Trauma Care - Implementation, Evaluation and Validation

LINA HOLMBERG
Dissertation presented at Uppsala University to be publicly examined in H:son Holmdalhsalen, Akademiska sjukhuset, ingång 100, 2 tr, Uppsala, Friday, 12 April 2024 at 13:00 for the degree of Doctor of Philosophy (Faculty of Medicine). The examination will be conducted in English. Faculty examiner: Assistant Professor of Surgery Sharig S. Raza (Hospital of the University of Pennsylvania and the Presbyterian Medical Center of Philadelphia, University of Pennsylvania School of Medicine).

Abstract

Trauma is a major cause of death and morbidity in all ages, which makes continuous improvement of trauma care a high priority. During the last decades, Sweden’s trauma system has evolved with initiation of a national trauma registry (SweTrau) in 2011 and the Swedish National Trauma Triage criteria (SNTTC) in 2017. However, the Swedish trauma panorama has evolved as well, something this thesis aimed to explore, alongside with evaluating the safety and accuracy of the SNTTC and performing the first validation of SweTrau. Paper I is a prospective stepped-wedge cohort study, showing unchanged 30-day mortality, over- and undertriage after the implementation of the SNTTC, as well as a reduction of the lowest level of trauma call by almost 50%, proving that the SNTTC are safe to use. In Paper II, a retrospective multicentre cohort study, the SNTTC are further investigated, displaying a sensitivity of almost 85% while also assessing specificity, positive predictive value (PPV) and positive likelihood ratio (LR+). With no additional enhancing criteria found, the SNTTC are concluded to efficiently identify severely injured patients. Paper III reports the first validation of SweTrau; an on-site re-registration compared with the original registration in SweTrau. It demonstrates that the data in SweTrau is reliable, with high accuracy (85.8%), correctness (89.7%), data completeness (88.5%) and correlation (87.5%), while being comparable to international trauma registries using the Utstein template of trauma. Case completeness and timeliness are identified as areas of improvement. In Paper IV, nine-year trauma trends in two major trauma centres are analysed in a retrospective cohort study. A sharp reduction in intensive care unit admissions is seen, as well as a worrying increase in penetrating trauma (>50%) and mortality for patients with a low injury severity score (1.3%-2.7%, p=0.005), all of which require further investigation. In conclusion; this thesis has confirmed that the SNTTC are safe and efficient, as well as pinpointed important trauma areas to focus on in the future. Finally, it has established the validity of the data in SweTrau - a major source of Swedish trauma research.

Keywords: Trauma triage criteria, undertriage, validation, trauma registry, accuracy, trauma trends, penetrating trauma, mortality.

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To my beloved Dad, who shared my passion for trauma.
I wish you had been here to see this.
“Death and taxes are the two most quoted inevitabilities of life; trauma qualifies as a legitimized third.”
- Alexander J Walt (1923-1996)
List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.


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### Abbreviations

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<th>Description</th>
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<tr>
<td>ACS-COT</td>
<td>American College of Surgeons Committee on Trauma</td>
</tr>
<tr>
<td>AIS</td>
<td>Abbreviated Injury Scale</td>
</tr>
<tr>
<td>ASA</td>
<td>American Society of Anesthesiologists physical status classification</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>ED</td>
<td>Emergency department</td>
</tr>
<tr>
<td>GCS</td>
<td>Glasgow Coma Scale</td>
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<tr>
<td>ICU</td>
<td>Intensive care unit</td>
</tr>
<tr>
<td>ISS</td>
<td>Injury Severity Score</td>
</tr>
<tr>
<td>LOS</td>
<td>Length of stay</td>
</tr>
<tr>
<td>LÖF</td>
<td>Landstingens Ömsesidiga Försäkringsbolag</td>
</tr>
<tr>
<td>M&amp;M</td>
<td>Morbidity and Mortality</td>
</tr>
<tr>
<td>MCC</td>
<td>Motorcycle crash</td>
</tr>
<tr>
<td>MOF</td>
<td>Multiple organ failure</td>
</tr>
<tr>
<td>MOI</td>
<td>Mechanism of injury</td>
</tr>
<tr>
<td>MVC</td>
<td>Motor vehicle crash</td>
</tr>
<tr>
<td>NISS</td>
<td>New Injury Severity Score</td>
</tr>
<tr>
<td>NFTI</td>
<td>Need For Trauma Intervention</td>
</tr>
<tr>
<td>NTDB</td>
<td>National Trauma Data Bank</td>
</tr>
<tr>
<td>NTDS</td>
<td>National Trauma Data Standard</td>
</tr>
<tr>
<td>NTS</td>
<td>New Trauma Score</td>
</tr>
<tr>
<td>OR</td>
<td>Operating room/Operating theater</td>
</tr>
<tr>
<td>RR</td>
<td>Respiratory rate</td>
</tr>
<tr>
<td>RTS</td>
<td>Revised Trauma Score</td>
</tr>
<tr>
<td>SBP</td>
<td>Systolic blood pressure</td>
</tr>
<tr>
<td>SFAT</td>
<td>Swedish Association for Acute Care Surgery and Trauma</td>
</tr>
<tr>
<td>SNTTC</td>
<td>Swedish National Trauma Triage Criteria</td>
</tr>
<tr>
<td>SweTrau</td>
<td>Swedish trauma registry</td>
</tr>
<tr>
<td>T-RTS</td>
<td>Triage Revised Trauma Score</td>
</tr>
<tr>
<td>TA</td>
<td>Trauma Alert (highest level of trauma call)</td>
</tr>
<tr>
<td>TBI</td>
<td>Traumatic brain injury</td>
</tr>
<tr>
<td>TR</td>
<td>Trauma Response (lowest level of trauma call)</td>
</tr>
<tr>
<td>TS</td>
<td>Trauma Score</td>
</tr>
<tr>
<td>TTA</td>
<td>Trauma Team Activation/Trauma call</td>
</tr>
<tr>
<td>TQIP</td>
<td>Trauma Quality Improvement Program</td>
</tr>
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</table>
Introduction

Trauma is a worldwide health problem that affects all ages and is responsible for almost a tenth (8%) of the global mortality. It constitutes three of the top five causes of death among young people between 15-29 years (road traffic injuries, suicides and homicides), with traffic injuries in the top three causes of death in the age group 5-49 years [1, 2]. Many survivors are also left with various disabilities, which have a significant impact on their ability to support themselves and contribute to the society [3]. In short, trauma plays a major role in the health burden of all countries in the world.

The practice of trauma care has, thankfully, evolved over the last 40 years, along with epidemiological changes. In 1983, Donald D. Trunkey presented a trimodal wave of the mortality of trauma patients [4] where roughly 50% were classified as “immediate deaths” that died on scene or in the pre-hospital setting. The second group, defined as “early deaths” and comprising about 30%, died within approximately four hours from bleeding and traumatic brain injury (TBI). The last group, “late deaths”, died from infection and multiple organ failure (MOF) [5, 6] within days to weeks and made up almost 20% of the patients. However, the definitions of “immediate”, “early” and “late” deaths have varied slightly in recent studies, with some including death in the emergency room in the “immediate” group and some extending the time period of the “early” group to include 24 hours [5]. Regardless, newer research suggests a shift of the tri-modal wave to a bi-modal wave, where the “late” deaths are significantly reduced and the two peaks now representing “immediate” and “early” deaths <4 h, with the absolute majority of deaths occurring within 24 hours [7]. This distribution supports the use of the expressions “the golden hour” and “the platinum ten minutes” [8] (or “scope and run”) [9-11]. The aim of this is definitive care within 60 minutes, with the ambulance leaving the scene in under ten minutes to reduce time until surgical treatment.

“Though shock may be temporarily alleviated by transfusion, it cannot be arrested or overcome; resuscitation divorced from surgery is folly.”
- William Heneage Ogilvie (1887-1971)

The nature of trauma varies greatly depending on the circumstances. The trauma panorama is not the same when comparing day- or nighttime, rural environment or city area, and may even differ between different socioeco-nomic areas in the same city. The main distinction, however, exists between
penetrating or blunt trauma and assaults or accidents. For example; in parts of South Africa, penetrating abdominal trauma is more common than blunt trauma and gunshot wounds are more prevalent than stab wounds [12], compared to the USA, where the ratio between gunshot wounds and stab wounds almost equals a ratio of 1:1 [13]. Nevertheless, most injuries in Europe are caused by blunt trauma [3], and the majority of penetrating trauma consists of stab wounds. This is also the case in Sweden, even if there is a very concerning tendency towards a higher incidence of penetrating trauma, especially gunshot wounds [14-17].

Alas, injuries resulting from trauma are likely to affect all of us to some extent during our lifetime. The continuous improvement of trauma care is therefore crucial, with the aim of building on the great advancements already made during the last half-century. In the future, more refined triage criteria, better scoring algorithms to predict severe injury, together with increased homogeneity among trauma systems and trauma registries are all high on the wish list.

This thesis will hopefully add another piece of the puzzle towards a more equal trauma care, both nationally and internationally.

“A discovery is rarely, if ever, a sudden achievement, nor is it the work of one man; a long series of observations, each in turn received in doubt and discussed in hostility, are familiarized by time, and lead at least to the gradual disclosure of truth.”
- Berkeley Moynihan (1865-1936)
Background

Trauma systems

Trauma systems, dictating the management of trauma care in a particular area or region, have developed in order to decrease both mortality and morbidity in trauma [6, 18, 19]. Guidelines exist for transfer destinations of trauma patients (depending on activated trauma call) and which competence requirements are needed for different levels of trauma receiving hospitals. Additionally, the trauma systems define how a trauma team ought to be staffed and which functions should be on stand-by during a trauma call (for example the operating room (OR) or the radiology department) [18]. This is an important question that should be carefully considered, weighing the benefit of additional resources against the situation where there simply are too many people present, or, as Clement A Hiebert distinctly put it:

“In any emergency setting, confusion is a function of the cube ($N^3$) of the number of people involved.”

Furthermore, the trauma system also addresses the issue of how the facilities should be equipped (Fig 1) and gives recommendations of location of the trauma room with regard to the OR or the intensive care unit (ICU).

![Figure 1. Example of equipment in the trauma room.](image-url)
Other key features of a trauma system are the use of trauma registries and regular morbidity and mortality conferences (M&M) [20-24], which are multidisciplinary meetings where the outcome of trauma patients is discussed with the aim of finding ways to improve the system, give feedback and strengthen the “Trauma Chain” (Fig 2) [25, 26] from pre-hospital care to rehabilitation.

![Figure 2. Components of the Trauma Chain. BLS: Basic Life Support. ALS: Advanced Life Support. First discussed at the TraumaCare2002 conference in Stavanger, Norway.](image)

Sweden has a national trauma registry and all regions have a common national trauma triage criteria activation protocol, however, even though the trauma systems are similar, they are not identical. Therefore, several projects of improvement within the field of trauma have been initiated by Landstingens Ömsesidiga Försäkringsbolag (LÖF [27]), a national non-profit health insurance company that works towards a more coherent national trauma care in Sweden. Other professional trauma organisations (for example the Swedish Association for Acute Care Surgery and Trauma – SFAT) [28] are also closely involved in this work.

**Triage of trauma patients**

Triage, or the decision of which patients should get treated first, was first developed on the battle fields [29] to guide which soldiers should get evacuated from the front to the medical facilities where (hopefully) a surgeon waited. The very heart of triage is simply but elegantly described by baron Dominique Jean Larrey [30] (1766-1842):

“We will always start with the most dangerously injured without regard to rank and distinction.”
This later evolved into triage in a civilian setting with guidelines for mass-casualty triage algorithms and hospital activation plans used in major accidents and terror attacks [31, 32]. The evolution of terrorism has furthermore brought an ethical discussion, where the pillar stone of triage has been questioned, in certain circumstances, when it comes to prioritising between the terrorist and its victims [33]. However, the overwhelming majority of trauma surgeons keep to the code of treating the most severely injured first.

The more common forms of today’s triage of trauma patients includes “field triage” by pre-hospital personnel (the ambulance bypasses a smaller hospital and transports the patient directly to a designated trauma centre in certain circumstances) and “in-hospital-triage” where the trauma criteria decide whether a trauma call should be initiated in the emergency department (ED) and if so; which level of trauma call (if there is more than one).

In Sweden, the trauma call is initiated by either a pre-hospital physician or, more commonly, the nurse in charge of the trauma room in the ED. The ambulance staff calls the trauma room with a report of the patient’s mechanism of injury, suspected or confirmed injuries and vital signs. Based on this, the nurse in charge activates a trauma call according to the trauma protocol.

In this thesis, to describe the highest level of trauma call the expressions “Full trauma team activation (TTA)” and “Trauma Alert (TA)” are used interchangeable, as are “Limited TTA” and “Trauma Response (TR)” for the lowest level of trauma call.

Trauma triage criteria

Internationally, there are many different combinations of trauma triage criteria. Some variations depend on the area in question, e.g. mountains with avalanches etc. American College of Surgeons Committee on Trauma (ACS-COT) recommends two-tiered trauma criteria with two levels of TTA, and also gives recommendations on transport to designated trauma centres which are ranging from Level 1 (highest level of trauma care) to Level 5 [18].

Even within the same country there may be discrepancies of the trauma triage criteria [34, 35] which might lead to unequal care and inconsistencies regarding which patients that are included in trauma registries. This could, as a consequence, lead to difficulties in comparing different registries and making comparisons even within the same registry, advocating for the strive towards more coherent criteria within and (preferable) between countries [36]. Locally adapted trauma triage criteria was indeed the case in Sweden until the implementation of the Swedish National Trauma Triage Criteria (SNTTC) in 2017 [27] (Fig 3), as a result of the collaboration between LÖF and the professional trauma organisations in Sweden.

Another factor to take into consideration when it comes to activation of trauma calls is how high the compliance to the trauma triage criteria is. It does not matter how accurate a particular set of criteria may be if the nurses and
doctors that activate the trauma call do not feel comfortable using the algorithm or believe in its usefulness. The compliance to trauma triage criteria has shown to be higher when it comes to Trauma Alert/Full TTA, with more significant injuries, whilst proving more of a challenge with Trauma Response/Limited TTA [37].

<table>
<thead>
<tr>
<th>SWEDISH NATIONAL TRAUMA TRIAGE CRITERIA</th>
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<tbody>
<tr>
<td><strong>Physiological</strong></td>
</tr>
<tr>
<td>1. Need for ventilatory support</td>
</tr>
<tr>
<td>2. Respiratory rate &lt;10 or &gt;29/min</td>
</tr>
<tr>
<td>3. Children: Signs of respiratory compromize</td>
</tr>
<tr>
<td>4. Systolic BP &lt;90 mmHg or no palpable radial pulse, Children: capillary refill &gt;2 seconds</td>
</tr>
<tr>
<td>5. Children: pulse &lt;90 or &gt;190 if 0-1 years old, &lt;70 or &gt;160 if 1-5 years old</td>
</tr>
<tr>
<td>6. GCS≤13</td>
</tr>
<tr>
<td><strong>Specific Injuries</strong></td>
</tr>
<tr>
<td>7. Penetrating trauma to the abdomen, chest, neck or extremities above elbow/knee</td>
</tr>
<tr>
<td>8. Open skull fracture/impression fracture</td>
</tr>
<tr>
<td>9. Face or neck trauma with threatened airway</td>
</tr>
<tr>
<td>10. Deformed chest wall</td>
</tr>
<tr>
<td>11. Severe pain in pelvis</td>
</tr>
<tr>
<td>12. Suspected spinal cord injury</td>
</tr>
<tr>
<td>13. ≥2 long bone fractures</td>
</tr>
<tr>
<td>14. Amputation above hand or foot</td>
</tr>
<tr>
<td>15. Massive external hemorrhage</td>
</tr>
<tr>
<td>16. Burn ≥18% TBSA or inhalation burn</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRAUMA RESPONSE CRITERA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanism of injury</strong></td>
</tr>
<tr>
<td>17. MVC &gt;50 km/h without seatbelt</td>
</tr>
<tr>
<td>18. Thrown out of vehicle</td>
</tr>
<tr>
<td>19. Extrication time &gt;20 min</td>
</tr>
<tr>
<td>20. MCC (or equivalent) &gt;35 km/h</td>
</tr>
<tr>
<td>21. Children: Hit/run over by vehicle</td>
</tr>
<tr>
<td>22. Fall &gt;5m in height, Children: Fall &gt;3m in height</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>CAUTIONS - (may influence trauma team activation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23. Ongoing deterioration</td>
</tr>
<tr>
<td>24. Increased risk of bleeding (anticoagulant drugs)</td>
</tr>
<tr>
<td>25. Age &lt;5 years old or &gt;60 years old</td>
</tr>
<tr>
<td>26. Severe preexisting conditions</td>
</tr>
<tr>
<td>27. Hypothermia (&lt;35°C)</td>
</tr>
<tr>
<td>28. Intoxication</td>
</tr>
<tr>
<td>29. Pregnancy</td>
</tr>
</tbody>
</table>

*Figure 3. The Swedish National Trauma Triage Criteria (SNTTC), in Paper II.*
Measuring the severity of injury

Abbreviated Injury Scale

Abbreviated Injury Scale (AIS) [38] is an international coding system used to grade the patient’s injuries in an objective way. Registrars have to attend a course with AIS-instructors and subsequently complete a written examination before being qualified registrars according to the AIS system.

In the AIS system, each injury is identified according to nine different anatomic regions (head, face, neck, thorax, abdomen, spine, upper extremity, lower extremity, external). The injuries are then coded and given a number between 1-6, where 1 point defines a very mild injury and 6 points describe an injury not currently possible to survive [39] (Table 1).

### Table 1. Injury severity for AIS grades and ISS/NISS (single injury). AIS: Abbreviated Injury Scale, ISS: Injury Severity Score, NISS: New Injury Severity Score.

<table>
<thead>
<tr>
<th>AIS</th>
<th>Severity</th>
<th>ISS/NISS</th>
<th>Severity</th>
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<tbody>
<tr>
<td>1</td>
<td>Minor</td>
<td>1-8</td>
<td>Minor</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3</td>
<td>Serious</td>
<td>9-15</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>16-24</td>
<td>Severe</td>
</tr>
<tr>
<td>5</td>
<td>Critical</td>
<td>25-75</td>
<td>Very severe</td>
</tr>
<tr>
<td>6</td>
<td>Maximum</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>(un survivable)</td>
<td></td>
<td></td>
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</tbody>
</table>

Injury Severity Score and New Injury Severity Score

The nine anatomic regions in the AIS system are comprised into six regions when assessing the overall injury severity [39]. The AIS-regions head and neck are combined, as is upper extremities and lower extremities. Also, the anatomic region spine is spread over three regions (cervical spine assigned to head or neck, thoracic spine to thorax and lumbar spine to abdomen), resulting in the following regions: head or neck, face, thorax, abdomen, extremities or pelvic girdle and external (Fig 4).

Initially, Injury Severity Score (ISS) was used [40], where one squares the three most severe injuries’ AIS points in three different body regions and then add them together. However, New Injury Severity Score (NISS) has become more commonly used to define a severely injured patient. It is a better way to predict in-hospital mortality [41] and MOF [42]. NISS is also superior when appreciating the severity in penetrating trauma [43], since NISS squares and sums the three most severe injuries regardless of which body region (the three most severe injuries of a penetrating trauma could for example include the liver, spleen and duodenum, however, only one of these injuries would have been considered using ISS).
Figure 4. AIS regions and their correlating ISS and NISS regions. AIS: Abbreviated Injury scale, ISS: Injury Severity Score, NISS: New Injury Severity Score.

Regardless of which score, ISS or NISS, the maximal number is 75. This can either be achieved by three different injuries, each with an AIS of 5 (which is conceivably survivable), or with an AIS of 6 in any anatomic region leading to an automatic ISS or NISS of 75. Therefore, an ISS or NISS of 75 does not necessarily equal death, and vice versa, death does not necessarily equal an ISS or NISS of 75.

