 (B) in the national trauma (NT) population with NISS >15. See Figure 11 for details. NORMIT: Norwegian survival prediction model in trauma; NISS: New Injury Severity Score.

In contrast, in the TC subpopulation NORMIT 1 underestimated survival in the Ps interval 0.38-1.00 (Figure 13A), while NORMIT 2 showed good calibration as the 95% calibration belt never crossed the diagonal bisector line, i.e., there was no under- or overestimation of survival (Figure 13B).

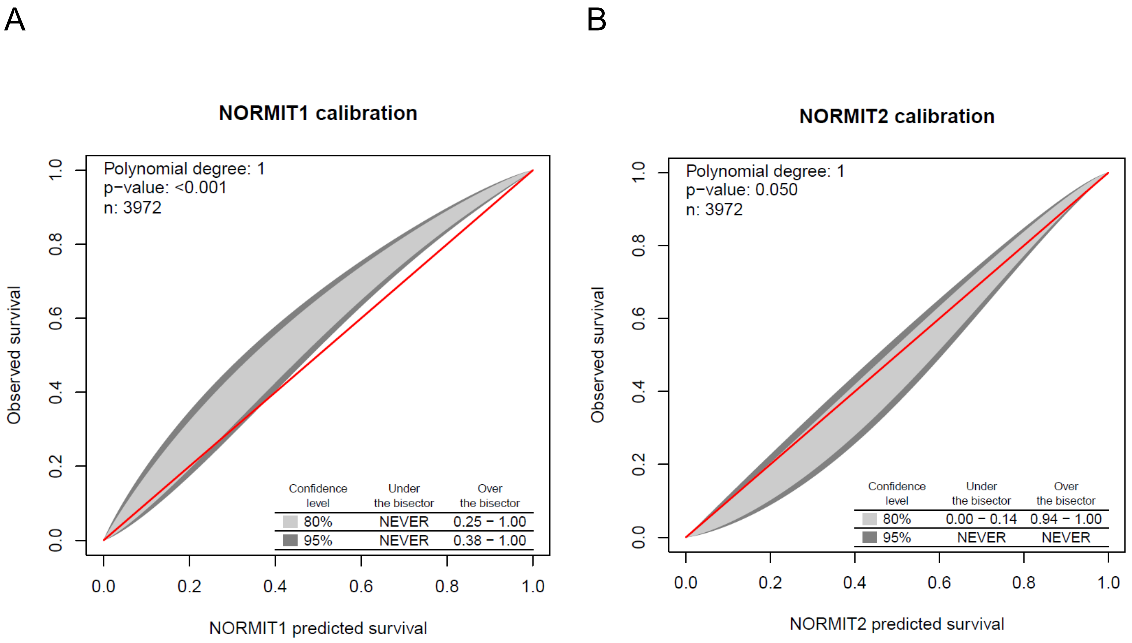

Figure 13. GiViTI calibration belt for NORMIT 1 (A) and NORMIT 2 (B) in the trauma centre (TC) subpopulation. See Figure 11 for details. NORMIT: Norwegian survival prediction model in trauma.

A nearly identical picture was observed in the subgroup with NISS>15 in the TC subpopulation (Figure 14).

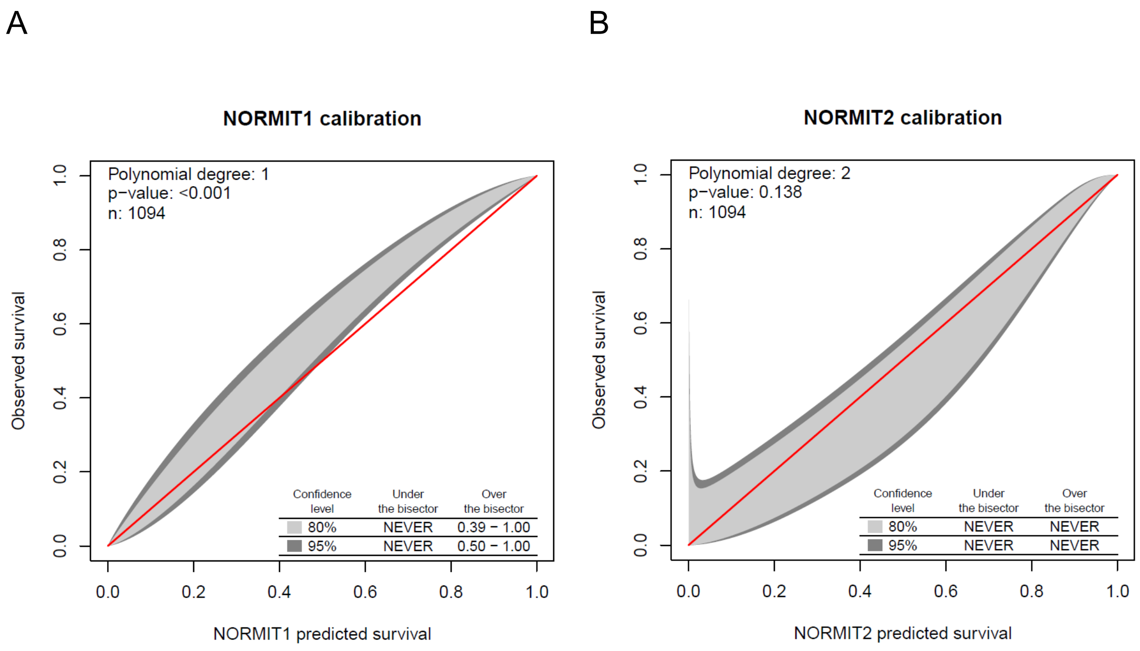

Figure 14. GiViTI calibration belt for NORMIT 1 (A) and NORMIT 2 (B) in the trauma centre (TC) subpopulation with NISS >15. See Figure 11 for details. NORMIT: Norwegian survival prediction model in trauma; NISS: New Injury Severity Score.

6 DISCUSSION

6.1 MORTALITY REVIEW – A NECESSITY?

6.1.1 Non-trauma related death

During 2007-2011, 10.5% (36/343) of the 30-day mortality in the trauma registry were not related to the injury. The high proportion of non-trauma related deaths persisted during 2012-2016 and reached, 14.4% (43/298). These proportions were higher than in previous studies, which for in-hospital death reported 5%[9] and for 30-day mortality 1.2%[51] of the deaths, not related to the prior traumatic event. Non-trauma related deaths in Papers I and II, were mainly due to an emergency medical condition, but the review revealed that they had indeed been subject to trauma and admitted with TTA, thus meeting inclusion criteria for the trauma registry. Therefore, it is advisable to establish if a death is trauma related in 30-day mortalities extracted from the trauma registries. The non-trauma related deaths in Paper I, had minor injuries (median ISS 2 [1-6]). Accordingly, it is less likely that the inclusion of these patients in registries will affect mortality rates among the severely injured patients (ISS > 15).

6.1.2 DOA patients and the criteria for identification

The DOA rate is seldom reported in studies and it is therefore difficult to get an idea of the actual proportion when comparing mortality between different centres. Additionally, differences between pre-hospital care guidelines and national policies for pronouncing death in the field, will also influence the number of DOA patients in hospitals. The most important limitation may however be the fact that there is not a universal method or criterion to identify these patients.

During 2007-2011, clinical review identified 17.6% (54/307) of the patients who died from trauma related causes as DOA. The DOA criteria according to Powell et al.[21] were utilized and in 49 (90%) of the patients, the criteria were fulfilled. The five patients that failed to fulfil the criteria had the absence of performed pre-hospital CPR.

Similar to non-trauma related death, the high rate of DOA persisted during 2012-2016 (17.6%) compared to 2007-2011, and reached 24.3% (62/255).

Byrne et al.[22] introduced in 2016 a new set of definitions based on presenting vital signs which demonstrated excellent predictive utility to identify patients who will go on to die. A DOA patient was defined by having no heart rate or SBP and GCS score motor component = 1 on admission. Our DOA patients were identified by clinical review and autopsy reports in both Paper I and II. In Paper II we applied retrospectively the Byrnes's definition, and demonstrated excellent agreement between these criteria and the review's judgment, thus suggesting that they are more precise (100%), in comparison with the Powell et al. criteria (90%), and that they could be used to identify DOA.

6.1.3 The effects of DOA on registries and quality improvement protocols

In Paper I, we showed that the exclusion of DOA reduced overall mortality from 4.2% to 3.4% and among ISS >15, mortality showed a trend in reduction from 17.5% to 14.8%. Further, exclusion of DOA patients increased the median age and the time to death, and decreased the median ISS. Therefore, our results support the need of standardized DOA definitions (such as Byrne's) which facilitates purposeful quality evaluations of mortality statistics[21, 83].

In Paper II, DOA patients were excluded in preventability analysis but included when looking for in-hospital errors. In almost every fifth DOA patient (12/62), one or more errors committed in trauma management were identified. For this reason, we suggest that DOA patients can be excluded from reports on mortality statistics and preventability assessment[22, 84] but should be included when assessing errors.

6.1.4 Causes of death

In our material, TBI was the most common cause of death independent of inclusion or exclusion of DOA, accounting for approximately 60% of the death over the period of 2007-2016. Comparable studies demonstrate similar high proportion of TBI as the main cause of death in Scandinavia (67%)[85] but smaller proportions (50%) in Europe and the United States[25, 86-90]. The reason for this may be differences in the proportion of blunt vs. penetrating trauma, out of which blunt trauma dominates in Scandinavia (>90%) whereas, in the United States and some parts of Europe, penetrating injury is more common. Additionally, another contributing aspect is the high median age in our trauma deaths (>70years), among which TBI was the most common cause of death. Our findings were in line with a study by Thompson et al.[91] which also demonstrated TBI as the most frequent cause of death in the geriatric trauma population. This is explained by a large proportion of elderly, which are subject to low energy blunt trauma (i.e. falls from same height or falls in stairs) and fulfils TTA criteria due to a discreet reduction in GCS (<14).

As in the case of characteristics amongst the deaths, the inclusion/exclusion of DOA patients altered the causes of death in the trauma population. In our material, exclusion of DOA patients increased the proportion of TBI as the cause of death from 50% to 61.6% and reduced haemorrhage from 21.4% to 6.8%.