The ISS and NISS can be further divided into four subgroups: 1-8 points (minor), 9-15 (moderate), 16-24 (severe) and 25-75 (very severe) [39] (Table 1), where a point over 15 (predicting 10 % mortality [44]) generally represents the cut-off for a severely injured patient.
Trauma Score, Revised Trauma Score and New Trauma Score

Trauma Score (TS) is an additional way to measure the severity of injury. In contrast to ISS and NISS, which focus on anatomical injuries and are calculated in retrospect, TS is based on the physiological vital signs of the patient. The original TS [45], presented in 1981 for the purpose of field triage, included Glasgow Coma Scale (GCS), systolic blood pressure (SBP) and respiratory rate (RR), as well as two more parameters: respiratory expansion and capillary refill time. These were harder to assess at the scene of trauma and therefore subsequently removed in the more modern adaption of TS: Revised Trauma Score (RTS) and New Trauma Score (NTS).

Revised Trauma Score (RTS) is calculated by coding GCS, SBP and RR into five different categories between 0-4, and then adding the numbers in a predefined formula to receive a total point which varies between 0-7.84. Any category number less than full point, that is; GCS<13, SBP<90 or 10<RR>29, means that the patient is severely injured (i.e. RTS<7.84) [46]. Triage RTS (T-RTS) is a modification used for field triage, where only the coded numbers for each category are added, with RTS<11 indicating a need for transport to a trauma centre.

New Trauma Score (NTS) is a (less used) modification of RTS that has removed RR and added peripheral oxygen saturation as a variable and is using the actual GCS instead of a category number. NTS also has modified coding levels of SBP and is calculated by using a different formula than RTS, generating a total score between 3-23 where a point of 18 or more indicates a severely injured patient [47].

Need For Trauma Intervention

Need For Trauma Intervention (NFTI) [48] is yet another way to describe a severely injured patient. Its definition reads: a patient that fulfills any of the following criteria is severely injured:

- Transfusion of packed red blood cells within 4 hours of arrival
- Discharge from ED to OR within 90 min of arrival
- Discharge from ED to interventional radiology
- Discharge from ED to ICU with a length of stay (LOS)>3 days
- Mechanical ventilation within 3 days of arrival
- Death within 60 days of arrival
Overview of injury severity scoring systems

In previous sections, different scoring systems for assessing the injury severity of a trauma patient have been discussed. These systems are intricately linked in a, at a first glance, not so obvious way. In order to make this a bit more tangible, a schematic overview of the systems and how they are connected is visualized below.

Figure 5. Overview of different scoring systems for trauma patients. AIS: Abbreviated Injury Scale, NISS: New Injury Severity Score, ISS: Injury Severity Score, NFTI: Need For Trauma Intervention, OR: Operating Room, ICU: Intensive Care Unit, TS: Trauma Score, GCS: Glasgow Coma Scale, SBP: Systolic Blood Pressure, RR: Respiratory Rate, RTS: Revised Trauma Score, NTS: New Trauma Score, Sat: Saturation.

Probability of survival

Several prognostic methods for survival probability (Ps) exist, primarily for benchmarking and comparing trauma care within and between centres. Based on some of the injury severity scoring systems mentioned in the previous sections, they are not suitable to “real-time” use since a lot of the parameters are not readily available and must be calculated in retrospect. The Ps-methods can be used to analyse potential “preventable deaths” and have been validated in different populations, as described below.

The TRISS method

The TRISS method is a combined description of survival probability, first mentioned in 1981 [45] and later in a more cited paper from 1987 [44]. It uses both anatomical (ISS) and physiological (RTS) descriptions of injury severity, as well as taking age into account (AgeIndex), where 1 point is given for
patients 55 years and over and 0 point for patients under 55 years. The TRISS score is then subsequentially calculated by using a logarithmic regression formula with different variables depending on if it is a blunt or penetrating trauma [49]. Each variable (b) is multiplied with the respective coefficient for ISS, AgeIndex and the components of RTS (GCS, RR, SBP), and added to the TRISS coefficient for blunt or penetrating trauma ($b_{p/b}$).

\[
\text{Survival probability } P_s = \frac{1}{1+e^{-b}}
\]

\[
b = b_{p/b} + b_{ISS} \times ISS + b_{Age} \times AgeIndex + b_{GCS} \times GCS + b_{RR} \times RR + b_{SBP} \times SBP
\]

The TARN method
The Trauma Audit & Research Network (TARN), a trauma registry in England, Wales, Northern Ireland and Republic of Ireland, published a modified method of survival probability ($P_s$) in 2006 [50], where for example gender is included and GCS is used instead of RTS (GCS + SBP + RR). Patients that would have been excluded in the original TRISS method due to missing data of SBP or RR can therefore be analysed. The $P_s$ model uses mortality after 30 days instead of 93 days (TRISS method) and is based on a European population with less penetrating trauma, as well as including children, burns, patients intubated on arrival, and referral patients which were excluded during the development of the TRISS method [50]. It is a complex method, using several age coefficients and additional coefficients for age-gender interaction, ISS, and intubation. Since its 2014 update ($P_{s14}$) it is also incorporating the Charlson Comorbidity Index [51] to address preexisting medical conditions [52].

The NORMIT method
NORMIT is a Scandinavian survival prediction model, developed in 2014 in Norway [53]. Unlike the TRISS and TARN methods, NORMIT uses NISS instead of ISS and the American Society of Anesthesiologists physical status classification (ASA) score as a measurement of comorbidity. It takes T-RTS, age, and an interaction term into account, and is altogether a simpler model, with fewer coefficients, than the TRISS and TARN methods. Its updated version, NORMIT 2, performed well when validated in a Swedish trauma cohort [54], and was superior when compared to the other two models (TRISS 09 and TARN 12) in a Norwegian study population [55].
Over- and undertriage

Triage, or the sorting of patients, is fundamental in trauma care. Since time is of the essence, incorrect triage may, in the worst-case scenario, be fatal. Hence, keeping both overtriage and undertriage to a minimum is vital. Overtriage implicates that a mildly injured patient initiates the highest level of trauma call, which is a waste of resources. Undertriage, more importantly, means that a severely injured patient does not receive the highest trauma call, which is potentially life threatening. There is unfortunately no consensus of the meaning of undertriage in the international trauma society [56], although a common definition is a patient with an ISS or NISS>15 that does not receive the highest trauma call. Other meanings of undertriage have different wordings but are roughly stating “a patient in need of trauma/emergency intervention that does not receive the highest level of trauma call” [57, 58]. Whichever definition, the important thing is to know what one is measuring in order to compare levels of under- and overtriage.

The Cribari Matrix method vs an alternative method

The Cribari Matrix method [18] (Table 2) is one way to calculate undertriage. Unfortunately, if a trauma centre revises its trauma triage criteria, leading to a decrease in the lowest level of trauma call, this could lead to a higher undertriage rate because of how the Cribari Matrix calculation is constructed. Therefore, another way to calculate undertriage has been suggested [59] (Table 2) which is not depending on the sum of patients with the lowest level of trauma call or no trauma call. The issue with this method, however, is that there are no guidelines on how high percentage of undertriage should be accepted, in contrast to the Cribari Matrix method where the ACS-COT has recommendations of undertriage <5 % [18].

Table 2. Calculation of over- and undertriage with the Cribari Matrix method and an alternative method.

<table>
<thead>
<tr>
<th></th>
<th>Not severely injured ISS/NISS&lt;15</th>
<th>Severely injured ISS/NISS&gt;15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full TTA/Trauma Alert</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Limited or no TTA/Trauma Response</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Cribari Matrix Method</td>
<td>Overtriage A/(A+B)</td>
<td>Undertriage D/(C+D)</td>
</tr>
<tr>
<td>Alternative method</td>
<td>Overtriage A/(A+B)</td>
<td>Undertriage D/(B+D)</td>
</tr>
</tbody>
</table>
Trauma registries

Trauma registries exist in different shapes and forms (Table 3); international registries, national registries, regional registries or local registries at individual hospitals. International trauma registries are found in Australia and New Zealand, [60], and the United Kingdom (England, Wales, Northern Ireland), Ireland, Denmark and Switzerland [52, 61, 62]. Germany [63], Norway [64], The Netherlands [65] and Sweden [66] have national trauma registries, while there are regional registries in for example Spain [67] and Finland [68]. In the USA, several regional trauma registries [69-72] report their data to the National Trauma Data Bank [73]. In addition, local registries are in place in Denmark [35], and a previous attempt to build a national trauma registry in Italy [74, 75] failed due to difficulties in the homogenous reporting of data, leading to the development of a regional registry in Lombardi [76].

Table 3. Examples of trauma registries.

<table>
<thead>
<tr>
<th>Registry</th>
<th>Acronym</th>
<th>Region</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia New Zealand Trauma Registry</td>
<td>ANZTR</td>
<td>Australia &amp; New Zealand</td>
<td>International</td>
</tr>
<tr>
<td>Dutch National Trauma Registry</td>
<td>NTR</td>
<td>The Netherlands</td>
<td>National</td>
</tr>
<tr>
<td>Helsinki Trauma Registry</td>
<td>HTR</td>
<td>Finland</td>
<td>Regional</td>
</tr>
<tr>
<td>National Trauma Data Bank</td>
<td>NTDB</td>
<td>USA</td>
<td>National</td>
</tr>
<tr>
<td>Navarra Major Trauma Registry</td>
<td>NMTR</td>
<td>Spain</td>
<td>Regional</td>
</tr>
<tr>
<td>Norwegian Trauma Registry</td>
<td>NTR</td>
<td>Norway</td>
<td>National</td>
</tr>
<tr>
<td>Swedish Trauma Registry</td>
<td>SweTrau</td>
<td>Sweden</td>
<td>National</td>
</tr>
<tr>
<td>Trauma Audit &amp; Research Network</td>
<td>TARN</td>
<td>UK &amp; Ireland, Denmark, Switzerland</td>
<td>International</td>
</tr>
<tr>
<td>Trauma Register DGU</td>
<td>TR-GDU</td>
<td>Germany</td>
<td>National</td>
</tr>
</tbody>
</table>

The Swedish trauma registry (SweTrau)

In Sweden, the national trauma registry (SweTrau) [66] was set up in 2011, with its first two years being more of an initiation phase. SweTrau is using The Revised Utstein template for uniform reporting of data following major trauma [77, 78] which is a consensus document agreed upon between representatives of Scandinavia, United Kingdom, Germany and Italy. It states which variables that should be included in a trauma registry and facilitates comparisons between different trauma registries since they are all using “the same language”.

SweTrau’s inclusion and exclusion criteria have changed over the years, with the current inclusion criteria being all trauma patients with an activated trauma call or an NISS>15 (including referral patients within seven days from injury). The exclusion criteria are isolated traumatic chronic subdural...
hematoma, patients with a protected identity or patients with an activated trauma call but no preceding trauma [79].

According to the annual report of 2022 [79], 11580 trauma patients were registered in SweTrau during that year, with more than 100 000 patients recorded in total in the registry. Two-thirds of the patients in SweTrau are male and they are also more prone to being victims of penetrating trauma than women.

Unfortunately, there is no automatic transfer of data between electronic patient charts and SweTrau. Instead, there are designated trauma AIS-registrars at the hospitals that have to search for the information manually in the patient records and then register it in SweTrau. They code the patient’s injuries according to the AIS system and SweTrau’s platform then automatically calculates both ISS and NISS. Finally, the trauma registrars follow up the 30-day mortality to finalise and sign the registration.

National Trauma Data Bank (NTDB) and TQIP
The National Trauma Data Bank (NTDB), founded in 1997 [80], is a national registry containing information on trauma patients in the USA. In 2007, the National Trauma Data Standard (NTDS) was implemented in order to make the data more coherent [80, 81]. Before this, however, the population of NTDB was very inhomogeneous due to regional and local discrepancies in inclusion criteria, e.g. differences in whether patients with isolated hip fractures or patients dead on arrival were to be included [81]. This also made it difficult to compare outcome and performance between centres. Therefore, after an initial pilot study involving 23 Level I and II trauma centres [82], the Trauma Quality Improvement Program (TQIP) was launched in 2010 [83]. TQIP is based on NTDB data [80, 81] while using more stringent inclusion criteria. This enables comparisons of risk-adjusted outcomes (mortality and complications) as well as several process of care indicators (measurement of intracranial pressure in traumatic brain injury, time to bleeding control or time to fixation of extremity fractures etc.) between trauma centres [81]. TQIP is also open for enrollment of international trauma centres [84] that fulfills the inclusion and exclusion criteria. The results of the TQIP analyses are presented in several patient cohorts [81, 85], focusing on various aspects of trauma care. Among these, but not excluded to, are:

- Blunt multisystem trauma (AIS>2 in at least two different areas)
- Penetrating injury (AIS>2 in neck, thorax or abdomen)
- Hemorrhagic shock (SBP<90 + blood transfusion <4h)
- Severe TBI (AIS>2 + GCS<9)
- Blunt splenic injury
- Elderly (Age>65)
- Isolated hip fracture (Age>65 + fall injury)
- All patients (except the isolated hip fracture cohort)
Trauma Register DGU (TR-DGU)
The German trauma registry also includes multiple quality process indicators, e.g. prehospital time, pelvic binder in pelvic fractures or time until whole-body CT/surgery/blood transfusion. It analyses the following subgroups [86]:

- No TBI (AIS head <2)
- Combined trauma (AIS head and body both >1)
- Isolated TBI (AIS head >2 + other injuries <2)
- Shock (SBP<90)
- Severe injuries (ISS>15)
- Elderly (>70 yr.)

Australia New Zealand Trauma Registry (ANZTR)
The Royal Australasian College of Surgeons (RACS) have their own Trauma Quality Improvement (TQI) Process Indicators, which are displayed in annual reports from ANZTR [60]. The reports focus on different groups, such as elderly (age>70), transfer patients and moderate to severe traumatic brain injury (AIS>2 [87]. The RACS TQI process indicators (in 2022) are listed below:

- Mortality
- Pre-hospital transport times
- Discharge destination
- Time to CT scan if GCS<13
- Trauma Team Activation for patients with ISS>12
- Blood alcohol collection in patients with ISS>12
- Time in first facility, if transferred
- Time in the emergency department

Validation of registries
Validation of a registry is a key component to ensure correctness of data. Many different registries (for example concerning vascular [88, 89], colon [90] and esophageal surgical procedures [91]) have been validated, and whereas the exact outline of the validations may differ, most include either an external [88] or internal validation, or both [89-92]. The external validation commonly consists of an evaluation of completeness (are all eligible cases included?) [93]. The internal validation may review validity (accuracy: is the data correct?) [94] and missing data. The validation may also address other quality indicators such as timeliness (is the data registered within a reasonable time from the event?) and comparability (are the variables and coding systems of the registry comparable with other similar registries?) [94].
Trauma registries in Norway [95], The Netherlands [65], Spain [96, 97] and Finland [68] have validated some of the indicators, while this thesis in Paper III presents the first validation of the Swedish trauma registry, evaluating all the above-mentioned indicators. The validation of SweTrau was performed on-site, by re-registration of eligible trauma patients at each of the participating hospitals, and a subsequent comparison of the data with the original registration in SweTrau, as visualized in Fig 6.

Figure 6. Example of validation of a trauma registry, as performed in Paper III.

Trends in trauma

During the years since the start of SweTrau, the trauma panorama has changed in Sweden. Penetrating trauma has increased, with Sweden now being in the top of gun-related homicides in Europe [16], an indeed troublesome development which calls for further investigations and prompt action from the society. The implication for Swedish health care, however, has been a greater exposure to penetrating injuries, and with it the need of rapid assessments and decisions regarding if the patient needs to go directly to the OR, or if further diagnostic tests may be performed.
Since bleeding is the main killer in trauma and time is of the essence, educating and informing the public is one way to ensure faster access to first aid. In the USA, the campaign “Stop the Bleed” [98] educates people on how to stop an arterial bleed, using tourniquets and pressure bandages – as one has to remember; it is often not necessary to perform advanced interventions, rather, simple measurements may be all that is needed to save a life.

Failure to promptly recognize and treat simple life-threatening injuries is the tragedy of trauma, not the inability to handle the catastrophic or complicated injury.”

- F William Blaisdell

Figure 7. Moments after resuscitation of a time critical patient at the trauma room.
Aims of the thesis

The overall aim of this thesis was to assess the trauma management in Sweden, through evaluation of national trauma triage criteria, validation of the national trauma registry and mapping of long-term trends in the trauma panorama.

The specific aims were:

I. To assess the safety and efficacy of the national trauma triage criteria, implemented in Sweden 2017, by comparing over- and undertriage with previously used algorithms.

II. To evaluate the Swedish National Trauma Triage Criteria (SNTTC) by finding the best performing criteria for predicting a severely injured patient, and seeking to identify a possible future criterion amongst the undertriaged patients.

III. To validate the Swedish trauma registry (SweTrau) with regards to accuracy, correctness, correlation, data completeness, case completeness, timeliness (efficiency) and comparability.

IV. To investigate trends of severe trauma in Sweden concerning 30-day mortality, patterns of mechanism of injury and penetrating trauma, as well as proportions of emergency interventions and admissions to the intensive care unit.
Patients and Methods

Paper I
A prospective stepped wedge cohort study between August 2016 and November 2017. Five hospitals in mid-Sweden were included with a study period of six months (four hospitals) and four and a half months (one hospital) both before and after the implementation of the new national trauma triage criteria. All patients registered in SweTrau by the participating hospitals during the study period were included. Referral patients and patients with missing essential data in SweTrau were excluded. Information on injury severity and level of activated trauma call were collected and under- and overtriage were examined, for both periods (pre and post the new criteria). Accredited AIS-registrars calculated the ISS, with the most severely injured patients re-scored by another registrar in order to validate the result.

Overtriage was determined by using the Cribari Matrix method (Table 2), while undertriage was analysed using both the Cribari Matrix method and an alternative method (Table 2) where the percentage of patients with ISS>15 that did not initiate a full TTA were evaluated. The alternative method was an important addition since the new criteria were expected to reduce the number of limited TTA and therefore impact the denominator in the calculation of the Cribari Matrix method, leading to a (seemingly) higher rate of undertriage. Undertriaged patients were furthermore examined in a subgroup analysis dividing the patients by mechanism of injury in order to find a common feature.

Prior to the new criteria, one hospital used paramedics instead of the trauma room nurse to initiate the TTA. Sensitivity analyses were thus performed by excluding this hospital and then calculate over- and undertriage again, to establish if the different triage process had a bearing on the results.

Finally, the average monthly number of trauma calls during 2014-2016 was studied in relation to the study period to highlight the seasonal variation of trauma in the context of interpreting the result.

Paper II
A retrospective multicentre cohort study including six trauma receiving hospitals in Sweden (one university hospital, three regional hospitals and two local hospitals). All these hospitals’ registered patients in SweTrau during 2018
were included. Referral patients, patients with missing information regarding the level of trauma call and patients wrongfully registered were excluded.

Data was extracted from SweTrau and further information was collected from local registrars when needed. Sensitivity, specificity, accuracy, positive predictive value (PPV) and positive likelihood ratio (LR+: sensitivity/(1 - specificity)) of the SNTTC were calculated, as well as undertriage and overtriage. The criteria were also analysed with regard to NISS, the specific criterion initiating the trauma call and any emergency intervention performed within 24 hours of admission. In SweTrau, the following procedures are considered an emergency intervention:

- Thoracotomy
- Laparotomy
- Pre-peritoneal pelvic packing
- Revascularization
- Endovascular intervention
- Craniotomy
- Intracranial pressure device
- Chest drain
- External fixation of fractures
- Major surgery of fractures
- Wound revision (in the operating room)

In the SNTTC, TA is the highest level of TTA and TR is the lowest level, with additional criteria called “Cautions” that may upgrade a non-TTA to a TR and a TR to a TA. The criteria are arranged in the order of ABCDE with physiological criteria first. Hence, the criterion with the lowest number is expected to be the first to threaten the patient’s life. To record the activating criterion, a “free variable” in SweTrau was utilised by the study hospitals’ registrars, as well as another “free variable” logging if the level of trauma call was accurate or not. If more than one criterion had been marked on the trauma chart, only the lowest number was noted.