The low proportion of haemorrhage as a cause of death (6.8%) during 2012-2016 is even lower in comparison with the time period 2007-2011 (11.1%), and with other studies in Scandinavia[62, 85]. During the same period the proportion of penetrating injuries increased from 8 to 11.1% at KUH, but the demography and severity of injury remained unchanged. The reason for the reduction of haemorrhagic death over time is not fully investigated. However, the implementation of new resuscitation strategies at our centre during the past six years (e.g., massive transfusion protocol and structured training in early resuscitation) may have contributed to the reduction of haemorrhage as a cause of death.

Deaths caused by organ dysfunction have declined substantially[92], some studies suggest a decline from 5% to 0% during the last decade[93-95]. This reduction is believed to be a result of improvements in critical care[94, 95], as well as advancements in resuscitation and operative treatment strategies[96]. In our material, 15% of deaths (2012-2016) were late deaths caused by organ dysfunction which is a small reduction compared to 2007-2011 (18%). It is likely that the reason for the high rate of death due to organ dysfunction compared to previous studies[93-95], is the large proportion of old comorbid trauma patients at our centre. This group is associated with later death due to pneumonia, respiratory insufficiency, kidney failure or combinations thereof.

Noteworthy, and likely a weakness, is that death was deemed to be due to organ dysfunction based only on clinical documentation in Paper II. In Paper I, however death was judged to be attributed to organ dysfunction when clinical documentation *or* the SOFA[73] score supported that (alone or in combination). Therefore, we cannot exclude that this has not affected the proportion of organ dysfunction as a cause of death in these papers.

6.1.5 Timing of death

There is a strong connection between cause of death and time of death, which was also observed in our studies; haemorrhagic deaths occur early, often within 1-2 hours (median time to death, minutes (IQR); 2007-2011: 60 [18-180], and 2012-2016: 131 [61-227]) and most TBIs and organ dysfunction occur late. As a result of that, the high number of deaths due to TBI and organ dysfunction increases the overall median time to death in our patients, in which the majority occurred between one and seven days or after. The temporal distribution of death remained similar throughout the study periods included in Paper I and II.

6.1.6 Preventable death and identification of errors by clinical review

To cite Donabedian, "Although some outcomes are generally unmistakable and easy to measure (death, for example) other outcomes, not so clearly defined, can be difficult to measure"[2], for instance preventable death. The reasons for this has previously been discussed (Background; Section 2.2).

In Paper II, we observed a relatively low proportion of potentially preventable deaths (4.0%) compared to what have been previously documented from other centres. Preventable death rates have been reported to be as high a 33%[28, 90, 97, 98] and as low as 2.5%[24, 99], the latter in high volume centres. The large range could be explained by differences in the definition of preventable deaths, the lack of standardization of the method to determine preventability or differences in trauma care quality or a combination thereof. Therefore, this uncertainty reduces its role as a comparison tool of quality in between centres. Instead it may be more appropriate within an institution measured over time.

The method by which preventability is identified, i.e., clinical peer review, has however advantages, one being identification of errors in patient care. In our material, we identified one or more errors in trauma management, in one patient of five. The majority of errors were procedural errors or inappropriate treatment during the initial resuscitation phase or during surgery. Interestingly, even though most errors were observed early, all death (including potentially preventable death) occurred late between 1 and 7 days or after, which is in line with what Teixeria et al.[24] also demonstrated. In total, 67 errors were identified in our study, thirteen of them being in potentially preventable deaths. Almost half (29 of 67) of the errors were due to clinical judgment errors, making the human factor the most common cause. This is also in line with previous studies in which the main type of error was clinical in overall mortality and in preventable deaths[24, 90]. In spite of the advances in diagnostic and interventional imaging, monitoring technology and critical care, the importance of human factor still remains[24], i.e. the competence of personnel involved in patient care (structure) and what is actually done by the personnel involved (process). Having said that, the human factor is not exclusively a bad thing. The Hawthorne effect, in which the awareness of being reviewed by health care providers and its potential positive influence on behaviour[100, 101], should not be disregarded.

6.2 PREDICTION MODELS – A VALUABLE RISK-ADJUSTMENT TOOL

6.2.1 Comparison between trauma centres – OUH vs. KUH

In Paper III, we demonstrated a higher survival at OUH when comparing medians and for KUH when comparing means of risk-adjusted survival in the total trauma population and in primary admissions. In secondary admissions, however, we found a survival disadvantage for OUH in both median and mean risk-adjusted survival, compared to KUH. The following main differences between OUH and KUH, were observed: The trauma patients at OUH were 1) older with a higher ASA-PS, 2) more severely injured, 3) more often secondary admissions and 4) more often transported with helicopter, in which a pre-hospital anaesthesiologist was present, compared to the trauma patients at KUH.

6.2.2 TRISS' limitations in a Scandinavian setting

The discrepancy between median and mean could be explained by variation in distributions of risk-adjusted survival (i.e., skewed) between the two centres, which in turn may be a result of different case-mix. Therefore, we examined the proportion and characteristics of patients with high Ps (≥80%) who, in spite of that, went on to died, consequently contributing notably to the lower mean survival rates. The patients in this subgroup (dead patients with a Ps ≥80%), had two distinct characteristics, i.e., high median age and high proportion of comorbidity. Comparing the two hospitals, we couldn't demonstrate a difference in ISS in this subgroup but the OUH population were older, had more comorbidity and a higher proportion of secondary admitted patients, compared to KUH. There were nearly twice as many patients in this subgroup at OUH than at KUH, thus contributing to the much lower institutional mean risk-adjusted survival at OUH. In the TRISS model, age is categorized in two groups (i.e., for adults:15-54 years and ≥55 years) with the same survival handicap for all patients ≥55 years. In other words, it does not differentiate between a patient who is 55 years old or 100 years old. Additionally, it has been shown that patients with high comorbidity also have an increased mortality risk[102, 103]. Comorbidity is disregarded in the TRISS model; thus, it is likely that the Ps is overestimated in a comorbid and old trauma patient.