A subgroup analysis of the severely injured patients (NISS>15) was also carried out to establish any discrepancies between the patients activating a TA versus the undertriaged patients.

**Paper III**

A validation of the Swedish trauma registry by on-site re-registration at trauma receiving hospitals in Sweden. All trauma receiving hospitals participating in SweTrau 2018 were included. Hospitals without any registrations in SweTrau, hospitals with negative answer to the validation request and hospitals where COVID restrictions made validation impossible were excluded.
The validation was carried out by two of the authors, studying patient charts and other relevant sources of information on the variables in SweTrau, and subsequently checking this data against the SweTrau registration. The injury severity (ISS/NISS) was validated in several ways; as an exact sum, as being in the same severity group (ISS/NISS 0-8 (mild injury), 9-15 (moderate injury), 16-24 (severe injury) and >25 (very severe injury)) and as ISS/NISS>15<. The different measurements of validity used in the study are stated below:

- **Accuracy**: the percentage of data with exact agreement between the original registration and the re-registration. Good (≥85 %), adequate (70-84 %) or poor (<70 %).
- **Correctness**: the sum of data with exact agreement AND data within acceptable range. Good (≥85 %), adequate (70-84 %) or poor (<70 %).
- **Correlation**: calculated with either Cohen’s Kappa (categorical, qualitative data) or Pearson’s correlation coefficient (numerical, quantitative data). Excellent (≥0.8), strong (0.6-0.79), moderate (0.4-0.59) or weak (<0.4).
- **Data completeness**: 1-missing data in SweTrau. Adjusting for mutually exclusive variables, e.g.; Respiratory rate upon arrival in hospital and Respiratory rate clinical category upon arrival in hospital. Good (≥85 %), adequate (70-84 %) or poor (<70 %).
- **Case completeness**: percentage of patients that meet inclusion criteria and are registered in SweTrau, determined from the emergency department ledgers of two randomly selected weeks at each hospital. Good (≥85 %), adequate (70-84 %) or poor (<70 %).
- **Timeliness**: efficiency; time from trauma to registration in SweTrau, with the 30-day mortality variable taken into account.
- **Comparability**: likeliness of variables in SweTrau with the Utstein template of trauma; an international consensus document on trauma registry variables.

**Paper IV**

A retrospective two-centre cohort study, studying trends in the Swedish trauma panorama over nine years. All patients with a NISS>15 or a TA from the two participating hospitals’ local SweTrau registries during 2013-2021 were included. Patients with missing vital data were excluded. Data was analysed regarding 30-day mortality, proportion of emergency interventions, intensive care unit admissions, mechanism of injury and type of trauma (penetrating or blunt).
Statistical analyses
Numerical data was assessed with Mann-Whitney U test or Kruskal-Wallis test, while categorical data was analysed with Chi-squared test or Fisher’s exact test, as appropriate. In Paper I and II, over- and undertriage were calculated with the Cribari Matrix method, and undertriage was additionally determined with an alternative method (Table 2).

Statistical analyses were performed with IBM SPSS Statistics, version 25 (Paper I) or 26 (Paper II-IV) (IBM Corp., Armonk, N.Y., USA), JoinPoint Regression Program, version 5.0.2 (Paper IV) and with Microsoft Excel for Mac, version 16.16.22. The level of significance was set at a $p$-value <0.05.

Paper I
Predictors for undertriage were assessed in a multivariable binary logistic regression analysis.

Paper II
Accuracy was determined by the area under the curve (AUC) from receiver operating characteristics (ROC)-points comparing sensitivity and 1-specificity. The website Vassarstats.net was used for additional statistical analyses.

Paper III
Correlation of categorical, qualitative data was calculated by using Cohen’s Kappa while numerical, quantitative data was calculated with Pearson’s correlation coefficient.

Paper IV
Trends were analysed with Chi-Squared test for trend and annual average percent change (AAPC), using the JoinPoint regression model. Confidence intervals for incidence rate were calculated via the website Medcalc.org.

Ethical considerations
All studies were approved by the regional ethics committee in Uppsala, Sweden (Dnr 2017/405, Dnr 2018/445, Dnr 2014/250 and Dnr 2022-03417-02).
Results

Paper I
A total of 1948 patients were included of which 66 were excluded, generating a study population of 1882 patients (Fig 8). The number of patients initiating the highest level of trauma call was mainly unchanged before and after implementation of the new criteria. Patients initiating the lowest level of trauma call were reduced by almost 50 % (46.3 %, 95 % CI 43.1-49.4 %) in the cohort in which the new criteria were implemented (988 with former criteria vs 531 with new criteria, Fig 8).

![Flow chart](image)

**Figure 8. Flow chart of patient population in Paper I.**

The absolute majority of the reduction (99.1 %) consisted of patients that were not severely injured (ISS<15). Also, to further underline this finding; almost 90 % (87.8 %) of the reduction was in the group of patients with ISS 0-2 – that is, essentially unharmed patients (Fig 9).
Overtriage was unchanged when comparing the former (71.3 %, 107/150 patients) and new criteria (72.2 %, 104/144 patients, \( p=0.866 \)). Undertriage with former criteria was 4.8 \( \% \) (50/1037, Cribari Matrix method) and 53.8 \( \% \) (50/93, alternative method), compared to 7.1 \( \% \) (39/551, Cribari Matrix method, \( p=0.063 \)) and 49.4 \( \% \) (39/79, alternative method, \( p=0.565 \)) with the new criteria.

When analysing the risk factors for undertriage, a binary logistic regression indicated a higher risk for undertriage in elderly patients (≥60 years old) (Table 4), as well as a trend in patients with low fall injury.

**Table 4.** Odds-ratio of risk factors for undertriage in Paper I.

<table>
<thead>
<tr>
<th>Mechanism of injury</th>
<th>Odds-ratio</th>
<th>95 % CI</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor vehicle crash</td>
<td>0.431</td>
<td>0.15 - 1.27</td>
<td>0.126</td>
</tr>
<tr>
<td>Motorcycle crash</td>
<td>0.743</td>
<td>0.19 - 2.84</td>
<td>0.664</td>
</tr>
<tr>
<td>Bicycle crash</td>
<td>0.546</td>
<td>0.13 - 2.35</td>
<td>0.416</td>
</tr>
<tr>
<td>Pedestrian hit</td>
<td>0.563</td>
<td>0.06 - 4.99</td>
<td>0.606</td>
</tr>
<tr>
<td>Gunshot wound</td>
<td>0.000</td>
<td>0.00 -</td>
<td>1.000</td>
</tr>
<tr>
<td>Stab wound</td>
<td>0.000</td>
<td>0.00 -</td>
<td>1.000</td>
</tr>
<tr>
<td>Low fall injury</td>
<td>2.704</td>
<td>1.00 - 7.35</td>
<td>0.051</td>
</tr>
<tr>
<td>High fall injury</td>
<td>1.681</td>
<td>0.63 - 4.47</td>
<td>0.298</td>
</tr>
<tr>
<td>Age ≥60 years</td>
<td>2.886</td>
<td>1.74 - 4.79</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ASA score ≥3</td>
<td>0.935</td>
<td>0.53 - 1.66</td>
<td>0.818</td>
</tr>
</tbody>
</table>

ASA: American Society of Anesthesiologists physical status classification.
In the sensitivity analysis, after excluding the hospital with triage by paramedics, 1311 patients remained. The results imply the same trend as in the overall cohort with unchanged overtriage between former and new criteria (67.5 % versus 68.2 %, p=0.915) and undertriage of 5.9 % versus 7.6 % (Cribari Matrix method, p=0.281). Also, the alternative method for undertriage showed similar results; 53.7 % (former), compared to 67.6 % (new, p=0.168).

The number of trauma patients registered in SweTrau during September-December (approximately the period of former criteria) was 2889, which is lower than during May-August (3196 patients, period of new criteria).

The inter-hospital re-scoring of AIS in severe cases generated the same ISS for the patients as the original scoring and there was no difference in 30-day mortality when comparing the former and new triage criteria.

Paper II

A total 741 patients were included of which 115 were excluded due to the following reasons: referral patients (n=105), double registrations (n=2), drowning (n=2) and missing data (n=6), thus generating a study population of 626 patients. Penetrating trauma comprised approximately 10 % of the population (9.7 %) as well as of the severely injured patients (NISS>15, 11 %), but made up almost a quarter (25.4 %) of the TA patients and nearly 70 % of the patients in need of an emergency intervention (68.4 %). More than half of the patients had one of the following two mechanisms of injury (MOI): “motor vehicle crash, MVC” (34.7 %) or “high fall” (19.3 %).

Overtriage was 49.8 % (102 of 205 patients, Cribari Matrix method) and almost a third of the overtriaged patients (31.4 %) had experienced a penetrating trauma (32 patients).

Undertriage was 11.2 % (47 of 421 patients, Cribari Matrix method) versus 28.8 % with the alternative method (47/163). Of the undertriaged patients, more than 50 % (24 patients) activated a TR or Caution. Examining the rest of the undertriaged patients, most of them (17/23) had either fallen less than five meters or had been hit by a blunt object.

The most common criterion, motorcycle crash>35 km/h (MCC, no. 20 in Table 5), had 72 activations, with seven patients over 60 years old, whereof five had an NISS>15. Glasgow Coma Scale <13 (GCS<13, no. 6) was second most common, with penetrating trauma (no. 7) taking the third place. Criterion no. 17 (MVC>50 km/h without seatbelt) was activated 25 times without identifying any severely injured patients.

LR+, sensitivity, specificity and PPV of the different criteria combinations and individual criterion are displayed in Table 5. Physiological criteria (no. 1-6) had high LR+ (6.7), specificity (93.3 %) and PPV (70.2 %) but low sensitivity (44.8 %). TA criteria (no. 1-16) had lower LR+ (3.5), specificity (82.3 %) and PPV (55.4 %) but higher sensitivity (62.6 %).

The overall accuracy of the criteria is visualized in Fig 10. The TA criteria had the highest accuracy with an AUC of 0.724, followed by physiological criteria (no. 1-6, AUC 0.690).
Figure 10. Accuracy of different combinations of criteria according to area under the curve (AUC) of receiver operator characteristics (ROC)-points in Paper II.

Paper III

A total of 120 patients, randomly selected, were validated at different hospitals. Initially, 52 hospitals were considered, with ten remaining after exclusions due to the following reasons: not affiliated with SweTrau (n=4), no patients registered in SweTrau in 2018 (n=6), negative or no answer to request to validate (n=7) and cancelled validation due to COVID-19 pandemic (n=25).

The study group exhibited the same demographics as the overall patients in SweTrau 2018, with most patients being healthy (ASA score 1-2, 85.8 %), male (68.3 %) and subject to blunt trauma (90.0 %). The population had a median age of 43 and a mean age of 44, while the mean of NISS was 12 (median 9) with ISS somewhat lower (mean 9 and median 5). The variables of SweTrau were validated (48 individual variables as well as four groups of variables, Table 6).

Accuracy was good (85.8 %) and only seven out of 48 variables had a poor accuracy (<70 %): individual NISS and ISS, Time of first CT scan, Time until first key emergency intervention, Time of trauma, Systolic Blood Pressure (SBP) upon arrival of EMS personnel at scene and Pre-injury ASA physical status classification, highlighted in red in Table 6. However, when grouped by >15<, both NISS and ISS displayed good accuracy (97.5 % and 92.5 %, respectively).

Regarding correlation between the original registration in SweTrau and the re-registration in the study, 87.5 % of the variables (42/48) had an either excellent (≥0.8) or strong (0.6-0.79) correlation. No variable had a week
correlation; however, the following variables exhibited a moderate (0.4-0.59) correlation: SBP clinical category upon arrival of EMS personnel at scene, Pre-injury ASA physical status classification, Trauma call re-prioritized, Glasgow Outcome Scale (GOS) at discharge from reporting hospital, Type of airway management and Highest level of pre-hospital care provided, highlighted as yellow in Table 6.

Table 6. Accuracy, correlation and comparability in Paper III.

<table>
<thead>
<tr>
<th>No</th>
<th>Variable</th>
<th>Accuracy</th>
<th>Pearson's r or Cohen's kappa</th>
<th>Comparability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of transportation</td>
<td>0.97</td>
<td>0.90</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>Glasgow Coma Scale (GCS) upon arrival of EMS personnel at scene</td>
<td>0.87</td>
<td>0.96</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>GCS motor component upon arrival of EMS personnel at scene</td>
<td>0.97</td>
<td>0.82</td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>Systolic blood pressure (SBP) upon arrival of EMS personnel at scene</td>
<td>0.85</td>
<td>0.81</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>SBP clinical category upon arrival of EMS personnel at scene</td>
<td>0.83</td>
<td>0.46</td>
<td>X</td>
</tr>
<tr>
<td>6</td>
<td>Respiratory rate (RR) upon arrival of EMS personnel at scene</td>
<td>0.83</td>
<td>0.95</td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>RR clinical category upon arrival of EMS personnel at scene</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td>Pre-hospital cardiac arrest</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>9</td>
<td>Pre-hospital airway management</td>
<td>0.99</td>
<td>0.85</td>
<td>X</td>
</tr>
<tr>
<td>10</td>
<td>Type of pre-hospital airway management</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>11</td>
<td>Highest level of pre-hospital care provided</td>
<td>0.86</td>
<td>0.59</td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>Time of trauma</td>
<td>0.61</td>
<td>0.86</td>
<td>Z</td>
</tr>
<tr>
<td>13</td>
<td>Time of alarm</td>
<td>0.80</td>
<td>1.00</td>
<td>T</td>
</tr>
<tr>
<td>14</td>
<td>Time of arrival at scene</td>
<td>0.78</td>
<td>1.00</td>
<td>S</td>
</tr>
<tr>
<td>15</td>
<td>Time of EMS personnel leaving the scene</td>
<td>0.89</td>
<td>1.00</td>
<td>S</td>
</tr>
<tr>
<td>16</td>
<td>Time of arrival in hospital</td>
<td>0.70</td>
<td>1.00</td>
<td>T</td>
</tr>
<tr>
<td>17</td>
<td>Type of trauma criteria</td>
<td>0.99</td>
<td>0.66</td>
<td>S</td>
</tr>
<tr>
<td>18</td>
<td>Activation of the trauma team</td>
<td>0.89</td>
<td>0.81</td>
<td>X</td>
</tr>
<tr>
<td>19</td>
<td>Trauma call re-prioritized</td>
<td>0.97</td>
<td>0.49</td>
<td>S</td>
</tr>
<tr>
<td>20</td>
<td>GCS upon arrival in hospital</td>
<td>0.88</td>
<td>0.93</td>
<td>X</td>
</tr>
<tr>
<td>21</td>
<td>GCS motor component upon arrival in hospital</td>
<td>0.98</td>
<td>0.74</td>
<td>X</td>
</tr>
<tr>
<td>22</td>
<td>SBP upon arrival in hospital</td>
<td>0.68</td>
<td>0.88</td>
<td>X</td>
</tr>
<tr>
<td>23</td>
<td>SBP clinical category upon arrival in hospital</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>24</td>
<td>RR upon arrival in hospital</td>
<td>0.85</td>
<td>0.73</td>
<td>X</td>
</tr>
<tr>
<td>25</td>
<td>RR clinical category upon arrival in hospital</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>26</td>
<td>Time of trauma criteria</td>
<td>0.98</td>
<td>0.90</td>
<td>X</td>
</tr>
<tr>
<td>27</td>
<td>Pre-injury ASA physical status classification</td>
<td>0.68</td>
<td>0.49</td>
<td>X</td>
</tr>
<tr>
<td>28</td>
<td>Mechanism of injury</td>
<td>0.88</td>
<td>0.86</td>
<td>X</td>
</tr>
<tr>
<td>29</td>
<td>Intent of injury</td>
<td>0.99</td>
<td>0.96</td>
<td>X</td>
</tr>
<tr>
<td>30</td>
<td>ISS, grouped by 1-8, 9-15, 16-24 &amp; 25-75</td>
<td>0.85</td>
<td>0.93</td>
<td>X</td>
</tr>
<tr>
<td>31</td>
<td>NISS, grouped by &lt;15&lt;</td>
<td>0.98</td>
<td>0.92</td>
<td>X</td>
</tr>
<tr>
<td>32</td>
<td>ISS, grouped by &lt;=15&lt;</td>
<td>0.85</td>
<td>0.85</td>
<td>X</td>
</tr>
<tr>
<td>33</td>
<td>Survival status (30-day mortality)</td>
<td>0.96</td>
<td>0.90</td>
<td>X</td>
</tr>
<tr>
<td>34</td>
<td>Glasgow Outcome Scale (GOS) at discharge from reporting hospital</td>
<td>0.70</td>
<td>0.51</td>
<td>X</td>
</tr>
<tr>
<td>35</td>
<td>Number of days on ventilator</td>
<td>0.88</td>
<td>0.94</td>
<td>X</td>
</tr>
<tr>
<td>36</td>
<td>Date of discharge</td>
<td>0.79</td>
<td>0.95</td>
<td>Z</td>
</tr>
<tr>
<td>37</td>
<td>Highest level of in-hospital care</td>
<td>0.93</td>
<td>0.90</td>
<td>X</td>
</tr>
<tr>
<td>38</td>
<td>Discharge destination</td>
<td>0.91</td>
<td>0.83</td>
<td>X</td>
</tr>
<tr>
<td>39</td>
<td>Inter-hospital transfer</td>
<td>0.98</td>
<td>0.98</td>
<td>X</td>
</tr>
<tr>
<td>40</td>
<td>Mortality conference</td>
<td>1.00</td>
<td>1.00</td>
<td>S</td>
</tr>
<tr>
<td>41</td>
<td>NISS grouped by 1-8, 9-15, 16-24 &amp; 25-75</td>
<td>0.85</td>
<td>0.93</td>
<td>X</td>
</tr>
<tr>
<td>42</td>
<td>ISS, grouped by &lt;15&lt;</td>
<td>0.98</td>
<td>0.98</td>
<td>X</td>
</tr>
<tr>
<td>43</td>
<td>ISS, grouped by &lt;=15&lt;</td>
<td>0.82</td>
<td>0.82</td>
<td>X</td>
</tr>
</tbody>
</table>

S: Variables exclusive to SweTrau (n=5). T: Time of alarm and Time of arrival in hospital instead of time from alarm to hospital arrival (n=2). X: exact agreement (n=37). Y: Venous or arterial blood gas.
Correctness of the variables was also good (89.7 %) with the vast majority (91.7 %) displaying a good or adequate correctness and only four variables showing a poor (<70 %) correctness: individual NISS and ISS, Time until first key emergency intervention and Pre-injury ASA physical status classification, displayed as the combination of green and yellow in Fig 11.

Figure 11. Accuracy and correctness in Paper III. RR: Respiratory rate. EMS: Emergency medical services. NISS: New Injury Severity Score. SBP: Systolic blood pressure. GOS: Glasgow Outcome Scale.

Case completeness was poor (44.3 %), nevertheless, none of the missed patients had initiated the highest trauma call or were severely injured.
Data completeness was overall good (88.5 %), with only seven variables exhibiting poor (<70 %) completeness: RR clinical category upon arrival of EMS personnel at scene, Time until normal base excess, Base excess, RR clinical category upon arrival in hospital, Time of trauma, Coagulation: INR and SBP clinical category upon arrival of EMS personnel at scene (Fig 12).

Median time of **timeliness** was roughly 4.5 months from the date of trauma, with 84.2 % registered after a year.

**Comparability** with the variables of the Utstein template of trauma revealed that 89.6 % of the variables were identical or had non-significant variations (Table 6). The five variables exclusive to SweTrau were: *Time of arrival at scene, Time of EMS personnel leaving the scene, Type of trauma criteria, Trauma call re-prioritized and Mortality conference.*

**Paper IV**

A total of 10816 patients were included with 229 excluded due to the following reasons: missing data on mortality (n=52), missing data on emergency intervention (n=2), missing data on injury mechanism (n=113) and missing data on ASA score (n=62), thus generating a study population of 10587 patients.

Patients with less severe injury (NISS<15) were younger and had fewer comorbidities than the overall population, similar to the penetrating group. The group NISS<15, however, had the same proportion of male patients as the overall population (roughly 70 %), in contrast to the penetrating group where there was a strong male predominance (90.1 %).

Overall 30-day mortality was 7.8 % for the entire study population, being 13.0 % for patients with NISS>15 and 1.7 % for NISS<15. Annual mortality for patients with NISS<15 increased during the study period, from 1.3 % to 2.7 %, \( p=0.005 \), while it was unchanged for the other groups (NISS>15, penetrating trauma and blunt trauma) (Table 7, Fig 13). More than half (52.4 %) of the deceased in the group NISS<15 died during the last three years of the study (2019-2021), with twelve patients dying from knife injuries, gunshot wounds (GSW) or suicides, compared to only three patients dying from these causes during 2013-1018. Also, during the three years from 2019 and onwards, there were 13 deaths in the emergency department – whereof eleven pre-hospital cardiac arrests in elderly patients subjected to blunt trauma – as opposed to none during the earlier years.

![Figure 13. Trends in mortality for different groups in Paper IV.](image-url)
Table 7. Chi-Squared test for trend and Annual average percent change (AAPC) in Paper IV.

<table>
<thead>
<tr>
<th></th>
<th>Chi-Squared test for trend p-value</th>
<th>JoinPoint regression AAPC (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mortality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISS&gt;15</td>
<td>0.963</td>
<td>-0.75 (-5.17, 4.11)</td>
</tr>
<tr>
<td>NISS&lt;15</td>
<td>0.005*</td>
<td>12.24* (7.53, 18.36)</td>
</tr>
<tr>
<td>Penetrating trauma</td>
<td>0.465</td>
<td>-2.90 (-10.85, 7.33)</td>
</tr>
<tr>
<td>Blunt trauma</td>
<td>0.079</td>
<td>1.14 (-3.95, 8.82)</td>
</tr>
<tr>
<td><strong>Emergency Intervention</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISS&gt;15</td>
<td>0.297</td>
<td>-0.64 (-2.34, 1.15)</td>
</tr>
<tr>
<td>NISS&lt;15</td>
<td>0.029*</td>
<td>1.51 (-0.73, 4.21)</td>
</tr>
<tr>
<td>Penetrating trauma</td>
<td>0.221</td>
<td>0.01 (-2.22, 2.49)</td>
</tr>
<tr>
<td>Blunt trauma</td>
<td>0.909</td>
<td>-0.11 (-1.66, 1.51)</td>
</tr>
<tr>
<td><strong>ICU</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISS&gt;15</td>
<td>&lt;0.001*</td>
<td>-3.00* (-4.61, -1.38)</td>
</tr>
<tr>
<td>NISS&lt;15</td>
<td>0.993</td>
<td>-0.57 (-5.48, 5.50)</td>
</tr>
<tr>
<td>Penetrating trauma</td>
<td>0.001*</td>
<td>-7.23* (-8.47, -5.90)</td>
</tr>
<tr>
<td>Blunt trauma</td>
<td>0.030*</td>
<td>-1.93* (-3.22, -0.59)</td>
</tr>
<tr>
<td><strong>Increasing MOI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knife</td>
<td>&lt;0.001*</td>
<td>7.46* (4.82, 10.81)</td>
</tr>
<tr>
<td>Hit by blunt object</td>
<td>0.006*</td>
<td>3.32* (1.54, 5.35)</td>
</tr>
<tr>
<td>GSW</td>
<td>&lt;0.001*</td>
<td>7.12* (4.82, 9.97)</td>
</tr>
<tr>
<td><strong>Decreasing MOI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCC</td>
<td>0.004*</td>
<td>-3.57* (-5.89, -1.26)</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>&lt;0.001*</td>
<td>-8.84* (-15.14, -2.80)</td>
</tr>
</tbody>
</table>


During the study period, there was no change in the proportions of emergency interventions in the different groups, although the two separate statistical measurements (JoinPoint regression model and Chi-Squared test for trend) were not in agreement with each other regarding NISS<15 (Table 7). For the group NISS>15, about half of the patients needed an emergency intervention, a number which was stable during the study period (Fig 14).

![Figure 14. Trends in emergency intervention for different groups in Paper IV.](image)
ICU admissions decreased for three out of four groups, the exception being patients with NISS<15 (Table 7). The admissions in the NISS>15 cohort was reduced from 62.1 % to 45.7 %, with the blunt and penetrating cohorts’ admissions declining sharply after 2019 (Fig 15).

**Figure 15. Trends in intensive care unit admission for different groups in Paper IV.**

When studying mechanisms of injury, the following had an increasing trend according to both statistical methods: assaults with knife, GSW and hit by blunt object, meanwhile MCC and pedestrian injuries declined (Fig 16). The proportion of penetrating trauma increased significantly during the study (12.4 % to 19.6 %, p<0.001).

**Figure 16. Trends in mechanism of injury in Paper IV.**
Discussion

This thesis has addressed different aspects of trauma systems, ranging from triage criteria and trauma registries, to different scoring methods for over- and undertriage, injury severity and survival probability. In Paper I and II, the SNTTC have been thoroughly evaluated regarding their efficacy, safety and accuracy. However, in order to continue to improve triage criteria, bigger multicentre studies, preferrable national ones, would be desirable. For this to be achievable in a reasonable way, inclusion of the activating criterium as a variable in SweTrau is recommended. Another suggestion is to regularly perform on-site validations of SweTrau, as a continuation of Paper III:s validation. Paper IV furthermore presents future study areas, concerning the rise in penetrating trauma and mortality in patients with a TA and NISS<15, as well as the appropriate care level for trauma patients. This thesis adds valuable insights to current trauma literature and will hopefully be a corner stone to continue to build on, not least by enabling studies based on validated data.

Implementation of national trauma triage criteria

Paper I displayed a maintained patient safety after implementation of the SNTTC, with unchanged over- and undertriage compared to the criteria previously used.

The study was initially planned to be a randomised controlled study with the patients being triaged by either the former or new trauma team activation criteria. However, due to Swedish law the ethical committee would not approve such a study unless a pre-signed consent form could be obtained, which, for obvious reasons, is not possible in the trauma setting. Instead, a prospective stepped wedge cohort study was performed as a way to study a change in policies on a system level [99], referred to as “pseudo-randomisation” where the implementation of new criteria mimics a cluster randomisation.

The principal difference with the SNTTC criteria compared to the former criteria is a significant cut down of the number of MOI criteria for initiating the lower level of trauma call. This change had its basis on the findings of several studies (both for field triage and in-hospital triage), reporting that MOI criteria often are inaccurate in predicting severe injury [100-102].

Paper I presented, as one might have expected, a clearly significant decrease of limited TTA. However, the prevalence of trauma, as well as
mechanism of injury, is varying during the year. The evaluation of the different trauma criteria in Paper I was made during different time periods, which may actually have led to an underestimation of the reduction in limited TTA, because the new criteria were studied during the summer (with usually higher levels of trauma calls). Nevertheless, the decrease in limited TTA almost exclusively occurred in patients not severely injured (ISS<15), further establishing the safety and efficacy of the criteria.

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The choice of measuring the undertriage in two different ways was made since both methods hold their own limitations. The Cribari Matrix method (Table 2) has an in-built error, where the result is affected by the total number of patients not initiating the highest level of trauma call. In Paper I, this became an important factor since the change in criteria rendered a lower number of limited TTA activations, in turn resulting in a decrease of the denominator and finally leading to an undertriage rate of 7.1 % (4.8 % before the implementation of the SNTTC). However not statistically significant, there is a possibility that this could be because of a type II error (a false negative result).

The use of the alternative method (Table 2) when calculating undertriage is preferable when evaluating triage over a period of time, since it is not affected by a change in TTA criteria (it simple presents the proportion of severely injured patients that does not initiate the highest level of trauma call) [59]. However, a rather significant weakness of this method is that there is no consensus regarding what is an acceptable level of undertriage. In Paper I, the undertriage was close to 50 % with this method.

Nonetheless, the analyses of undertriage in Paper I indicate that further modification of the TTA criteria may be required for specific patient cohorts (elderly?) and MOI (low fall injuries?), while bearing in mind that the results of over- and undertriage reflect the study setting; a high road safety with modern cars and where the majority of patients suffer from blunt trauma.

Evaluation of the Swedish national trauma triage criteria

Paper II evaluated the SNTTC in a multicentre setting, confirming that the current combination of trauma triage criteria has adequate sensitivity, specificity, LR+ and accuracy to identify severely injured patients.

The study population was similar to other international studies [42, 102, 104-108] and 30-day mortality was also comparable [102, 104-107], as was the (expected) higher mortality of the TA group [104-106].

With triage, accuracy (a high sensitivity with an acceptable specificity) is best illustrated by the area under the curve (AUC) [109]. Sensitivity, specificity and the accuracy reflected by the AUC is described as the “general strength” of the criteria, while PPV and LR+ calculate the “clinical usefulness”. PPV is influenced by the prevalence of severely injured patients and represents the probability of a patient being severely injured if the criterion is
activated [110]. LR+ (i.e. the slope of the ROC-curve generating the AUC [111]) has the advantage of not being sensitive to prevalence [112].

Because of the retrospective nature of the cohort study, the results are depending on the accurate registration of collected data. A patient selection bias due to missed patients may be present, as well as bias due to the registrars not being blinded to the trauma activation criteria when calculating NISS. However, since NISS consists of an objective assessment of specific injuries, this potential bias was not deemed a significant factor.

The results indicate that either TA criteria (highest AUC) or the physiological criteria (no. 1-6, highest LR+, specificity and PPV) might seem like possible candidates to use as stand-alone criteria. However, the sensitivity of both TA criteria (62.6 %) and the physiological criteria (44.8 %) are not good enough, which would lead to too high undertriage. Taking this into account, the only acceptable combination is the SNTTC as a whole, with a sensitivity of 84.7 %, even though a lower LR+, specificity and PPV have to be accepted.

The overtriage of the SNTTC with the Cribari Matrix method (Table 2), nearly 50 %, was similar to other international studies [113, 114]. It is an improvement from when the SNTTC were first implemented (the overtriage was calculated to 72.2 % [105]), but is nonetheless higher than the recommendation from ACS-COT of 25-35 % [18]. Penetrating trauma, however three times more common among the overtriaged patients, comprised almost a quarter of the group of patients that needed an emergency intervention. Thus, penetrating trauma does not always generate a high NISS but still demands a trauma team present on arrival at the hospital, in turn affecting the overtriage. This fact only emphasizes that the TA criteria identify not only the severely injured patients, but also patients in need of an emergency intervention. Moreover, the PPV of the TA criteria was 55.4 %, versus 51.7 % in an American study [115], implying that the SNTTC are performing well when compared internationally.

From when the SNTTC were implemented [105], the undertriage with the Cribari Matrix method (Table 2) has increased from 7.1 %-11.2 %, which is more than recommended [18], but comparable [113] or lower than other studies [114]. This can possibly be due to the reduction in number of Trauma Responses/No trauma activations (79.3 % vs 67.3 %) [105] since this means a decrease in the denominator of the Cribari Matrix method (Table 2). The alternative method of calculating undertriage (Table 2) [59] shows, on the other hand, a clear reduction of undertriage since the implementation of the SNTTC from 49.4 % (37/79) [105] to 28.8 % (47/163).

The undertriaged patients unveiled no common denominator, even though the combination of Trauma Response no. 20 (MCC) + Caution no. 25 (Age>60) should have triggered a TA more often, underlining the well-known issue with compliance to trauma triage criteria [37]. Furthermore, since only 163 patients were severely injured in this cohort, the number of patients may have been too small to evaluate some criteria.
Validation of SweTrau

Paper III reported the first validation of the SweTrau, performed via re-registration of randomly selected trauma patients on-scene at different hospitals. The overall validity of the registry proved to be high, with certain areas identified in need of further improvement.

The major limitation of Paper III is the forced reduction of the study population due to severe restrictions at some of the included hospitals during the COVID-19 pandemic. Nonetheless, the population is still considered representative since the study group shares the same demographics as SweTrau as a whole and since the loss of hospitals was random.

The limit of NISS>15 (a marker of a severely injured patient) as an inclusion criterium for SweTrau was valid, with only 2.5 % of the patients being either upgraded or downgraded during the re-registration, compared to 5.6 % in a Norwegian study [95] using ISS>15 as the limit.

Both overall accuracy and correctness were good (85.5 % and 89.7 %, respectively). Furthermore, some of the variables had been rounded up or down during the initial registration, a fact to keep in mind when comparing this study to the few other studies calculating these statistics, such as overall accuracy 94.3 % in a Finnish study [68] and overall correctness 98 % and 97.1 % in a Spanish [97] and Finnish [68] study. Four variables had both poor accuracy and poor correctness (<70 %) in common: NISS, ISS, Time until first key emergency intervention and Pre-injury ASA physical status classification. The latter variable also only had a moderate correlation, which highlights a possible need for additional education in ASA-scoring for registrars in SweTrau. Furthermore, looking at the results of NISS and ISS, they had on the other hand both good accuracy and correlation as grouped by <15< and grouped by 1-8, 9-15, 16-24 & 25-75, which are more useful in the clinical setting than the absolute agreement (accuracy) of individual NISS and ISS points. The same tendency, low accuracy of injury score (ISS) but high correlation (although lower than in this study; 0.84 and 0.81 vs. 0.91), is also seen in studies from The Netherlands [65, 116].

The goal of timeliness is a complete registration in SweTrau 31 days after the trauma (due to the 30-day mortality variable). The median time in this study, however, was 4.5 months which in turn leads to delays when extracting up-to-date data for reports, statistics and research, and therefore constitutes an important area when it comes to further improvement of the registry.

Case completeness for severely injured patients (NISS>15) was 100 %, although the overall case completeness was poor (44.3 %), indicating that finding all patients with the lowest level of trauma call is a challenge, possibly partly due to lack of time and resources for the registrars. Besides, the results of case completeness in this study must be interpreted with caution since the sample became too small to properly draw any clear conclusions from. Nevertheless, as case completeness is dependent on the inclusion criteria of a
registry, it is harder to compare case completeness between registries (some may only focus on severely injured patients while others include all trauma patients). Studies with case completeness as a parameter are also scarce in international literature, with very diverging results [68, 96] which also makes it difficult to interpret. Currently in SweTrau, case completeness is approximated by comparing included patients with the Swedish Intensive Care Registry, which roughly only covers severely injured patients and not those with the lowest trauma call and NISS<15, which are the ones that get missed, according to this study.

The overall data completeness (88.5 %), with 81.3 % of the variables having >80 % data completeness, is similar to other international studies [68, 97, 117]. Moreover, the variables with poor data completeness were primarily “clinical category”, where an exact measurement of for example blood pressure or respiratory rate was missing, and there was no estimation of pulse or breathing pattern recorded in the patient chart. Not all trauma patients get blood tests either, especially if they are not seriously injured, which explains the poor data completeness for variables like Base excess, Time until normal base excess and Coagulation: INR. Also, Time of trauma is a very unreliable variable (missing in approximately 50 % of the cases) due to the inherent uncertainty in its nature, which is wise to keep in mind when conducting studies.

Finally, the overwhelming majority of variables in SweTrau correspond exactly to the variables of the Utstein template of trauma [78], with only minor variations of the rest of the variables, making SweTrau comparable to international registries also based on this template.

Trends in the Swedish trauma panorama

Paper IV investigated trends in the Swedish trauma panorama during nine years, in which time penetrating trauma increased with over 50 % and the mortality for patients with NISS<15 rose significantly, from 1.3 % to 2.7 %.

The choice of using two statistical methods for the analyses (Chi-Squared test for trend and JoinPoint regression [118]), with both having to be in agreement for a result to be considered significant, was made in order to strengthen the validity of the results, in addition to simplifying their interpretation by using annual average percent change (AAPC) derived from JoinPoint.

Traffic injuries (e.g. pedestrian accidents and MCC) declined during the study, consistent with international findings [120, 122, 125], while assaults, such as “hit by a blunt object”, GSW and knife injuries increased, similar to a study from Denmark [120] but contradictory to a study from the USA [125], indicating a shift towards “violence-oriented” MOI getting more prevalent in Scandinavian trauma cohorts.

For severely injured patients with NISS>15, the overall mortality (13.0 %) is in line or better than several Swedish [119] and international studies [120-
as well as the annual SweTrau reports which had a mean of approximately 17% mortality for this group during the same time period. The noted increase in mortality for patients with NISS<15, especially from 2019 and onwards, might be discussed in relation to the implementation of the SNTTC in 2017. Nevertheless, a study from 2019 [105] showed no change in TA:s or proportion of severely injured patients before and after the new criteria, weakening this argument. Looking closer at this rise in mortality, suicides and violence (knife injuries and GSW) together with ED deaths were overrepresented, constituting more than half of the deceased patients. Additionally, patients pronounced dead before arrival at hospital are not included in SweTrau, potentially leading to false low mortality numbers, as showed in a Swedish study [15]. The overall proportion of penetrating trauma also changed clearly from 12.4% to 19.6%, an increase of more than 50%, indicating a negative trend supported by other research [14, 15]. In summary, this changing panorama may be a contributing factor to the rise in mortality for patients with NISS<15, however, since this is a retrospective register-based study, it is difficult to draw conclusions on an individual level. Excluded patients are a possible bias, nonetheless, since they only comprised about 2%, the influence should be negligible.

Although the proportion of emergency interventions remained stable during the study, the descending rate of ICU admissions is noteworthy; more pronounced during 2020-2021 and the COVID-19 pandemic, which stands in contrast to other international studies [123, 124]. Any suggestions of trauma patients being down-prioritised in Swedish ICU:s during the pandemic is however discarded by the fact that mortality was unchanged in all groups except for NISS>15, and when looking at the deceased patients in this group, the rate of ICU admissions was not changed. This interesting finding implies a potential of having more trauma patients treated at a lower care level (intermediate care or regular ward) with patient safety maintained.
Conclusions

I The implementation of national trauma triage criteria in Sweden has led to a reduction of the lowest level of trauma call by almost a half whilst over- and undertriage has remained unchanged compared to former criteria, thus showing increased efficiency in use of in-hospital resources without compromising patient safety.

II The SNTTC have decreased under- and overtriage since their implementation, while being efficient in identifying severely injured patients and patients in need of an emergency intervention. The current criteria exhibit the best sensitivity compared to other examined combinations, with no additional criteria identified that would improve the protocol enough to promote a change.

III SweTrau has a high validity, including good accuracy, correctness and data completeness, and the majority of variables display an either strong or excellent correlation. The registry is also comparable to other trauma registries using the Utstein template of trauma, while timeliness and case completeness are areas of improvement.

IV The 30-day mortality in patients with TA and NISS<15 more than doubled during 2013-2021, while penetrating trauma increased with over 50% and the rate of ICU admissions was reduced - findings clearly warranting further investigations. Simultaneously, traffic accidents decreased whereas there was no trend in the proportion of emergency interventions.
Future perspectives

This PhD thesis has shed light on some aspects of trauma care, yet, there are still many important areas that need to be further investigated and clarified. Amongst these are the definition of undertriage, which trauma triage criteria are indeed the best, and how to make trauma registries more coherent in order to easier compare trauma care internationally. The rise in penetrating trauma in Sweden is truly concerning, demanding further consideration, especially in relation to the increased mortality in the NISS<15 group. In summary, although the picture of trauma care now may be a bit clearer, there is much that could be improved, with new algorithms and treatments to be discovered and of course team work in the midst. Reach for the stars, the sky is the limit!