We suggest that, secondary admissions, need to be analysed separately when comparisons are made between hospitals. The reason for this is the fact that treatment is initiated in the pre-hospital setting, continued at the receiving hospital and pursued during inter-hospital transportation, therefore adding to the heterogeneity within secondary admissions compared to primary. The median risk-adjusted survival was twice as high, and the mean risk-adjusted survival was 4.5 times higher for secondary admissions at KUH compared to OUH. These differences were substantially bigger than the differences observed in primary admissions. Secondary admissions at both hospitals were characterized by high age and higher level of comorbidity. The lower survival amongst secondary admissions at OUH could be explained by the fact that there were more patients with Ps ≥0.8 transferred from other hospitals that died at OUH. As discussed above, the adjustment for age in the TRISS model is unsatisfactory, especially for analyses in the secondary admission group, in which the median age by far surpasses the upper age limit of ≥55 years (83 years at KUH and 72 years at OUH).

All in all, our data suggests that the observed differences in risk-adjusted survival between the trauma centres may be an effect of suboptimal adjustment for age and disregard of comorbidity. However, it is not possible to rule out the influence of the system differences between the centres on mortality.

6.2.3 A tool for identifying preventable death?

WHO suggests, in the guidelines for the preventable death panel review procedure, cut-off limits for Ps in preventability analysis. In Paper II, we tested these limits retrospectively by comparing them to potentially preventable and non-preventable death judged by the peer review.

In the DOA patients, both TRISS and NORMIT estimated adequately a very low survival rate, but in all other deaths, i.e., non-DOA patients, TRISS was more optimistic, estimating higher survival compared to NORMIT. In other words, TRISS was outperformed by NORMIT. The features of NORMIT and its suggested benefit has previously been described. The model scores injury by using NISS instead of ISS, incorporates age as a continuous variable (in contrast to categorical) and uses pre-injury ASA-PS as a measure of health status. Therefore, in line with prior conclusions, the better performance of NORMIT compared to TRISS may be explained by the fact that it is more suited in survival prediction in our old and comorbid population with predominantly blunt injury mechanism to a single body region (isolated TBI)[104].

By applying the WHO's Ps cut-off limit to identify non-preventable deaths (<25%), 2 of the 10 potentially preventable deaths would have been missed (when using both TRISS and NORMIT) and should therefore not be used to exclude patients from peer review. When the cut-off limit of Ps >50% was used to identify potentially preventable deaths for peer review, the 3 and 4 potentially preventable deaths with a Ps lower than 50% (calculated both by TRISS and NORMIT) would never have been identified. Taken together, our results demonstrate that the cut-off limits of Ps <25% and >50% cannot be used as a tool to identify preventable or non-preventable deaths and the peer review of all death should be regarded as the preferred method.

Survival prediction models are of value when applied on an entire trauma population, in particular, over time within the same institution, but its contribution in the analysis of preventability in the individual patient is limited. The inconsistency between the predicted survival and the actual outcome of the individual patient in Paper II suggests that the way we treat our patients (process of care) and their response to treatment, may overrule the effect of physiology on admission, patient factors and degree of injury (on which the Ps is calculated) on outcome.

6.2.4 NORMIT - a more suitable prediction model?

To evaluate and compare the NORMIT models' survival prediction abilities we used receiver operating characteristic (ROC) curves and the GiViTI calibration belt in two distinct populations, one national population (NT) and one subpopulation consisted of patients admitted to a single trauma centre (TC). To further investigate the effect of case-mix we subdivided the two populations in regard of injury severity (NISS>15).

6.2.4.1 Discrimination - ability to separate survivors and non-survivors

The high AUCs for NORMIT 1 and 2 demonstrates an excellent ability to separate survivors and non-survivors[105] in both study populations, and also in their subgroups of severe injuries. The AUC is considered to be a popular and useful statistic method, in particular in development of diagnostic tests but it may not necessarily detect small differences in discriminative ability between two models[106]. A majority of the trauma patients did not have life-threatening injuries, thus having a high Ps and therefore easy to predict as survivors. A better indicator of high discriminating ability is therefore less overlap in Ps values between trauma survivors and non-survivors[79]. For both NORMIT 1 and 2, we found high median Ps values among trauma survivors in both populations and, as expected, lower median Ps values among non-survivors. The median Ps values in non-survivors were higher in the NT population than the TC subpopulation (0.60 vs. 0.35 according to NORMIT 1; 0.66 vs. 0.49 with NORMIT 2). In other words, patients that went on to die in the NT population had a clearly higher probability of surviving than patients who died after being admitted to the TC subpopulation. The actual difference between trauma centres and non-trauma centres is probably even larger, since the trauma centre subpopulation is included in the total national population.