The eternal question of undertriage

As earlier discussed, there are different ways to define undertriage (Matrix method, percent of patients with ISS/NISS>15 not receiving the highest trauma call, patients in need of an emergency intervention etc.). There is a need for a national consensus regarding the definition and calculating of over- and undertriage, after which, hopefully, this variable could be included in SweTrau in order for hospitals to track their performance and compare it with others. This would enable a prospective national multicentre study, recording undertriage in all SweTrau affiliated hospitals and then evaluating potential differences between hospitals, MOI and seasonal variations, for example.

No matter the exact definition of undertriage; elderly with low fall is a risk group, as highlighted in Paper I. However, the question is if this patient group really benefits from the presence of a full trauma team at arrival in hospital, or if it may be more useful to have a modified “trauma route”, similar to patients suffering from stroke or heart attack. A quick assessment of the (eventual) immediate threat to life, a swift diagnosis with the aid of imaging techniques (e.g. computed tomography), followed by the best care for the individual patient is perhaps the ultimate goal to reach for? A prospective study with implementation of such a protocol at one site, compared with conventional care at another site and subsequent evaluation of the outcome may be a feasible way to move forward.
Joint triage criteria and registries – to be or not to be?

Trauma triage criteria differ both between and within countries – indicating that there is no perfect combination that suits all. It is possible that regional adaptations need to be made due to certain circumstances, however, a common trunk of criteria should, in a perfect world, be achievable. Another important factor with trauma registries is that even if the variables may be almost identical, the inclusion criteria of the registries may vary (e.g. one registry includes only patients with the highest level of trauma call, while another registry includes all patients with a trauma call, regardless the level, which makes it hard to compare). Not to mention the problem of finding all patients with the lowest level of trauma call, leading to a seemingly lower case completeness, as pointed out in Paper III. Future collaborations to make registries more uniform is sought for.

Interesting questions to address include the removal of further criteria that do not discriminate severely injured patients from not severely injured patients, as suggested in Paper II \((MVC>50 \text{ km/h without seatbelt})\). Another noteworthy criterium is shock index (SI), which is the ratio of heart rate to systolic blood pressure, discussed in Paper I as a possible future addition to triage protocols. As suggested in Paper II, adding the triggering criterium to the variables in SweTrau would facilitate an evaluation of individual criteria in an even larger multicentre scale, potentially further improving over- and undertriage and patient outcome.

Is the level of significance?

In Paper IV the notion that some trauma patients may be cared for at a lower care level with the same outcome is introduced. This obviously depends on the local conditions and availability of intensive and intermediate care. Not all hospitals make this distinction and have only one higher level of care, however, where different levels of higher care exist this constitutes an interesting finding to explore. Dedicated trauma wards, competent of intermediate care, are already implemented in several centres. An evaluation of outcome for patients treated at these sites, compared to mixed intermediate wards, could be how to proceed. The decreased ICU-admissions, especially from 2020 and onward, is of particular interest and a retrospective study from the years before, during and after the COVID-pandemic, compared with other Nordic countries, would provide more insight. Finally, the worrisome finding of a doubled mortality in patients with TA and NISS<15, together with the rise in penetrating trauma, needs exploring. A national retrospective study involving these groups during a longer period, evaluating the mortality in the light of survival probability, might be an appropriate approach.
Trauma är ett mycket stort hälsoproblem i hela världen där exempelvis trafikolyckor återfinns som en av de tre vanligaste dödsorsakerna i åldrarna 5-39 år. Trubbigt våld, såsom trafikolyckor, är den primära traumaorsaken i Europa, medan penetrerande våld (framför allt kniv- och skottskador) är vanligast i till exempel delar av Sydafrika. Dock har en oroande ökning av penetrerande våld skett i Sverige under det senaste decenniet, vilket i sin tur påverkar hur arbetet mot olyckor och våld ska prioriteras, och även hur sjukvårdens omhändertagande av olika typer av traumapatienter ska planeras. Denna avhandling syftar till att belysa olika aspekter på traumavård, såsom triagering (sortering) av traumapatienter med hjälp av olika kriterier och validering av data som ligger till grund för forskning inom trauma. I avhandlingen ingår även en kartläggning av traumapanoramaten i Sverige under de senaste nio åren, vilket förhoppningsvis kan ligga till grund för framtida studier.

Stora framsteg har gjorts inom traumaforskningen under de senaste 40 åren, vilket förändrat riktlinjer för både ambulanssjukvård och sjukhusvård. Studier har bland annat visat att de allra flesta traumapatienter som avlider dör direkt på skadeplats av så svåra skador att det inte går att överleva dessa. För att minska antalet patienter som dör inom de första timmarna, ofta av blödningar, har det återkommit frågan om att snabbare omhänderta vård, diagnostik och behandling för att minska detta antal används begreppet ”The golden hour” vilket innebär att en svårt skadad patient bör komma till sjukhus och få avancerad vård inom en timme från traumat. Detta har i sin tur också ändrat ambulansens arbete på skadeplats där patienten snabbt lastas ombord och förs direkt till sjukhus istället för att ambulanspersonalen stannar kvar och utför ytterligare åtgärder innan avtransport.

Sammanfattningsvis finns det fortfarande mycket kvar att göra inom traumavården. Att snabbt identifiera de svårt skadade patienterna samt följa upp vården med tillförlitliga registerdata är en del av detta. Förhoppningen är att denna avhandling kommer att bidra till det fortsatta arbetet mot en bättre och mer jämlig traumavård, i en framtid där fler traumapatienter överlever.
Delarbete I

I delarbete I studeras införandet av de Nationella traumalarmskriterierna för att se om de är både säkra och träffsäkra jämfört med de tidigare använda algoritmerna, så att inte allvarligt skadade patienter missas vid prioriteringen av vilka som ska få snabbast vård på sjukhus.

De Nationella traumalarmskriterierna infördes successivt i Sverige under 2017. Innan dess hade varje region egna protokoll med kriterier som utlöste traumalarm på respektive sjukhus. Kriterierna var ofta likartade men kunde skilja sig något, vilket medförde att vissa trauma utlöste traumalarm på några sjukhus men inte andra, vilket bidrog till en ojämlik vård.

I studien ingår fem sjukhus i Mellansverige där de tidigare kriterierna jämförs med de Nationella traumalarmskriterierna genom att studera sjukhusens traumapatienter under en tidsperiod innefattade sex månader (i ett fall fyra och en halv månad) både före och efter införandet. Informationen erhölls från det svenska traumaregistret (SweTrau) där alla patienter som antingen utlöst ett traumalarm eller bedöms vara allvarligt skadade registreras.

Undertriage, det vill säga en svårt skadad patient som inte utlöser den högsta nivån av traumalarm (Nivå 1) enligt kriterierna, beräknades, liksom övertriage, vilket betyder att ett Nivå 1-larm aktiverats för en patient som inte är svårt skadad. Undertriage är en patientfara eftersom det kan innebära längre tid till rätt vård medan övertriage är ett problem avseende resursfordelningen.

Dödligheten för de 1882 inkluderade patienterna var oförändrad före och efter införandet av de Nationella traumalarmskriterierna, samtidigt som antalet Nivå 2-larm (den lägre larmnivån) minskade med 46,3 % (från 988 till 531). Inga statistiska skillnader kunde ses för under- eller övertriage, där undertriage gick från 4,8 % före till 7,1 % efter och övertriage från 71,3 % till 72,2 %. Ålder>60 år var en riskfaktor för undertriage, och drygt en femtedel av alla fallolyckor undertriagerades. Trots införandet av de Nationella traumaarmakriterierna utlöste fortfarande ungefär hälfsten (49,4 %) av alla allvarligt skadade patienter inte ett Nivå 1-larm.

Delarbete II

I delarbete II utvärderas de Nationella traumalarmskriterierna på en mer detaljerad nivå där både individuella kriterier samt grupper av kriterier granskas avseende hur träffsäkra de är när det gäller att hitta en svårt skadad patient. Analyser utfördes också för att hitta potentiella ytterligare kriterier som lägga till algoritmen för att förbättra den.

De Nationella traumalarmskriterierna består av 29 kriterier som aktiverar ett Nivå 1- eller Nivå 2-larm (vissa kriterier används också för att uppgradera larmnivån). Träffsäkerheten av kriterierna bedömdes med olika statistiska beräkningar, såsom sensibilitet (andelen av de svårt skadade patienterna som utlöser ett specifikt kriterium), specificitet (andelen av de patienter som inte är svårt skadade och som inte utlöser ett specifikt kriterium), positivt likelihood
ratio (LR+) (en kvot beskrivande sannolikheten att en patient är svårt skadad om ett specifikt kriterium är utlöст), positivt prediktivt värde (PPV) (sannolikheten att en patient är svårt skadad om ett specifikt kriterium är utlöst) och accuracy (träffsäkerhet; sensitivitet jämfört med 1-specificitet). Dessutom beräknades undertriage och övertriage.

Sex sjukhus med 626 patienter registrerade i SweTrau under 2018 inkluderades i studien. De Nationella traumalarmskriterierna som helhet hade en sensitivitet på mer än 80%, medan de kriterier som enbart utlöser Nivå 1-larm visserligen hade en lägre sensitivitet (62,6%) men istället en högre LR+, specificitet och PPV samt den högsta träffsäkerheten (accuracy) av de olika kombinationerna av kriterier.

Bilolycka >50 km/h utan bilbälte identifierade inga svårt skadade patienter trots flera aktiveringar, dock är det för få patienter i studiegruppen för att man med säkerhet kan säga att detta kriterium ska tas bort.

Övertriage minskade betydligt jämfört med Delarbete I; från 72,2% till 49,8% och en tredjedel av dessa patienter hade blivit utsatta för penetrerande våld varav hälften var i behov av en akut åtgärd. Undertriage hade ökat något från Delarbete I (7,1% till 11,2%) men ett viktigare fynd var att andelen svårt skadade patienter som inte utlöser ett Nivå 1-larm hade minskat väsentligt, från 49,4% till 28,8%.

Delarbete III
I delarbete III granskas SweTrau för att klargöra ifall informationen i registret är tillförlitligt och stämmer med uppgifterna i patientjournalen, en så kallad validering. Detta hade inte gjorts tidigare men är en viktig kvalitetsstämpel då en stor mängd forskning och kvalitetsarbete baseras på data i SweTrau.

I SweTrau finns flera moduler med fastställda variabler, där till exempel uppgifter om blodtryck, medvetandegrad, skador och åtgärder registreras. Information om olika tider (tid till sjukhus, skiktröntgen, operation etc.) noteras också, liksom om patienten avlider inom 30 dagar. Registreringen utförs av lokala, utbildade registrerare på respektive sjukhus som hittar uppgifterna i journalen och därefter för in dem manuellt i SweTrau.

Valideringen skedde på plats på respektive sjukhus där SweTrau-registret jämfördes med informationen i journalen. Följande parametrar bedömdes: exakt överensstämmelse (accuracy), adekvat överensstämmelse (correctness), hur väl variablerna i SweTrau korrelerar med de faktiska uppgifterna i journalen (correlation), om registreringen i SweTrau gjorts i rimlig tid efter traumat (timeliness), hur mycket data som saknades (data completeness) samt om vissa patienter saknades helt fastän de borde vara med i registret (case completeness). Slutligen bedömdes om registrets variabler överensstämmer med andra internationella traumaregisters variabler (comparability) vilket skulle möjliggöra jämförelse mellan olika länder och deras register.

Ursprungligen var planen att valideringen skulle ske på samtliga traumatmottagande sjukhus i Sverige, men på grund av grund b樓d annat restriktioner
under COVID 19-pandemin så kunde enbart tio sjukhus valideras, inkluderande totalt 48 variabler och fyra grupper av variabler för 120 slumpvis utvalda patienter.

Informationen i SweTrau stämde exakt i 85,8 % av fallen, hade adekvat överensstämmerlje i 89,7 % och korrelerade till 87,5 % . Variablerna var fullständigt ifyllda till 88,5 % medan enbart 44,3 % av patienterna som borde registrerats fanns med (dock fanns alla allvarligt skadade med i stickprovet). Mediantiden till registrering var ca 4,5 månad (målet är drygt en månad) och SweTrau visade sig vara jämförligt attraktiv till andra traumatregister som använder samma slags protokoll för variablerna.

**Delarbete IV**

I delarbete IV beskrivs trender i traumatpanoramat på två universitetssjukhus (Akademiska sjukhuset i Uppsala och Karolinska universitetssjukhuset i Stockholm) under nio år, mellan 2013-2021. Studien tittar på dödlighet efter 30 dagar (mortalitet) hos allvarligt skadade trauma patienter samt hur andelen patienter som är i behov av en akut åtgärd (operation, drän i bröstkorg m.m.) eller inläggning på intensivvårdsavdelning (IVA) har förändrats. Även frekvensen av olika skademekanismer och penetrerande våld kartläggs.

Data från de båda sjukhusens lokala SweTrau-register analyserades vilket omfattade 10585 patienter efter att 229 patienter exkluderats på grund av att det saknades nödvändig information för studiens frågeställningar. Trenderna analyserades med två olika statistiska metoder för att ytterligare stärka resultatet, och sammanställdes i tabeller och grafer.

Mortaliteten under studien var oförändrad kring 10 % för allvarligt skadade patienter (10,0 %–10,9 %) medan den ökade för patienter som inte var allvarligt skadade (1,3 %–2,7 %). Andelen patienter som behövde en akut åtgärd var stabil under studieåren, ca 50 % för de allvarligt skadade och kring 45 % för patienter med penetrerande våld medan en tredjedel av patienter med trubbigt våld behövde en akut åtgärd. Avseende antalet inläggningar på IVA så var det en minskning för allvarligt skadade patienter (62,1 %–45,7 %) medan det inte var någon signifikant skillnad för de patienter som inte var allvarligt skadade (10,7 %–7,7 %). Dock sågs en tydlig minskning i inläggning på IVA i grupperna penetrerande (38,1 %–31,8 %) och trubbigt våld (24,5 %–13,6 %), säkert under pandemiåren 2020-2021. Gällande skademekanismer så minskade andelen motorcykelolyckor och olyckor med fotgängare medan andelen knivskador, träffad av trubbigt föremål och skottskador ökade. Patienter med penetrerande våld ökade med 58 % under studien, från 12,4 % till 19,6 %.
Slutsatser

I De Nationella traumalarmskriterierna är säkra att använda jämfört med tidigare använda protokoll. I studien minskade antalet Nivå 2-larm med ca 50 % utan att fler svårt skadade patienter missades, vilket sparar resurser och ger bättre precision vid utlösande av traumalarm.

II De Nationella traumalarmskriterierna har en hög träffsäkerhet. Den nuvarande kombinationen av kriterier är överlägset samtliga andra undersökta kombinationer och inga potentiella kriterier hittades som kunde förstärka träffsäkerheten ytterligare.

III Valideringen av SweTrau visar att registret har en bra överensstämmelse med uppgifterna i patientjournalen och är tillförlitligt när det gäller de allra flesta variabler. Tid till registrering efter traumat och att få med alla patienter som ska registreras, även de med mindre skador, är områden som kan förbättras.

IV Mortaliteten mer än fördubblades mellan 2013-2021 för trauma patienter som inte bedömdes som svårt skadade, penetrerande våld ökade med över 50 % och inläggningar på IVA minskade - fynd som kräver ytterligare undersökning. Trafikolyckor hade en nedåtgående trend medan andelen patienter i behov av akut åtgärd var oförändrad.
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A doctoral dissertation from the Faculty of Medicine, Uppsala University, is usually a summary of a number of papers. A few copies of the complete dissertation are kept at major Swedish research libraries, while the summary alone is distributed internationally through the series Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Medicine. (Prior to January, 2005, the series was published under the title “Comprehensive Summaries of Uppsala Dissertations from the Faculty of Medicine”.)
Paper I
A prospective stepped wedge cohort evaluation of the new national trauma team activation criteria in Sweden – the TRAUMALERT study

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Abstract

Background: Trauma triage based on prehospital information facilitates correct allocation of in-hospital resources. The Swedish national two-tier trauma team activation (TTA) criteria were revised in 2016. The current study aimed to evaluate the safety and efficacy of the new criteria.

Methods: Five centres covering trauma care for 1.2 million inhabitants registered all trauma patients prospectively in the Swedish trauma registry (SweTrau) prior to and after stepwise introduction of new TTA criteria within the cohort (a prospective stepped-wedge cohort study design; period August 2016–November 2017). Evaluation of full- and limited-TTA frequency, under- and overtriage were performed at equal duration before and after this change.

Results: The centres registered 1948 patients, 1882 (96.6%) of which were included in the study. With new criteria, frequency of full-TTA was unchanged, while limited-TTA decreased with 46.3% (from 988 to 531). 30-day trauma mortality was unchanged. The overtriage was 107/150 (71.3%) with former criteria, and 104/144 (72.2%) with new criteria, \( p = 0.866 \). Undertriage was 50/1037 (4.8%) versus 39/551 (7.1%), \( p = 0.063 \). Undertriage was consistently >20% in patients with fall injury. Among patients with Injury Severity Score (ISS) > 15, 50/93 (53.8%) did not initiate full-TTA with former, vs 39/79 (49.4%) with new criteria, \( p = 0.565 \). Age > 60-years was a risk factor for undertriage (OR 2.89, \( p < 0.001 \)), while low fall injuries indicated a trend (OR 2.70, \( p = 0.051 \)).

Conclusions: The newly implemented Swedish TTA criteria result in a reduction in limited TTA frequency, indicating an increased efficiency in use of resources. The over- and undertriage is unchanged compared to former criteria, thus upholding patient safety.

Keywords: Wounds and injuries, Trauma, Triage, Patient safety, Prospective stepped wedge cohort design, Epidemiology

Background

In trauma care, a multidisciplinary, resource intensive acute patient management is crucial to maximize the “golden hour” [1] during which effective resuscitative interventions are performed [2]. This acute trauma care is initiated through activation of a trauma team which often consists of multiple medical specialties, support staff and resource allocation with operating capabilities and CT-scanner availability.

Whilst rapid trauma team activation (TTA) is a cornerstone in trauma care, inadequate TTA may drain resources from other patients. Therefore, triage is an important tool to direct medical efforts towards patients with the most urgent needs [3, 4]. The American College of Surgeons Committee on Trauma (ACS-CoT) and the Center for Disease Control and Prevention (CDC) have published Guidelines for Field Triage of injured patients [4]. A two-tier trauma alert system is often used. Physiologic derangement or...
specified anatomical injuries in trauma patients initiate a full TTA, whilst Mechanism of Injury (MOI) criteria alone initiate a limited trauma alert [5, 6]. The efficacy of trauma triage criteria is evaluated with assessment of over- and undertriage. (Additional file 1: Table S1) [7].

The perfect triage system is assumed to activate a full TTA for all severely injured patients, and a limited or no TTA for patients with minor or no injuries. The Injury Severity Score (ISS) is a method to define the severity of injury during trauma. A patient with ISS > 15 is regarded as severely injured, and should thus initiate a full TTA when using the optimal triage system. The ISS is calculated using the Abbreviated Injury Score (AIS) where injuries in different body areas are scored. The ISS is used as basis for evaluation of over- and undertriage. Overtriage is an assessment of what proportion of full TTAs that are activated by patients with minor injuries (ISS ≤15), i.e. resulting in unnecessary use of hospital resources. Undertriage, on the other hand, assesses the proportion of of severely injured patients with ISS > 15 not initiating full TTA. Over- and undertriage are the primary markers of how successful a triage system is in allocating adequate resources to patients in real life.

The development of effective triage criteria is a challenge [8–10]. In Sweden, modified two-tier ACS-CoT trauma triage criteria have been used, Table 1. Evaluation of these criteria in a retrospective cohort indicates that although they do result in an acceptable over- and undertriage, they also result in many limited trauma team activations in un-injured patients [11]. In 2015, the Swedish trauma association created a multidisciplinary workgroup involving twenty professional trauma-related organizations, with the task to develop national consensus-based TTA guidelines. The new TTA algorithm (Table 1) was introduced in late 2016 and implemented nationally in a step-wise fashion.