The observed differences need to be commented. Firstly, the TC subpopulation is expected to have generally lower Ps values because it consists of more severely injured patients who are also older and have more comorbidity (see discussion in previous section). Secondly, the resources and trauma competence available at a designated trauma centre should be associated with better performance, leading to more lives saved and thus to lower Ps in non-survivors. The observed median Ps values in the TC subpopulation in Paper IV are comparable to those previously found in the Norwegian OUH population, where median Ps of 0.32 (NORMIT 1) and 0.41 (NORMIT 2) were found[54]. Both OUH and KUH are designated trauma centres with comparable trauma populations, and assumedly with similar trauma processes and quality of care which should yield similar outcomes.

Furthermore, the Ps values were lower for NORMIT 1 compared to NORMIT 2 among non-survivors both in the NT (0.60 vs. 0.66) and even more pronounced in the TC (0.35 vs 0.49) subpopulation. This observation suggests that the NORMIT 1 model showed better discrimination than the NORMIT 2 model. An alternate interpretation is that Ps values estimated with NORMIT 2 can be expected to be higher because the NORMIT 2 model was derived from a more recent trauma population (2005-2009) with a lower risk-adjusted mortality[78] compared to the original NORMIT 1 population (2000-2006).

6.2.4.2 Calibration – agreement between predicted and observed survival

More important in this setting is to accurately assess the model calibration, i.e., the agreement between survival predictions and observed outcomes over the full span of probabilities[105]. Skaga et al stated[54] that the mildly and the very severely injured patients are easier to predict as survivors and non-survivors respectively, and therefore a well calibrated prediction model is distinguished by high performance in the mid-bands of Ps strata. In the current study, the GiViTI calibration belts displayed a variety of deviations dependent of population and injury severity. NORMIT 1 overestimated survival in the NT population independent of injury severity, however to a lower extent than NORMIT 2 which overestimated survival in wider Ps-intervals. Hence, we conclude that both models perform poorly (generally more optimistic) in our NT population independent of injury severity but that NORMIT 1 outperforms NORMIT 2. Contrary to what was seen in the NT population, we demonstrated in the TC subpopulation an underestimation of survival by NORMIT 1 in the higher Ps-intervals independent of injury severity, but good model performance for NORMIT 2 independent of injury severity. This implies that the observed survival rates were equal to the survival rates predicted by NORMIT 2.

The different model performance between the NT and TC populations might be explained by selection differences or case-mix. However, that is exactly (at least the latter) what the NORMIT model was designed to adjust for. More likely, is the fact that the variation in trauma outcome between the two populations, may be caused by differences in trauma care processes and quality. It is expected that designated trauma centres perform better than non-designated trauma hospitals, in particular amongst severely injured patients. Consequently, survival can be expected to be lower among the NT population which consisted of patients admitted to all Swedish hospitals with an emergency unit.

The poor performance of the NORMIT model in a national Swedish setting might also be due to major differences between the Swedish national trauma system and the local system in Southeast Norway where the NORMIT model was derived (i.e., selection differences). In the Southeast Norway trauma system, there is a single regional Level I trauma centre with cooperating hospitals and an extensive emergency medical system including anaesthesiologist-manned cars and helicopters delivering advanced emergency care at the site of injury and during patient transport[54], that supplement ground ambulances. This may also contribute in explaining the good performance in the Swedish trauma centre, which in many regards is similar to the original model derivation and validation system[104].

6.3 LIMITATIONS

Specific methodological weaknesses of different review methods as well risk-predictions models (in particular TRISS) have previously been discussed in this thesis. In the following section, we will focus on more general limitations.

6.3.1 Study design

All papers in this thesis are based on observational retrospective cohort studies. In general, this study design is considered to be of lower grade, especially in comparison to randomized controlled trials (RCT) which are considered to be top ranked in the hierarchy of evidence. Having said that, the prospective randomization process is challenging, in particular in a trauma setting, mainly due to ethical reasons (for instance obtaining informed consent).

The retrospective design also needs to be commented. This type of design may affect and potentially reduce the quality of the data. However, all trauma registry data (including SweTrau and local trauma registry at KUH and OUH) were acquired prospectively, the trauma registries are based upon the same core dataset, the clinical patient records are exclusively computerized and of good quality and the amount of missing data was generally small except in Paper IV. The amount of missing data, causes and its implications is further elaborated in the coming section.

6.3.2 Missing data

In the original NORMIT study by Jones et al.[53], missing data was less than <1%, in the Finnish external validation study by Raj et al.[60] 7.1% and in the recent NORMIT 2 update study by Skaga et al.[54] 0.26%. In Paper IV we observed 18.7% missing data in the NT population and 2.7% in the TC subpopulation.

In the NT population, the data entry was reliant on multiple sources i.e., participating hospitals, majority being non-designated trauma hospitals with limited structural resources and competence in trauma management in comparison to designated trauma centres, which may explain the high number of missing data, compared to the TC subpopulation.

Similar to Jones and Raj et al. (and many others)[44, 53, 54, 107, 108], we accounted for the missing hospital values by replacing them with pre-hospital ones and when that was not possible we used listwise deletion. There is no established cut-off in the literature regarding an acceptable percentage of missing data in a dataset for valid statistical inferences but a missing rate of greater than 10% has been suggested to interfere with statistical analysis[107]. The pattern of missing data in trauma registries is rarely at random, and studies on trauma populations from United States have demonstrated that patients excluded due to missing RTS values had more severe injuries and worse prognosis than patients with complete data and that such differential exclusion will bias the conclusions drawn[17, 44, 77, 109]. Similar to other studies, missing RTS values and ASA-PS classifications were the most common reason for exclusion in the Paper IV and this may have affected the analysis regarding NORMIT's accuracy, particularly in the NT population. The missing data in Paper IV illustrates also the common dilemma of trying to enhance the precision of prediction models based on variables that are not always easy to collect. The more variable you add to the model the more you increase the risk of problem with missing data.

6.3.3 Different registries and injury coding

In Papers III and IV, the data that were used, originated from different registries and thus coded and inserted by different registrars/coders. Without an inter-rater reliability test prior to data comparison, it is impossible to rule out differences in coding practice between the different registries, but the Utstein Trauma Template used by all the involved registries and the formal training of trauma registrars/coders and their certification in injury coding (Abbreviated Injury Scale [AIS])[68-70] by the Association for the Advancement of Automotive Medicine (AAAM)[71], were meant to minimize such differences.

In Paper III, during the first part of the study, the anatomic injuries at KUH were coded according to AIS 2005 (AIS05)[69] and according to AIS 2005-update 2008 (AIS08)[70] during the rest. At OUH, all injuries were coded according to AIS 2005-update 2008 (AIS08)[70]. It has been demonstrated that different AIS versions (i.e. AIS98[68] vs. AIS08) are not always comparable[110] but similar comparisons between AIS05 and AIS08 have not been made. Thus, we cannot rule out that the differences in anatomic injury classification may have disturbed the comparison.

The same rationale is applicable on Paper IV. The different AIS versions might have contributed to the poor calibration ability of NORMIT 1 and 2 in the NT population. In SweTrau, NISS is coded according to AIS08, while both NORMIT models are based on AIS98. It has been suggested that AIS08 generates lower ISS and NISS than AIS 98[111]. Seemingly lower injury severity would lead to higher estimated Ps, i.e., overestimated survival for a given injury. This could however not explain the results from the TC subpopulation with underestimation of survival by NORMIT 1 and good model performance by NORMIT 2, which in fact contradicts the above reasoning. Further, in the original NORMIT 2 study the model showed even better performance when it was "stressed" with AIS08[54].

6.3.4 Different methods of measuring model performance

In Paper IV, in order to measure model performance, we used the GiViTI calibration belt, which is a different method compared to the methods used in the original NORMIT 1 and 2 models. In the NORMIT 1 model, calibration was first explored through calibration plots, and second by using a Hosmer–Lemeshow (H-L) goodness-of-fit test[112]. In the NORMIT 2 model, calibration was explored as in NORMIT 1 through calibration plots but the overall model performance was evaluated with the scaled Brier score[113]. Even though the GiViTI belt and H-L test have been found to generate similar results,[82, 114, 115] the different methods of exploring model performance might, although less likely, have contributed to the different results observed.

7 CONCLUSION

The studies included in this thesis allow the following to be concluded:

Clinical peer review of all trauma deaths is essential to correctly interpret mortality, i.e., identify patients that are dead on arrival and deaths not directly related to the injury which both unrecognized distort mortality statistics.

Clinical peer review can identify preventable deaths and more importantly errors committed in trauma management. Therefore, clinical peer review of mortality should be an integral part of a trauma system.

Risk-prediction models in trauma have a low predictive ability in selecting the right patients to review, hence all trauma deaths should be subject to review.

TRISS is not suitable when adopted on Scandinavian populations which in large consist of elderly with relatively high levels of comorbidity. A survival prediction model that takes this into account may be a better choice for Scandinavian trauma populations.

The newly updated Norwegian survival prediction model in trauma (NORMIT 2) is a valid method to be used as a risk-adjustment tool in a Swedish designated trauma centre population.

8 FUTURE RESEARCH

8.1 A SOLUTION FOR CASE-MIX

Trauma is a heterogeneous disease and, as we have shown in this thesis, highly affected by case-mix. In Paper III we demonstrated the limitations of TRISS to correctly adjust for age and comorbidity in a Scandinavian trauma population. In Paper IV, we concluded that NORMIT models perform poorly in a more heterogeneous national (Swedish) trauma population but more precise in a designated trauma centre population, once again underlining the importance of appropriate case-mix adjustment.

In order to assist prediction models and reduce the impact of case-mix, the comparison of risk-adjusted survival can be made in clinically relevant and well defined subgroups[116]. Such a distinct division has been done by Hemmila et al.[116] in the Trauma Quality Improvement Program" (TQIP) developed by The American College of Surgeons Committee on Trauma (ACS-COT)[117] . The TQIP was proposed by the ACS-COT as the next paradigm to improve quality of care in trauma. There are currently over 800 participating trauma centres across the United States. By gathering and processing data form these centres, TQIP can provide feedback to the centres' performance as well as identify institutional characteristics that trauma centre personnel can implement to improve patient outcome. TQIP accomplishes its work by using risk-adjusted benchmarking to provide the centres with accurate national comparisons[118].