The aim of this study was to evaluate the safety and efficacy of the new national TTA criteria in terms of over- and undertriage compared to the previously used algorithm.

Methods
Study design
The study was performed in a population based setting in five Swedish hospitals covering trauma care for a total population of 1.2 million inhabitants. The actual change in TTA criteria was planned for implementation March 1st 2017 all over Sweden, and the study was planned and initiated in the spring of 2016. Initially the plan was a prospective before- and after cohort study but as is often the case with simultaneous clinical guideline implementations at different institutions, the actual change in TTA criteria took place at different times at the including hospitals. The study design was thus adapted to a stepped wedge cluster design of the introduction of the new trauma triage criteria. The evaluation of the TTA criteria in this cohort was performed using the prospective registration of trauma patients in the Swedish trauma registry (SweTrau). A pre-study power calculation indicated that to detect a change in undertriage from 4 to 8% with the Matrix method [7] with 80% power and 5% significance, a sample size of 553 patients per group was required.

Swedish trauma registry and participating hospitals
SweTrau is a national trauma registry in Sweden established in 2011, based on “the revised Utstein Trauma Template for Uniform Reporting of Data following Major Trauma, 2009” [12]. The registry includes all patients where a full or limited trauma alert has been activated, as well as all trauma patients with a New Injury Severity Score (NISS) > 15. This also includes trauma patients secondarily transported to a higher-level trauma centre. Forty-eight hospitals, including all but one university hospital, participate in the registry [13].

Five hospitals in the mid-Sweden participated in the current study, Fig. 1. These hospitals had harmonized criteria for full- and limited TTA prior to the transition to the new national criteria, which were stepwise implemented in the region, Fig. 2. All primary trauma patients registered in SweTrau at these centres before and after the change of TTA criteria were included in the study. Patients registered after secondary trauma transfer were excluded, as well as patients where information on TTA level or injury severity was lacking. The evaluation period was 2 × 6 months in four and 2 × 4.5 months in one hospital, Fig. 2.

Triage
In-hospital triage was performed by a senior nurse according to guidelines when contacted by the pre-hospital staff, or by a senior anaesthesiologist in the medical helicopter service. At one of the hospitals (Västerås county hospital), the triage was performed by pre-hospital staff and reported by phone to the receiving nurse prior to the change in TTA criteria. After implementation of the new criteria, all hospitals performed in-hospital triage by a senior nurse. The effect of this practice change on outcome was assessed in a sensitivity analyses (see below).

The trauma team
The resources allocated differ between limited and full TTA. The initial survey is conducted by the surgeon on call for limited TTA, and as a team effort for full TTA. A senior consultant specialized in trauma care receives a “stand by call” during limited TTA if the alert is upgraded and this consultant is designated trauma
Table 1: Former and new trauma team activation criteria

### Full trauma team activation

**Former TTA criteria**

**Physiology**
- A - Obstructed airway
- B - Respiratory rate <8 or >30/min
- SpO2 <90% with suplement of oxygen
- Diminished breathsounds
- C - Systolic BP <90mmHg
- Pulse >120 bpm
- D - GCS<12
- Focal neurologic defect

**Specific injuries**
- Penetrating trauma to the abdomen, chest or neck
- ≥2 fractures of long bones
- Pelvic fracture without stability
- Amputation above hand or foot
- Burn ≥18% TBSA or inhalation burn
- Flail chest
- Spine fractures
- Drowning or hypothermia

**New TTA criteria**

**Physiology**
- Need for ventilatory support
- Respiratory rate <10 or >29/min
- Children: Signs of respiratory compromise
- Systolic BP <90mmHg or no palp radial pulse
- Children: Capillary refill >2 seconds
- Children: pulse <90 or >190 if 0-1 yrs, <70 or >160 if 1-5 yrs
- GCS≤13

**Specific injuries**
- Penetrating trauma to the abdomen, chest, neck or extremities above
- ≥2 fractures on long bones
- Severe pain in pelvis
- Amputation above hand or foot
- Burn ≥18% TBSA or inhalation burn
- Deformed chest wall
- Suspected spinal cord injury
- Massive external hemorrhage
- Open skull fracture/impression fracture
- Face or neck trauma with threatened airway

### Limited trauma team activation

**Former TTA criteria**

**Mechanism of injury**
- MVC>70km/h with seatbelt
- MVC>50km/h without seatbelt
- Extrication time >30min
- Thrown out of vehicle
- Casuality in same vehicle
- MCC>30km/h
- Pedestrian or bicyclist hit by vehicle
- Fall >3m in height

**New TTA criteria**

**Mechanism of injury**
- MVC>50km/h without seatbelt
- Extrication time >20min
- Thrown out of vehicle
- MCC (or equivalent) >35km/h
- Children: Hit/run over by vehicle
- Fall >5m in height
- Children: Fall >3m in height

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*Cautions* - *(may influence trauma team activation)*

- Ongoing deterioration, anticoagulatory medications, extremes in age, severe preexisting conditions, hypothermia (<35°C), intoxication or pregnancy

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**Spo2** Periferal capillary oxygen saturation, **BP** Blood pressure, **GCS** Glasgow coma scale, **MVC** Motor vehicle crash, **MCC** Motorcycle crash, **TBSA** Total burn surface area
leader for full TTA. The affiliated staff for full, limited and no TTA is listed in Table 2.

**Evaluation of safety and efficacy**

ISS was used as basis for evaluation of over- and undertriage. The choice of ISS, rather than NISS (which serves as inclusion for SweTrau) for this evaluation was based on the fact that NISS is regarded as less accurate in predicting risk of mortality in blunt trauma [14]. Additionally, the ACS-CoT recommendations for acceptable levels of over- and undertriage are based on ISS [17]. The ISS was calculated for all patients using the Abbreviated Injury Score 2005 rev 2008 (AIS). The actual scoring was performed by accredited AIS-scoring professionals at all including hospitals using the AIS-module of the trauma registry. The most severe cases where validated by re-scoring at another including hospital to ensure accuracy and adequacy in the scoring. Patients with an ISS > 15 were considered severely injured [15, 16]. Over- and undertriage was calculated using the Matrix method, Additional file 1: Table S1 [7]. Additionally, the proportion of severely injured patients who did not initiate full TTA was evaluated with former and new criteria as a measure of safety, (Additional file 1: Table S1) [17]. This additional method was necessary as the design of the new criteria aimed to reduce the number of limited trauma alerts, hence per se influencing the denominator in the evaluation of undertriage based on the Matrix method. Changes in number of TTA were evaluated in four different groups based on ISS (0–15, 16–24, 25–49 vs 50–75) [18, 19].

**Sensitivity analyses**

To evaluate the potential effect of the differing triage routine in Västerås county hospital on overall outcome, TTA frequency and over- and undertriage were calculated separately when excluding this hospital in a sensitivity analysis.

As the implementation of new TTA criteria occurred late 2016/early 2017 in most hospitals, the former criteria were primarily used during autumn and winter months, whilst the new criteria were more often used during spring and summer months. To assess the potential effect of the seasonal variation on TTA frequency, an evaluation of the number of TTAs registered in the SweTrau during different months for the period 2014–2016 was performed in relation to the current study.

**Statistics**

Data were assessed for normality with histograms. Categorical data were reported as ratios with 95% confidence intervals (CI), and were assessed with chi-square. Non-normally distributed data were reported as medians with interquartile range (IQR) and compared with Mann-Whitney-U test. Predictors for undertriage were assessed in a multivariable binary logistic regression analysis. A p-value of < 0.05 was regarded as significant. Statistical analyses were performed with IBM SPSS Statistics version 25 (IBM Corp, Armonk, New York, USA).
Results

During the study period, 1948 trauma patients were registered in SweTrau at the participating centres, 66 (3.4%) of which were excluded, Fig. 3. The numbers of patients initiating full TTA, limited TTA and no TTA before and after change of trauma criteria are presented in the flow chart, Fig. 3. The number of patients receiving full TTA and those not initiating TTA was not significantly different in the two cohorts (before and after implementation of the new criteria). There was a 46.3% (95% CI 43.1–49.4%) decline in the number of cases leading to a limited TTA in the cohort in which the new criteria was implemented (988 limited TTA with former criteria vs 531 limited TTA with new criteria, Fig. 3).

Study population demographics are presented in Table 2. The proportion of male patients activating any alert increased with the new criteria, as did the median ISS of patients with limited TTA. There was no difference in 30-day mortality after trauma based on the triage criteria.

To assess if reduction in TTA activation occurred in patients with severe injury or not, all patients were divided into four subgroups according to their ISS values [19] as presented in Fig. 4. The most important reduction in number of limited TTAs occurred in the patients that were not severely injured (ISS 0–15, decrease in TTA by 48.1% with new compared to former criteria). Overall, 99.1% of the reduction occurred in patients with ISS ≤ 15, and 87.8% of the reduction was in the group of patients with ISS 0–2.

Over- and undertriage

Overtriage was 71.3% (107/150 patients) with the former TTA criteria and 72.2% (104/144 patients) with the new TTA criteria, $p = 0.866$. Undertriage calculated with the Matrix method was 4.8% (50/1037) with former criteria and 7.1% (39/551) with new criteria, $p = 0.063$. When assessing the severely injured patients (ISS > 15), 53.8% (50/93) did not initiate full-TTA with former, vs 49.4% (39/79) with new criteria, $p = 0.565$.

Subgroup analysis of undertriage

Undertriaged patients according to injury mechanism are presented in Fig. 5. Road traffic accidents constitute 55.3% (656/1187) of all patients with former criteria and 52.9% (368/695) with new criteria. Ten patients subject to road traffic accidents were undertriaged with former and nine with new criteria, $p = 0.204$. Patients subject to low fall injury constituted 13.8% of the trauma patients (164/1187) with former and 12.2% (85/695) with new criteria, $p = 0.327$. Eighteen of these patients were undertriaged with both former and new criteria $p = 0.051$.

Binary logistic regression analyses of risk factors for undertriage indicate a higher risk for undertriage in...
**Table 2** Study population demographics after subdivision into the studied groups

<table>
<thead>
<tr>
<th></th>
<th>Former criteria (n = 1187)</th>
<th>New criteria (n = 695)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age – years, median (IQR):</td>
<td>36 (21–60)</td>
<td>40 (22–61)</td>
<td>0.173</td>
</tr>
<tr>
<td>Full trauma team activation</td>
<td>40.5 (23–63)</td>
<td>43 (22–62)</td>
<td>0.726</td>
</tr>
<tr>
<td>Limited or no trauma team activation</td>
<td>36 (21–59)</td>
<td>40 (21–61)</td>
<td>0.129</td>
</tr>
<tr>
<td>Male gender, % (n):</td>
<td>59.0 (704)</td>
<td>64.6 (450)</td>
<td>0.013</td>
</tr>
<tr>
<td>Penetrating trauma, % (n):</td>
<td>2.4 (29)</td>
<td>7.8 (54)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td><strong>Glasgow Coma Scale (GCS) in Emergency</strong> Department, % (n):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal or minimal injury (GCS 15)</td>
<td>84.4 (1037)</td>
<td>82.3 (572)</td>
<td>0.003</td>
</tr>
<tr>
<td>Mild injury (GCS 13–14)</td>
<td>5.1 (60)</td>
<td>8.6 (60)</td>
<td>0.002</td>
</tr>
<tr>
<td>Moderate injury (GCS 9–12)</td>
<td>1.1 (13)</td>
<td>3.6 (25)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Severe injury (GCS 8 or below)</td>
<td>2.1 (25)</td>
<td>2.9 (20)</td>
<td>0.290</td>
</tr>
<tr>
<td>ASA score, median (IQR):</td>
<td>1 (1–2)</td>
<td>1 (1–2)</td>
<td>0.254</td>
</tr>
<tr>
<td><strong>Injury Severity Score, median (IQR):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full trauma team activation</td>
<td>8 (1–16)</td>
<td>9 (1–16)</td>
<td>0.977</td>
</tr>
<tr>
<td>Limited or no trauma team activation</td>
<td>1 (0–4)</td>
<td>2 (1–8)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td><strong>New Injury Severity Score (NISS), median (IQR):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full trauma team activation</td>
<td>9 (3–25)</td>
<td>9 (2–21)</td>
<td>0.848</td>
</tr>
<tr>
<td>Limited or no trauma team activation</td>
<td>2 (0–4)</td>
<td>3 (1–9)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td><strong>30-day mortality % (n):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full trauma team activation</td>
<td>13.8 (20)</td>
<td>12.1 (17)</td>
<td>0.662</td>
</tr>
<tr>
<td>Limited or no trauma team activation</td>
<td>1.7 (18)</td>
<td>2.6 (14)</td>
<td>0.268</td>
</tr>
</tbody>
</table>

ASA: American Society of Anesthesiologists physical status classification; IQR: Inter-quartile range

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**Fig. 3** Flow chart of patients included in the study
Fig. 4 Number of trauma team activations (TTA) with former and new criteria according to injury severity score (ISS) group

Fig. 5 Proportion of undertriaged patients based on mechanism of injury. Error bars indicate 95% confidence interval
patients ≥60 years of age, Table 3. There was a trend for increased risk for undertriage in patients with fall injury.

**Sensitivity analyses**
When excluding Västerås county hospital, 1311 patients remained for analysis. The number of limited TTA decreased from 707 to 316 after change of TTA criteria (55.3% reduction, \( p = 0.001 \)). The number of full TTA as well as the number of patients not initiating TTA was unchanged. Overtriage was 67.5% with former criteria, versus 68.2% with new, \( p = 0.915 \). Undertriage with Matrix method was 5.9% versus 7.6%, \( p = 0.281 \). Among severely injured patients, 53.7% did not initiate full TTA with former criteria, versus 67.6% with new criteria, \( p = 0.168 \). Thus, overall the sensitivity analysis indicates the same trend as in the overall cohort, with reduction of limited TTA and stable over- and undertriage.

The re-scoring of AIS in severe cases between hospitals did result in minor variances regarding AIS-codes for injuries but it did not result in any differences regarding AIS-score and subsequently no differences in ISS for any patient.

In order to analyse the seasonal variation in TTA, the SweTrau registry was consulted for the period 2014–2016. The mean number of TTA registered in SweTrau during the months of September–December, which was the period during which the former criteria were used at most centres, was 2889. During the period May–August (new criteria), the number of registered cases was in average 3196. The monthly national trend in TTA registration in SweTrau is presented in Fig. 2.

**Discussion**
The current analysis confirms that the updated national TTA criteria in Sweden are safe, with levels of over- and undertriage remaining unchanged compared to former criteria. Additionally, the new criteria put less strain on acute care in-hospital resources. They result in a significant decrease in the number of limited TTA, without compromising patient safety. However, the analysis of undertriage in the current paper indicates that further modification of the TTA criteria may be required for specific patient cohorts and MOI. This concerns particularly elderly patients and those subject to fall injury, where undertriage was higher than expected.

In this study, a prospective stepped wedge cohort design was used to evaluate change in triage criteria. The optimal methodology to study such intervention without bias would have been a randomized controlled study, where patients would have been triaged with one of the two criteria based on randomization. Although we initially aimed for such a study design, it was not accepted by the ethical review board. They required informed consent prior to randomization from all patients, which we regarded as impossible to achieve. Unfortunately, Swedish law does not accept randomization without informed consent, in contrast to for instance the UK, where the Mental Capacity Act makes a two stage consent process possible [20]. The prospective stepped wedge cohort design is a pragmatic and suitable choice for studying an intervention on a system level [21], sometimes called a pseudo-randomization. The benefits of such study design include the fact that the introduction of a new routine resembles a cluster randomization, controlling for bias. The stepped wedge introduction of the intervention to some extent controls for changes due to temporal trends. The population-based element of this study, and the use of an established trauma registry [13], increases the generalizability of the analysis.

The main change in the new Swedish TTA criteria compared to the former ones is the substantial reduction in MOI criteria for initiating limited TTA. This is based on several studies questioning the validity of MOI criteria in predicting severe injury [5, 22, 23]. The MOI remaining in the new criteria are either evidence based (fall≥5 m, extrication time > 20 min) [5] or of a more obvious nature (thrown out of vehicle, child struck by car) where the consensus group could not agree upon their removal. The important reduction in limited TTA with the new criteria (which almost exclusively occurred in patients with ISS ≤ 15) in combination with maintained undertriage level supports the consensus group’s aim in judiciously restraining limited TTA criteria without jeopardizing patient safety.

The power-estimation was performed with the hypothesis that if undertriage according to the Matrix method increased from 4 to 8%, it would be reliably detected. The method of choice for evaluation of undertriage is a matter of debate, as the Matrix method includes an inherent error, where undertriage is affected by the total number of patients initiating a limited or no TTA. In the

### Table 3 Odds-ratio of risk factors for undertriage

<table>
<thead>
<tr>
<th>Mechanism of injury</th>
<th>Odds-ratio</th>
<th>95% CI</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle accident</td>
<td>0.546</td>
<td>0.13–2.35</td>
<td>0.416</td>
</tr>
<tr>
<td>Motorcycle accident</td>
<td>0.743</td>
<td>0.19–2.84</td>
<td>0.666</td>
</tr>
<tr>
<td>Pedestrian hit</td>
<td>0.563</td>
<td>0.06–4.99</td>
<td>0.606</td>
</tr>
<tr>
<td>Gunshot wound</td>
<td>0.000</td>
<td>0.00–1.00</td>
<td></td>
</tr>
<tr>
<td>Stab wound</td>
<td>0.000</td>
<td>0.00–1.00</td>
<td></td>
</tr>
<tr>
<td>Low fall injury</td>
<td>2.704</td>
<td>1.00–7.35</td>
<td>0.051</td>
</tr>
<tr>
<td>High fall injury</td>
<td>1.681</td>
<td>0.63–4.47</td>
<td>0.298</td>
</tr>
<tr>
<td>Age ≥ 60 years</td>
<td>2.886</td>
<td>1.74–4.79</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ASA score ≥ 3</td>
<td>0.935</td>
<td>0.53–1.66</td>
<td>0.818</td>
</tr>
</tbody>
</table>

ASA: American Society of Anesthesiologists physical status classification
the change of TTA criteria per se resulted in a reduction in number of patients initiating a limited TTA, and thus reduced the denominator for the calculation of undertriage according to the Matrix method. Additional file 1: Table S1 [17]. This resulted in an increase in undertriage calculated with this method (from 4.8 to 7.1%). Although this increase was not statistically significant, this could be due to a type II error. Additionally, based on the Matrix method, the undertriage for the new criteria increased to above the recommended level of 5% based on ACS-CoT recommendations.

The method of calculating undertriage based on proportion of severely injured patients not initiating a TTA is more robust when assessing triage over time regardless of TTA criteria [17]. The main weakness of the method is that there is no current definition on what is an acceptable percentage for undertriage. In our study, the undertriage was close to 50% with this method. Although the overall rate of undertriage calculated with this method was unchanged when comparing the former and new criteria, the fact that approximately half of the patients with severe injury did not initiate a full TTA indicates that there may be a need for further revision of the criteria. A detailed analysis of the trauma mechanism and injury panorama in these patients would inform this process. An important aspect is to assess compliance to TTA criteria, i.e. that all patients who meet the criteria also receive TTA. A previous study indicates that compliance may affect both the cost-efficiency of TTA as well as patient safety [11].

The results of the current study highlights a persistent problem: the inability of former as well as new TTA criteria to successfully reduce undertriage in elderly patients and those subject to injury from fall. Many of these severely injured patients who are undertriaged have single life-threatening injuries, however, and may not always benefit from a full trauma team. Future studies with the aim to reduce undertriage in these patients, or to improve the resource allocation in an alternative way, are warranted.