In TQIP, patients are divided in three distinct cohorts: (1) Blunt multisystem injury, (2) penetrating truncal injury and (3) blunt single system injury. Selection of these three separate cohorts is done to reflect the wide spectrum of trauma patients and their associated challenges. Dividing the analysis into specific cohorts facilitates each centre to better evaluate its system performance from different process perspectives. Additionally, it provides an opportunity for centres with an overrepresentation of a special type of patient group to better understand their performance in comparison to other centres[116].

8.2 OTHER APPROACHES IN MEASURING QUALITY

The common feature in this thesis has been Donabedian's principle of quality management, the main emphasis, outcome, although aspects of structure and process have also been discussed. Let us, once more, remind ourselves of the model by looking at Figure 1, but this time keeping the focus on process. Process quality indicators (or process indicators), as previously described, relates to what is actually done by those involved in patient care.

To cite Glance et al.[119], "unlike outcome, which can identify a quality problem, but not its root cause, process indicators are directly actionable because they quantify adherence to best practices". Process indicators for trauma care have previously been developed by the American College of Surgeons, researchers and local institutions[120-122].

8.2.1 Process indicators

Measuring the quality of health care by the use of process indicators can promote improvements in the delivery of care[1]. They can facilitate the comparison of actual care against ideal criteria for the purposes of quality measurement, benchmarking and identifying potential opportunities for improvement[33]. The Institute of Medicine defines it as, “the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with professional knowledge”[123]. Process indicators are also believed to be an efficient tool for achieving rapid implementation of new evidence into clinical practice[119].

At present, there are many different process indicators of trauma care available[124]. However, the weakness of many of the suggested is the lack of strong evidence supporting large areas of clinical practice[119]. In trauma, randomized trials to support evidence for process indicators are lacking and those that are used are mainly based on expert consensus statements. Additionally, register-based studies have raised concerns about their precision in identifying quality of care issues[125-127]. Other studies have resulted in questions about the reliability and validity, and description of outcomes following implementation, are scarce[128, 129]. Instead, studies performed in the United States have shown that many of the old process indicators do not have any relationship to the patient´s outcome[119, 124, 130].

Recognizing this challenge, ACS-COT is within the framework of TQIP evaluating new processes indicators[116, 117].

Further, Santana et al. seized the opportunity to improve and standardize process indicators, by developing in 2014, a group of 31 evidence-informed (in contrast to evidence-based) quality indicators for adult injury care, shown to have content validity. It was done through a mixed approach consisting of a consensus methodology and international survey[33]. One of these process indicators were in fact the peer review method which was mainly used in Paper II and to some extent in Paper I. Our results emphasized the importance of peer review for correct interpretation of trauma mortality statistics and quality of care improvements.

In the Utstein Trauma Template[131], which represents the current European standard for documenting and reporting data in trauma registries, four process indicators are suggested: ‘Time from alarm until arrival at scene’, ‘Time until normal base excess’, ‘Time until first key emergency intervention’ and ‘Time until first CT scan’. However, once again, the relationship between these and outcome has not yet been evaluated.

In summary, although substantial efforts have been made to increase the evidence in support for process indicators, there still remains a long way to go. To quote Stelfox et al.: “Just because a common set of evidence-based (process) quality indicators of trauma care have not been developed does not mean that they cannot be developed”[124]. Well-designed, carefully evaluated and appropriately implemented, process quality indicators could play an important role in improving healthcare[132]. This is a task that we should take upon.

9 POPULÄRVETENSKAPLIG SAMMANFATTNING

Dödsfall till följd av traumatisk skada är, enligt Världshälsoorganisationen (WHO), den vanligaste dödsorsaken i västvärlden hos individer under 45 års ålder.

Idag är det dubbelt så vanligt för män än kvinnor att råka ut för en traumatisk skada. Den vanligaste skademekanismen är trubbigt våld. En annan mekanism, som i Skandinavien har utgjort en liten del av allt trauma, men där vi på senare tid ser en viss ökning, är s.k. penetrerande skador (skärande föremål och skjutvapen).

Utfallet efter en traumatisk skada beror på flertalet faktorer. Skadetyp, skademekanism och framförallt omfattningen av skadorna tillsammans med ålder och samsjuklighet spelar en avgörande roll. Den tid det tar för den skadade att nå sjukhuset samt de åtgärder som vidtas under intransport och inne på sjukhuset är likaså av betydelse.

För att förbättra omhändertagandet och kunna mäta effekten av olika behandlingar av traumapatienter krävs ökad kunskap inom området. En förutsättning för detta är registrering av standardiserade data om traumapatienter i så kallade kvalitetsregister.

Kvalitetsregister finns inom olika medicinska inriktningar inklusive traumavården. Det finns dock felkällor i dessa register. När det kommer till traumaregister, finns det exempelvis patienter som har angivits ha avlidit inom 30 dagar efter ett olycksfall (en vanlig och vedertagen tidsram) och som följaktligen tolkas som ett traumarelaterat dödsfall, men som i själva verket har avlidit av helt andra orsaker, vilket ger en skev bild av verkligheten. Det rör sig framförallt om äldre och sjuka patienter som har varit med om en lindrig skada och som avlider inom 30 dagar p.g.a. medicinska orsaker, t ex hjärtinfarkt och infektioner. Ett annat problem är att patienter som dör till följd av sina skador redan innan de anländer till sjukhus, men som registreras som om de hade avlidit på sjukhus, påverkar dödsstatistiken.

Detta fenomen studerades i första delarbetet där vi visade att 10,5% av dödsfallen i Karolinskas traumaregister hade avlidit av icke traumarelaterade orsaker. Dessutom var 17,6% redan döda vid ankomst till sjukhus och när man exkluderade dessa i dödsstatistiken ändrades viktiga karaktärsdrag hos patientgruppen. Med andra ord måste samtliga dödsfall granskas och felaktigt registrerade dödsfall sorteras bort för att man på ett korrekt sätt ska kunna tolka och dra slutsatser från registerdata.

Kvalitet på traumavården kan utvärderas på olika sätt. Ett sätt är att mäta olika utfallsmått, som t.ex. överlevnad efter trauma eller andel undvikbart dödsfall. Baserad på slutsatserna från första delarbetet, inleddes arbetet med att granska samtliga registrerade traumadödsfall på Karolinska Universitetssjukhuset. Det huvudsakliga syftet var förutom att säkerställa att dödsfallen var traumarelaterade, att nu även identifiera dödsfall som var potentiellt undvikbara samt förbättringsområden i omhändertagandet. Detta gjordes genom en strukturerad granskning utfört av en expertkommitté bestående av olika specialiteter där samtliga deltar i omhändertagandet av traumapatienten. Under en 4 års period konstaterades att 4% av dödsfallen på Karolinska Universitetssjukhuset var potentiellt undvikbara och hos var femte dödsfall identifierades förbättringsområden – nivåer som är jämförbara med andra stora traumacentra. Vi drog slutsatsen att strukturerad granskning av döda är viktigt för att identifiera undvikbar död och förbättringsområden vilket är ett första steg för att kunna vidta åtgärder.

Att korrekt kunna förutspå (prediktera) sannolikheten för överlevnad genom en s.k. prediktionsmodell efter trauma kan användas vid kvalitetssäkring. Modellen kan användas som ett verktyg för att jämföra överlevnad efter trauma mellan två olika grupper (populationer) av patienter från olika sjukhus som är olika med avseende på patientfaktorer (ålder, samsjuklighet, typ av skada, skadans allvarlighetsgrad m.m.). Man kan med hjälp av en prediktionsmodell beräkna en förväntad dödlighet som sen kan jämföras med den faktiska dödligheten. Är dödligheten högre jämfört med det som beräknades kan detta framförallt bero på ett sämre traumaomhändertagande, då man redan har korrigerat för olikheterna mellan patienterna med modellen.

Redan på 80-talet utarbetades en sådan modell i USA och som idag används runt om i världen däribland på Karolinska Universitetssjukhuset. Det finns dock vissa begräsningar med modellen och den har bl. a visat sig vara svår att tillämpa på populationer som skiljer sig från den population som modellen togs fram i.

I delarbete 3 användes den amerikanska modellen för att beräkna och jämföra sannolikheten för överlevnad mellan två traumasjukhus, ett i Stockholm och ett i Norge. Jämförelsen visade på skillnader i dödlighet. Därtill fanns det skillnader i struktur samt arbetsprocesser inom vissa delar av traumavården mellan sjukhusen. Analyserna indikerade emellertid att skillnaden i överlevnad inte bara kunde bero på skillnader i traumaomhändertagandet utan snarare på att modellen förbisåg vissa faktorer. Den skandinaviska traumapopulationen består till stor del av äldre med samsjuklighet, något som den amerikanska modellen inte kunde justera för.

Forskare i Norge har utarbetat en prediktionsmodell (NORMIT) baserad på en norsk population och som bör fungera bättre på skandinaviska traumapatienter. I delarbete 4 riktades fokus mot den norska modellen där dess prediktionsförmåga utvärderades och vi kunde då konstatera att den, till skillnad från den amerikanska, var mer exakt och tillförlitlig i sin prediktion av överlevnad.

Slutsatserna i denna avhandling är att granskning av traumadödsfall är viktigt, dels för att kunna tolka registerdata och dels för att identifiera förbättringsåtgärder. För att förbättra vården av traumapatienten behövs också modeller som kan användas för att mäta utfall och som tar hänsyn till skillnader mellan patienterna och deras skador. En sådan skulle kunna vara den norska prediktionsmodellen, NORMIT.

10 ACKNOWLEDGMENTS

It all began on a rainy September day in 2011. I had just started working as an aspiring surgical resident at Karolinska University Hospital in Huddinge. To be honest, I had no experience in surgery, let alone trauma. As a matter of fact, at the end of my internship I had even applied and been accepted for residency in endocrinology, but changed my mind in the last minute. On my first day of work, I was placed in the surgical emergency department responsible for emergencies as well as trauma calls. Thankfully I wasn’t alone. I had an experienced consultant as back-up. The pager went off. Young girl who had fallen from a horseback. The quality of care would have been poor by any standards if it hadn’t been for my back-up. For the few of you who actually have read this thesis, this would have been a fine illustration of the lack of “structure”, i.e., poor competence of involved personnel resulting in negative outcome. To make a long story short. The consultant saved the day, the young girl pulled through and my contribution was to put on a cervical collar (incorrectly). That consultant’s name was Lisa Strömmer. Three days after this incident she asked me if I were interested in getting involved in a research project. The rest is history. She obviously had an eye for recognizing talent ;-).

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