The overtriage rate was unchanged during the study period (71–72%), and was substantially higher than the 35–50% which is recommended by the ACS-CoT. This indicates a potential for further sharpening of the triage criteria to reduce remaining inefficiencies. During the TTA criteria revision, pulse rate was excluded as a TTA criteria because of the lack of evidence for its validity as a standalone criterion [24]. The shock index (SI, ie the ratio of heart rate to systolic blood pressure) has been proven in several studies to accurately predict severe injury [25, 26], and could be considered for future revisions of the criteria.

**Limitations**

The prospective stepped wedge design of this study does not compare TTA during the same time of year while both mechanisms of trauma and prevalence is seasonal. An analysis of trauma registration in the SweTrau showed that the number of trauma in Sweden generally is higher during the summer months, when the new criteria were evaluated in the current cohort. Fig. 2. The reduction in the number of TTA with the new criteria despite evaluation during the summer months indicates that the effect of the new criteria in lowering the number of TTA may even have been underestimated.

While the data was analysed regarding undertriage for specific mechanisms of injury, the study was not powered for the subgroup analyses, introducing a risk for type II error. Additionally, there was no information available regarding the impact of each specific TTA criteria in triggering each TTA level. A future prospective study assessing the efficacy of each specific criteria for full TTA could amend current evidence and assist in further revision of TTA criteria.

The adequacy of triage criteria is affected by the trauma panorama and the prevalence of MOI in the studied population. The population-based setting of this study ensures that the analysis is relevant for a Scandinavian/Western European population, e.g. where blunt trauma mechanism is more prevalent than penetrating trauma, and where the vehicles involved in road traffic accidents are relatively modern with adequate safety equipment. The under- and overtriage with these criteria may vary in other populations.

**Conclusions**

The newly implemented Swedish TTA criteria are safe, with levels of over- and undertriage remaining consistent after change of TTA criteria. The number of limited TTA diminished significantly with the new criteria, resulting in an increased efficiency in use of in-hospital resources, without compromising patient safety. Additional evaluation of TTA criteria are motivated in order to further reduce overtriage as well as for specific subgroups where undertriage is high, in particular elderly patients subject to fall injuries.

**Additional file**

Additional file 1: Table S1. Definition of methods used for assessment of over- and undertriage. (DOCX 35 kb)

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Availability of data and materials
Will be made available upon reasonable request.

Authors’ contributions
FL, LH, KT, JW, PP and KM contributed to conception and design of the study. They collaborated in acquisition of data and drafting the manuscript. MB, CJ, HE and KM contributed in analysis and interpretation of data and revising the manuscript critically for important intellectual content. All authors have read and approved the final manuscript submitted for publication.

Ethics approval and consent to participate
The regional ethics committee in Uppsala, Sweden approved of the registry-based study (Dnr 2017/405), without requiring informed consent from the patients.

Consent for publication
Not applicable

Competing interests
The authors declare that they have no competing interests.

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Trauma triage criteria as predictors of severe injury - a Swedish multicenter cohort study

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Abstract
Background: Adequate performance of trauma team activation (TTA) criteria is important in order to accurately triage trauma patients. The Swedish National Trauma Triage Criteria (SNTTC) consists of 29 criteria that trigger either a Trauma Alert, the highest level of TTA, or a Trauma Response. This study aimed to evaluate the SNTTC and its accuracy in predicting a severely injured patient in a multicenter setting.

Methods: A cohort study in Sweden involving six trauma receiving hospitals. Data was collected from the Swedish Trauma Registry. Some 626 patients were analyzed with regard to the specific criteria used to initiate the TTA, injury severity with New Injury Severity Score (NISS) and emergency interventions. Sensitivity, specificity, positive predictive value (PPV) and positive likelihood ratio (LR+) of the criteria were calculated, as well as undertriage and overtriage.

Results: All 29 criteria of SNTTC had a sensitivity > 80% for identifying a severely injured patient. The 16 Trauma Alert Criteria had a lower sensitivity of 62.6% but higher LR+ (3.5 vs all criteria 1.4), specificity (82.3 vs 39.1%) and PPV (55.4 vs 37.6%) and the highest accuracy (AUC 0.724). When using only the six physiological criteria, sensitivity (44.8%) and accuracy (AUC 0.690) decreased while LR+ (6.7), specificity (93.3%) and PPV (70.2%) improved.

Conclusion: SNTTC is efficient in identifying severely injured patients. The current set of criteria exhibits the best sensitivity compared to other examined combinations and no additional criterion was found to improve the protocol enough to promote a change.

Keywords: Trauma triage criteria, Sensitivity, Specificity, Accuracy, Undertriage

Background
There has been a number of different trauma team activation (TTA) protocols in Sweden until 2017, when The Swedish National Trauma Triage Criteria (SNTTC, Fig. 1) was implemented after a revision by an expert group assigned by the professional medical societies involved in trauma in Sweden [1]. A study of the SNTTC showed a reduction in the lower-level TTA:s (Trauma Responses) by half, without compromising the undertriage [2], and similar studies evaluating under- and overtriage of TTA protocols exists [3–5]. However, there are few major studies about performance of TTA protocols in-hospital regarding other important performance parameters such as sensitivity, specificity and positive predictive value (PPV). Four single-centre studies [6–9] have evaluated different combinations of sensitivity, specificity and PPV of TTA protocols, but these studies were not comprehensive in terms of trauma population, e.g. excluding pediatric cases or focusing on pediatric or geriatric trauma patients. Evaluation of individual TTA criteria is even more scarce with partly outdated single centre studies; one calculating the odds ratio (OR) for individual criterion [10], another ranking individual TTA criteria using receiver operator characteristics (ROC) to
visualize sensitivity, specificity, positive likelihood ratio (LR+) and OR [11] but not calculating sensitivity and specificity of the TTA protocol or reporting PPV for individual criteria.

The need to investigate the performance of TTA criteria, in order to further refine the accuracy in the triage of trauma patients and their correct level of TTA, is therefore paramount. This is especially of interest after implementation of a set of new criteria, such as in the SNTCC situation in Sweden. In this study, we aimed to perform a thorough evaluation of both individual and combinations of TTA criteria in the newly implemented SNTCC in a multicenter setting, including the whole trauma population. The overall objective was to evaluate the SNHTC, individually and in groups, to see if there is a need for further revision of the criteria. The primary aim was to identify the best performing criteria in predicting a severely injured patient and to examine if a combination of criteria could predict the majority of the severely injured patients. Secondary aims were to investigate if
there were any criterion that could be omitted in order to enhance the accuracy, and to seek a common denominator among the undertriaged patients that could represent a future trauma triage criterion.

Methods
SweTrau and calculating injury severity
Internationally, one of the most commonly used definitions of a severely injured patient has been an Injury Severity Score (ISS) of more than 15 [12]. The modification New Injury Severity Score (NISS) is however regarded as more accurate [13–15] in assessing penetrating trauma victims and in-hospital mortality [14, 16]. NISS> 15 is also one of the inclusion criteria of the Swedish Trauma Registry (SweTrau) [17], founded in 2011, with 92% of the trauma receiving hospitals in Sweden participating in 2018 [18]. In our study, NISS was used to determine the severity of the patient’s injuries.

Study design
We performed a multicenter cohort study in Mid Sweden involving one trauma center (university hospital) and five trauma receiving hospitals (acute care hospitals), in total serving approximately 950,000 people [19] with a SweTrau registration coverage ratio of 76.9% [18]. Inclusion criterion was all registered patients in SweTrau between 1st of January 2018 and 31st of December 2018. Exclusion criteria consisted of referral patients, patients with missing information about the level of TTA and patients wrongfully registered. The data from SweTrau were supplemented with additional information from the local registrants where data were missing.

SNTTC
The SNTTC consists of a two-tier system; Trauma Alert is the highest level of TTA and Trauma Response is the lowest (Fig. 1). The criteria for Trauma Alert activation (number 1–16) are arranged in the order of ABCDE with physiological criteria (no. 1–6) and specific injuries from head to toe (no. 7–16), hence the criterion with the lowest number can be expected to first threaten the patients’ life. A Trauma Response (mechanism of injury criteria, no. 17–22) can be upgraded if it is combined with one or more Cautions (no. 23–29), while one or more Cautions might upgrade a non-TTA to a Trauma Response (but not to a Trauma Alert). Severely injured patients (NISS>15) that do not activate a Trauma Alert are regarded as undertriaged, while patients with NISS<15 that activate a Trauma Alert are overtriaged, as recommended by the American College of Surgeons Committee on Trauma (ACS-COT) [20].

Trauma team activating criteria
SweTrau uses variables from the revised Utstein template for uniform reporting of data following major trauma [21]. It does not have a variable defining which criterion that was used to activate the TTA. In order to evaluate each criterion, the participating hospitals used a free variable in SweTrau to record the activating criterion and another free variable for recording if the activated TTA was correct or not, or if a patient who had not activated a TTA should actually have done so. This assessment was done prospectively during the hospitals’ regular trauma registrations in SweTrau. If several criteria had been used, only the criterion with the lowest number was recorded (Fig. 1).

NISS
NISS is calculated by using the Abbreviated Injury Scale (AIS [22]), a scoring system for trauma patients where a trained registrant scores each injury in different body areas. The patients’ medical charts are reviewed for clinical injuries, radiology reports and operation notes and a total NISS is then calculated in the SweTrau database (AIS version 2005, update 2008).

Emergency intervention
An emergency intervention is registered in SweTrau if it is performed within 24 h of admission and consists of one or more of the following: thoracotomy, laparotomy, pre-peritoneal pelvic packing, revascularization, endovascular intervention, craniotomy, intracranial pressure device, chest drain, external fixation of fractures, major surgery of fractures, wound revision (in the operating room) or unspecified intervention.

Statistics
The prevalence of each criterion and combinations of criteria of the SNTTC were examined, together with the percentage of severely injured patients (NISS>15). The sensitivity, specificity, PPV and LR+ (sensitivity/1-specificity)) of different combinations of the criteria were calculated, as well as for each criterion with more than five patient activations. Overtriage was determined by the ratio of patients who were not severely injured but had a Trauma Alert according to the criteria, divided by all patients with a Trauma Alert, whilst undertriage equaled patients who were severely injured but did not have a Trauma Alert according to the criteria, divided by all patients who did not have a Trauma Alert – the Cribari Matrix method [20, 23]. Undertriage was also additionally calculated as the percentage of patients severely injured in total [23]. The accuracy of the criteria was determined by the area under the curve (AUC)
from receiver operating characteristics (ROC) -points comparing sensitivity and 1-specificity. The severely injured patients were further analysed to see if there was a difference in characteristics between the undertriaged patients and the patients with a Trauma Alert according to criteria.

Statistical analyses were performed with IBM SPSS Statistics, version 26 (IBM Corp., Armonk, N.Y., USA), with VassarStats, a website for statistical computation (http://vassarstats.net), and with Microsoft Excel for Mac, version 16.16.22. Data were assessed for normality with histograms. Categorical data were analysed with Chi-square test, except for when the expected count in one cell was <5 – then Fisher’s exact test was used. Numerical data without normal distribution were assessed with Mann Whitney U test. The level of significance was set at a $p$-value less than 0.05.

**Results**

**Study cohort**

A total of 741 patients were identified and after excluding 115 patients (referral patients ($n=105$), double registrations ($n=2$), drowning ($n=2$), missing data ($n=6$)) a population of 626 patients (Fig. 2) was analyzed with regard to if there had been a TTA according to the SNTTC, if the patient had a NISS> 15 and if the patient had received an emergency intervention. The characteristics of the population and the subgroups of patients with a Trauma Alert, severely injured patients (NISS> 15) and patients requiring an emergency intervention are presented in Table 1. Penetrating trauma represented 9.7% of the population and 11% of the group of NISS> 15, but comprised 25.4% of the Trauma Alert patients and 30.5% of the patients needing an emergency intervention. The two most common mechanisms of injury (MOI); ‘motor vehicle crash, MVC’ (34.7%) and ‘high fall’ (19.3%) made up more than half of the total patients. ‘High fall’ is defined in SweTrau as the patient’s height times 1.5, in coherence with the Utstein Trauma Template – note that this is separate from the Trauma Response criterion no. 22, which is a defined fall height (5 m for adults, 3 m for children) to activate a trauma call.

**Prevalence of the criteria**

The prevalence of criteria activations, grouped by patients severely injured or not, is shown in Fig. 3. The most common criterion was *motorcycle crash > 35 km/h* (MCC, no. 20 in Fig. 1) with 72 activations, of which eleven patients were severely injured. The second most common criterion was *Glasgow Coma Scale < 13* (GCS < 13, no. 6) with 58, whereof 38 had a NISS> 15, followed by *penetrating trauma above elbow or knee* (no. 7) with 47 activations and 12 severely injured patients. Criterion no. 17 (*MVC > 50 km/h without seatbelt*) was activated 25 times but none of the patients were severely injured.

**Accuracy of the criteria**

LR+, sensitivity, specificity and PPV of the different criteria combinations and individual criterion with more than five activations are displayed in Table 2. Physiological criteria alone (no. 1–6) had high LR+ (6.7), specificity (93.3%) and PPV (70.2%) but low sensitivity (44.8%). Trauma Alert criteria (no. 1–16) had lower LR+ (3.5), specificity (82.3%) and PPV (55.4%) but higher sensitivity.
The overall accuracy of the different combinations of the criteria can be visualized in Fig. 4. The combined Trauma Alert criteria had the highest accuracy with an AUC of 0.724, followed by physiological criteria (no. 1–6, AUC 0.690). Cautions and Trauma Response criteria had both an AUC below 0.5 (0.465 and 0.430).

**Overtriage**

Overtriage with the Matrix method was 49.8% (102 of 205 patients). Twenty-one percent of the overtriaged patients needed an emergency intervention (21/102). Of the overtriaged patients, 32 (31.4%) activated criteria no. 7 (penetrating trauma above elbow or knee) of which 14 (43.8%) needed an emergency intervention.

**Undertriage**

Undertriage with the Matrix method was 11.2% (47 of 421 patients) while the undertriage was 28.8% (47/163) of the severely injured patients in total. Half of the undertriaged patients (24 patients) activated a Trauma Response or Cautions and the rest did not activate a criterion. Fifty percent of the patients that activated a criterion triggered either no. 20 (MCC, six patients), or criterion no. 25 (Age < 5 or > 60, six patients). Of 72 activations of no. 20, only 7 patients were > 60 years old, but 5 of those had an NISS > 15. The majority of undertriaged patients that did not activate a criterion (17/23) had either fallen less than 5 m or been hit by a blunt object. When comparing the undertriaged patients with the correctly triaged patients with NISS > 15 (Table 3), there was a higher percentage of children (12.8% vs. 2.6%, \(p = 0.018\)) and a higher ASA score (30.4% vs. 15.2%, \(p = 0.028\)) among the undertriaged patients. The NISS was lower (19 vs. 27, \(p = 0.000\)), there was no penetrating trauma (0% vs. 15.5%, \(p = 0.004\)) and there was a less need for emergency intervention (10.6% vs. 50.9%, \(p = 0.000\)). One of the undertriaged patients died within 30 days, compared to 19 of the correctly triaged patients (2.2% vs. 17.1%, \(p = 0.011\)).
Discussion
This multicenter evaluation of the newly implemented SNTTC confirms that the current combination of the 29 criteria has adequate sensitivity and LR+ to reliably identify severely injured patients, with an AUC of 0.619. Although a selection of a subgroup of the criteria, e.g. physiological criteria alone or the Trauma Alert criteria alone would increase the AUC and specificity, this would occur at a cost of reduced sensitivity. Among undertriaged patients, no specific criteria suitable for inclusion in the trauma triage system could be identified. Notably, one of the drawbacks of the SNTTC is the extensive number of variables. Although the current study could not identify specific variables that were clearly unnecessary as part of the criteria, further refinement of trauma triage criteria to streamline processes with a minimum number of criteria, while upholding adequate sensitivity, is of value for trauma optimization.

Study cohort
The characteristics of our study population is consistent with other international studies [2–4, 6, 9, 10, 13] with a male predominance, a clear majority of blunt trauma, a young median age at around 38 but with the severely
injured patients being older. In the Trauma Alert and emergency intervention subgroups, penetrating trauma is the leading cause although only comprising about 10% of the total population. This is explained by the fact that penetrating trauma results in activation of Trauma Alert based on a specific criterion, and penetrating trauma is itself prone to need emergency intervention. Overall 30 day mortality is in line with other studies [2–4, 6, 9] as is the expected higher mortality of the Trauma Alert group [2–4].

Prevalence of the criteria

The criteria not used or with < 5 activations could be explained by various factors, including too few patients – especially for no. 16 (burn ≥ 18% or inhalation burn) where the low frequency of major burn injuries might need a bigger study cohort. Another reasonable explanation is that many of the patients with a higher number, for example criterion no. 10 (deformed chest wall) or no. 6 (GCS < 13) could also activate a lower number (e.g. no. 1, need for ventilatory support). Unfortunately, since only the lowest number was recorded there is not enough information to suggest removal of the unfrequently used criteria with a higher number.

Critereion no. 20 (MCC) was the most prevalent criterion but the majority of patients were not severely injured. Nevertheless, eleven patients had a NISS> 15, why the criterion's position among the Trauma Response Criteria still seems appropriate. Criterion no. 17 (MVC) was activated 25 times without identifying a single severely injured patient which makes it a possible candidate to consider for removal from the SNTTC, even though this must be examined further before any definitive conclusions can be drawn.

Table 2 Criteria statistics

<table>
<thead>
<tr>
<th>Criteria/criterion</th>
<th>LR + (95% CI)</th>
<th>Sensitivity % (95% CI)</th>
<th>Specificity % (95% CI)</th>
<th>PPV % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological (no. 1–6)</td>
<td>6.7 (4.6–9.8)</td>
<td>44.8 (37.1–52.8)</td>
<td>93.3 (90.5–95.3)</td>
<td>70.2 (60.3–78.6)</td>
</tr>
<tr>
<td>Trauma Alert (no. 1–16)</td>
<td>3.5 (2.8–4.4)</td>
<td>62.6 (54.6–69.9)</td>
<td>82.3 (78.4–85.6)</td>
<td>55.4 (47.9–62.7)</td>
</tr>
<tr>
<td>Trauma Alert + Cautions (no. 1–16 + 23–29)</td>
<td>2.1 (1.8–2.4)</td>
<td>73.0 (65.4–79.5)</td>
<td>64.8 (60.2–69.1)</td>
<td>42.2 (36.4–48.2)</td>
</tr>
<tr>
<td>Trauma Alert + Trauma Response (no. 1–22)</td>
<td>1.7 (1.5–2.0)</td>
<td>74.2 (66.7–80.6)</td>
<td>56.6 (51.9–61.1)</td>
<td>37.6 (32.3–43.1)</td>
</tr>
<tr>
<td>All Criteria</td>
<td>1.4 (1.3–1.5)</td>
<td>84.7 (78.0–89.6)</td>
<td>39.1 (34.7–43.3)</td>
<td>32.9 (28.4–37.6)</td>
</tr>
<tr>
<td>Cautions (no. 23–29)</td>
<td>0.6 (0.4–1.0)</td>
<td>10.4 (6.4–16.4)</td>
<td>82.5 (78.7–85.6)</td>
<td>17.3 (10.7–26.6)</td>
</tr>
<tr>
<td>Trauma Response (no. 17–22)</td>
<td>0.5 (0.3–0.7)</td>
<td>11.7 (7.3–17.8)</td>
<td>74.3 (70.0–78.2)</td>
<td>13.8 (8.7–20.9)</td>
</tr>
</tbody>
</table>

**LR +** positive likelihood ratio, **PPV** positive predictive value, **BP** blood pressure, **GCS** Glasgow Coma Scale, **MCC** Motorcycle crash, **MVC** Motor vehicle crash, **NA** Not applicable
The aim is to get a high sensitivity (percentage of patients with NISS>15 that activate the criteria) but not at the expense of too low specificity (percentage of patients with NISS<15 that do not activate the criteria), which is best illustrated by the accuracy shown by AUC\(^24\) of the different combinations of criteria. In the trauma triage evaluation literature, AUC is not commonly used as a statistical method, and we only found one such study\(^1\), from California. The trauma criteria of this study are quite similar to SNTTC and out of the five SNTTC criteria with the highest LR\(^+\) (e.g. the slope of the ROC-curve generating the AUC\(^25\)), four (no. 1, 2, 12 and 4) were found among the top five of the above mentioned study. However, the Californian study does not compare the AUC of different combinations of criteria (which is the case in the current study); which makes further comparisons difficult.

Different studies have chosen different measurements to evaluate and then decide which criteria they believe to be superior. If one considers AUC the best measurement, then the Trauma Alert Criteria (no. 1–16) have the highest predictivity (although too low sensitivity to be acceptable). Sensitivity, specificity and the accuracy reflected by the AUC is more of a measurement of the ‘general strength’ of the criteria, compared to PPV and LR\(^+\) that better calculate the ‘clinical usefulness’ of the criteria. PPV shows the specific probability

### Table 3  Severely injured patients – differences between patients with Trauma Alert (according to criteria) and undertriaged patients (NISS>15 but no Trauma Alert according to criteria)

<table>
<thead>
<tr>
<th>Characteristics of severely injured patients (NISS &gt;15, n = 163)</th>
<th>Trauma Alert (n = 116)</th>
<th>Undertriage (n = 47)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age - years, median (IQR)</td>
<td>48.5 (27–61)</td>
<td>55 (29–69)</td>
<td>0.259(^2)</td>
</tr>
<tr>
<td>Children &lt; 15 years old (%)</td>
<td>3 (2.6)</td>
<td>6 (12.8)</td>
<td>0.018*(^3)</td>
</tr>
<tr>
<td>ASA score 3 or higher (%)</td>
<td>17 (15.2)</td>
<td>14 (30.4)</td>
<td>0.028*(^1)</td>
</tr>
<tr>
<td>NISS - median (IQR)</td>
<td>27 (22–42.5)</td>
<td>19 (17–24)</td>
<td>0.000*(^2)</td>
</tr>
<tr>
<td>Penetrating trauma (%)</td>
<td>18 (15.5)</td>
<td>0 (0)</td>
<td>0.004*(^1)</td>
</tr>
<tr>
<td>Emergency intervention (%)</td>
<td>59 (50.9)</td>
<td>5 (10.6)</td>
<td>0.000*(^1)</td>
</tr>
<tr>
<td>LOS - median (IQR)</td>
<td>8 (2–15)</td>
<td>6 (3–11)</td>
<td>0.418(^7)</td>
</tr>
<tr>
<td>30 day mortality (%)</td>
<td>19 (17.1)</td>
<td>1 (2.2)</td>
<td>0.011*(^1)</td>
</tr>
</tbody>
</table>

NISS New Injury Severity Score, IQR Interquartile range, ASA score American Society of Anesthesiologists physical status score, LOS Length of stay. \(^1\)Mann-Whitney U test. \(^2\) Fisher’s exact test. \(* p < 0.05\)
that a patient is severely injured if the criterion/criteria is activated but it is influenced by the prevalence of severely injured patients in the population [26]. LR+, on the other hand, is not sensitive to prevalence [27]. It is interpreted as how many times more likely it is for a severely injured patient to activate the criterion in question than for a not severely injured patient. The higher LR+, the stronger the association with NISS>15. When dealing with LR+ one must also consider the subjective ‘pretest probability’ of the patient the criterion is applied to, which means that two different patients may have different risks to be severely injured, given a certain criterion with a specific LR+. In our study, this is especially relevant to the Trauma Response criteria where an elderly patient with anticoagulant medication that has been in a motorcycle crash is more likely to be severely injured than a young, healthy patient – even though the LR+ for MCC is 0.5 in both cases. The ‘pretest probability’ is in this case highlighted by the two Cautions used: ‘elderly’ (no. 25) and ‘anticoagulant medication’ (no. 24). The SNTTC thus has Cautions as an ‘built-in pretest probability’, making LR+ a good measurement for the usefulness of the criteria. If PPV or LR+ are considered the best tests to find a severely injured patient, then the physiology criteria (no. 1–6) have the highest predictivity, however, they also have too low sensitivity to be acceptable.

Overall, when looking at these statistics, one is tempted to suggest to only use Trauma Alert criteria (highest AUC) or even only use the physiological criteria (no. 1–6, highest LR+ and specificity and PPV). The problem with this reasoning is that the sensitivity of both Trauma Alert criteria (62.6%) and, especially, the physiological criteria (44.8%) are not sufficient, which would lead to unacceptable high undertriage if these two combinations were to be used independently as sole trauma triage criteria. If we consider another scenario; taking the combination ‘Trauma Alert + Cautions’, that interestingly have a better LR+ (2.1 vs. 1.7), specificity (64.8 vs. 56.6%) and PPV (42.2 vs. 37.6%) than ‘Trauma Alert + Trauma Response’, the sensitivity is still only 73%. Considering all this, the only combination with a high enough sensitivity to be acceptable is SNTTC:s current combination of All criteria (84.7%), even though we have to accept lower LR+ (1.4), specificity (39.1%) and PPV (32.9%).

Although the local protocol of trauma triage criteria from a previous study [6] at a Swedish trauma center appears to have higher sensitivity (90.3% vs 84.7%) and specificity (48.2% vs 39.1%) than SNTTC, the confidence intervals of sensitivity overlap and, more importantly, nearly 30% of the included patients in the study had missing data which makes the results not comparable.

In a Norwegian study [9] the sensitivity of the trauma triage criteria was 87%, but again with overlapping confidence intervals with SNTTC and with a significantly lower PPV (22% (CI 20–26) vs SNTTC (39% (CI 35–44)). PPV of SNTTCs Trauma Alert criteria alone is 55.4% compared to 51.7% in an American study [11], indicating that SNTTC is performing well in an international comparison.

Overtriage

The overtriage with the Matrix method is nearly 50%, similar to the overtriage in two studies from Norway (55%) [28] and the USA (45%) [29]. This is higher than the 25–35% the ACS-COT recommends [20], but a clear improvement since the implementation of the SNTTC in 2017 when the overtriage was calculated to 72.2% [2]. Penetrating trauma was more than three times as common among the overtriaged patients than in the total population, showing that a single stab– or gunshot wound not necessarily generates a NISS >15 and thus; that the Trauma Alert criteria not only identifies the severely injured patients, but also the patients in need of an emergency intervention. It is important to acknowledge that NISS is only known after discharge, and hence there is clearly a need for triage criteria to prudently identify patients at risk of developing major complications or needing acute interventions. In the current study, the overtriaged patients contributed to more than a fifth (22.1%) of the total emergency interventions. The overtriage should therefore be considered with this in mind.

Undertriage

Compared to a previous study in the mid Sweden region [2] the undertriage with the Matrix method have increased from 7.1 to 11.2%, which is higher than the 5% recommended by ACS-COT [20], but comparable with a study from Norway [28] (10% undertriage) and considerably lower than in a study from the USA [29] (24% undertriage). This increase can partly be explained by the decrease in number of Trauma Responses/No trauma activations (79.3% vs 67.3%) [2] and since this means a decrease in the denominator it will lead to a higher undertriage. Another, and perhaps more appropriate, way to compare the undertriage is to calculate it as percentages of the total number of severely injured patients [23], which on the contrary shows a clear reduction of undertriage from 49.4% (37/79) in the previous study [2] to 28.8% (47/163) in this study.

A closer evaluation of the undertriaged patients unfortunately did not reveal a common denominator to be considered as a future criterion, however, the combination of Trauma Response no. 20 (MCC) + Caution no. 25 (Age >60) appears very troublesome, which is a strong indicator that the Cautions indeed should be used...
together with the Trauma Response criteria to activate a Trauma Alert, and also underlines the well-known problem with compliance to trauma alert criteria [30]. The importance of old age as an TTA criterion, except when it comes to ground-level falls, is equally highlighted in an American study [31] but with the cut-off limit set at 70 years old.

Limitations and strengths
This study is a multicenter report, covering both a trauma center and trauma receiving hospitals with the same, national trauma triage criteria, which is a strength in terms of generalizability of the results. The SNTTC are to a large extent similar to other international trauma triage criteria, for example Norway’s, although with regional differences of the combinations. As this study evaluates both the individual criteria as well as different combinations, the results could be of value for other trauma systems than the Swedish cohort currently studied.

This study has the general limitations of a retrospective cohort study, depending on the accurate registration of collected data. There may be a patient selection bias due to patients missed and therefore not registered in SweTrau. However, the registrars had received thorough instructions to scan the admissions to all intensive and intermediate care wards for trauma patients. Furthermore, they received lists of all trauma calls from the hospitals’ central pager system and they were also instructed to manually check all trauma admissions to the emergency department during the study period. Thus, the effect of possible missing cases on the outcome of this study should be minimal. The SweTrau data was in some cases supplemented with information from the registrars for completeness, which is a potential source of bias. The registrars were not blinded to the trauma activation criteria when calculating NISS and this could potentially be a limitation to the study. However, as NISS comprises an objective calculation of the specific injuries of the patient according to AIS 2005 rev. 08, this lack of blinding should not result in significant bias. To minimize the potential differences when calculating the AIS and NISS the registrars had completed the international accreditation course for AIS-coding and used the integrated AIS-module in SweTrau based on AIS 2005 rev. 08. There are also some limitations when using the Cribari Matrix method to calculate undertriage, for example; when the Trauma Responses decline, undertriage will increase due to the construction of the calculating formula. We have tried to address this issue by also using an additional method when calculating undertriage, as described in Methods, section Statistics and ethics. Finally, there may have been too few patients to properly evaluate some criteria resulting in a risk for type II error, especially since only 163 patients had a NISS> 15, and we encourage future studies to validate our results.

Conclusions
The SNTTC is efficient in identifying severely injured patients and patients in need of an emergency intervention, with decreased undertriage as well as overtriage since its implementation. The Trauma Alert Criteria (no. 1–16) has the highest accuracy of the criteria combinations, however, none of the combinations have a high enough sensitivity to replace All criteria. An analysis of the undertriaged patients did not identify any additional criteria to add to the SNTTC in order to further reduce undertriage. Since there is a risk that our study may have too few patients to make more far-reaching conclusions, the authors strongly suggest that trauma registries include the triage criterion used to trigger the trauma call as a variable to continue to evaluate trauma triage criteria. We would also like to underline the necessity of all trauma receiving hospitals to register in trauma registries.

Abbreviations
AIS-COT: American College of Surgeons Committee on Trauma; AIS: Abbreviated Injury Scale; AUC: Area under the curve; GCS: Glasgow Coma Scale; ISS: Injury Severity Score; LR+: likelihood ratio; MCC: Motorcycle crash; MOI: Mechanisms of injury; MVC: Motor vehicle crash; NISS: New Injury Severity Score; OR: Odds ratio; PPV: Positive predictive value; ROC: Receiver operator characteristics; SNTTC: Swedish National trauma Triage Criteria; SweTrau: Swedish Trauma Registry; TTA: Trauma Team Activation.

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Authors’ contributions
LF contributed to literature search, study design, data collection, data analysis and interpretation and writing; KM, AW, HA and CJ contributed to study design and critical revision. KT contributed to data collection and critical revision; FL contributed to study design, data interpretation and critical revision. All authors have read and approved the manuscript.

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Availability of data and materials
Data available from the corresponding author upon reasonable request.

Declarations
Ethics approval and consent to participate
The study was approved by the Regional Ethics Review Board in Uppsala, Sweden (Dnr 2018/445). Access to data was granted by the board of the Swedish Trauma Registry (SweTrau) following the ethical approval by the Regional Ethics Review Board, who waived the need for informed consent for this registry-based study.

Consent for publication
Not applicable.
Competition interests

The authors declare that they have no competing interests.

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Validation of the Swedish Trauma Registry (SweTrau)

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Abstract

Purpose Validation of registries is important to ensure accuracy of data and registry-based research. This is often done by comparisons of the original registry data with other sources, e.g. another registry or a re-registration of data. Founded in 2011, the Swedish Trauma Registry (SweTrau) consists of variables based on international consensus (the Utstein Template of Trauma). This project aimed to perform the first validation of SweTrau.

Methods On-site re-registration was performed on randomly selected trauma patients and compared to the registration in SweTrau. Accuracy (exact agreement), correctness (exact agreement plus data within acceptable range), comparability (similarity with other registries), data completeness (1-missing data) and case completeness (1-missing cases) were deemed as either good (≥85%), adequate (70–84%) or poor (<70%). Correlation was determined as either excellent (≥0.8), strong (0.6–0.79), moderate (0.4–0.59) or weak (<0.4).

Results The data in SweTrau had good accuracy (85.8%), correctness (89.7%) and data completeness (88.5%), as well as strong or excellent correlation (87.5%). Case completeness was 44.3%, however, for NISS > 15 case completeness was 100%. Median time to registration was 4.5 months, with 84.2% registered one year after the trauma. The comparability showed an accordance with the Utstein Template of Trauma of almost 90%.

Conclusions The validity of SweTrau is good, with high accuracy, correctness, data completeness and correlation. The data are comparable to other trauma registries using the Utstein Template of Trauma; however, timeliness and case completeness are areas of improvement.

Keywords Validation · Trauma registry · Accuracy · Correctness · Timeliness · Comparability

Background and aims

Validation of registries

Validation of registries is a key component in ensuring solid, reliable data for research and improvement of patient care. Validations can be made in different ways, with the end goal being to ensure that the data in the registry adequately represents the population studied. Internal validity assesses whether the data in the registry is accurate when compared to an original data source (e.g. patient charts), whilst external validity evaluates whether the registry adequately captures all the population intended to be included in the registry. Validity can be assessed with accuracy [1–6] (the percentage of data with exact agreement between two data sets) or correlation [1, 2] (a correlation coefficient that also takes the possibility of chance into account). Accuracy and correlation are however not always the most suitable ways to judge a registry since there sometimes can be small deviations in data that are not clinically important but nevertheless still impact accuracy and correlation. Therefore, correctness [6, 7]—the sum of data with exact agreement AND data within an acceptable range—can be a more useful way to describe how well data is correct in a way that is clinically relevant. Other important aspects of validation are case completeness, i.e. percentage of cases that should have been included that actually are included [1, 2, 4, 6–8], as well as data completeness (as low percentage of missing data as possible) [1–3, 6, 7]. Finally, comparability [1, 2, 4]—how similar the variables of the registry are compared to other registries in the same field—and timeliness [1, 2, 4]
Severity of injuries

The goal of trauma care is to swiftly identify a severely injured patient and allocate sufficient resources at the right time. In registry-based trauma research, the definition of a severely injured patient varies [9] from any patient needing an emergency intervention within a certain time span, to a trauma patient receiving enough points on different injury scales. One of the most common ways to assess the severity of injuries is to determine the Injury Severity Score (ISS) or the New Injury Severity Score (NISS) [10]. NISS is regarded as more accurate concerning penetrating trauma [11] and in depicting in-hospital mortality [12], as well as postinjury organ failure [13]. Both ISS and NISS are calculated using the Abbreviated Injury Scale (AIS) [14], where a score of more than 15 defines a severely injured patient. The difference between ISS and NISS is that ISS is calculated using the three most severe injuries in three different body parts (the body is divided into 6 areas according to AIS) which are then squared and added to a sum, while NISS is calculated by squaring the three most severe injuries regardless of body part, which are then added to get the total sum.

The Swedish Trauma Registry (SweTrau)

The Swedish Trauma Registry (SweTrau) was initiated in 2011 [15] with more hospitals gradually enrolling during the years. In 2018, 48 of 52 trauma receiving hospitals were enrolled, even though not all of them registered in SweTrau at the time (Fig. 1). The inclusion criteria of the registry are all trauma patients that have activated a trauma call or admitted patients with a NISS of more than 15 or referral patients with an NISS more than 15 and a trauma date within seven days from admission. The exclusion criteria of SweTrau are isolated chronic subdural haematoma and patients with trauma call but no trauma. According to the Swedish National Trauma Triage Criteria (SNTTC) [16], a trauma call can be either a Trauma Alert (the highest level of trauma call) or a Trauma Response. The variables of SweTrau is based on The Utstein Template of Trauma [17].

Trauma registries

Although there are numerous local, regional and national trauma registries existing worldwide, very few studies aimed to validate trauma registries exists, and most of the studies only validate one or two aspects of the registry. For example, in a Norwegian study of their national trauma registry [5], 144 patients were examined regarding injury coding and scoring, while in a Dutch study [18], accuracy and correlation were calculated for injury coding, scoring and survival status. Similar, in a study from the Netherlands [19], injury coding, scoring and survival status were assessed, however, only correlation was calculated. Furthermore, trauma registries are difficult to compare due to the difference in variables. In 2011, Ringdal et al. [20] showed in a large multicenter study that a number of international trauma registries had implemented The Utstein Template of Trauma [21] for a more uniform reporting of variables in trauma, which SweTrau also uses. Other trauma registries utilizing the Utstein Template of Trauma are Major Trauma Registry of Navarre (MTRN, Spain), and the Helsinki Trauma Registry (HTR, Finland). MTRN has been evaluated in two studies for case completeness [22] as well as data completeness and correctness [23]. In a study examining all registered patients (312) in HTR during 2013 [6], accuracy, correctness, data completeness and case completeness were calculated, while correlation, timeliness and comparability were not evaluated. To our knowledge, a validation of a national trauma registry that examines all these parameters has not been performed. Our hypothesis at the outset of this study was that the data in SweTrau is valid and can be used for reliable trauma research. The data of SweTrau, however, has not yet been validated which is why we believe this study to be an important addition to international trauma research.

Aim

The aim of this study was to validate SweTrau by assessing accuracy, correctness, correlation, data completeness, case completeness, timeliness (efficiency) and comparability.

Materials and methods

Re-registration process

We sought to validate SweTrau by on-site visits while manually re-registering a number of randomly selected trauma patients registered in 2018 and comparing them to the original registration in SweTrau. This was done by two of the authors (LH and MFB) who have completed the AIS course and are experienced SweTrau registrars. The re-registration was made by examining the patient charts and paramedic notes and then compare the original data with the registration in SweTrau. The intent was to validate approximately 5% of the total registrations, in line with the recommendations of American College of Surgeons [24] for validating trauma registries (to re-abstract 5–10% of patient records). An initial estimation of 400 patients as sample size was re-adjusted to 450 (5.1%) when the SweTrau’s annual report from 2018 was released (8862 patients registered in 2018). We planned to validate 30 patients in each...
of the seven university hospitals, as well as ten patients at
the regional and local hospitals. Out of 52 trauma receiv-
ing hospitals, 48 were affiliated with SweTrau. Thirteen
hospitals were excluded due to: not having registered any
patients in SweTrau (n = 6), authors not allowed access to
hospital records due to logistic issues (n = 2) and failure to
answer our request to validate (n = 5). Thus, 35 hospitals
were planned to take part in the validation process (Fig. 1).
Unfortunately, due to the COVID-19 pandemic, access to
hospitals for validation was severely restricted, and the study
was only possible to carry out on-site re-registration at 10
different trauma receiving hospitals (120 patients) before
all possibilities of validation at the included hospitals were
withdrawn.

Validation terms

**Accuracy** was determined as the percentage of data with
exact agreement between the original registration and the
re-registration.

**Correctness** was defined as the sum of data with exact
agreement AND data within acceptable range. Data within
acceptable range was defined as the following difference:

- Glasgow Coma Scale (GCS) upon arrival of EMS person-
  nel at scene/upon arrival in hospital: ± 1 point.
- Number of days on ventilator: ± 1 day.
- Respiratory rate (RR) upon arrival of EMS personnel at
  scene/upon arrival in hospital: ± 5 breaths.
- Systolic blood pressure (SBP) upon arrival of EMS per-
  sonnel at scene/upon arrival in hospital: ± 10 mmHg.
- Time of trauma/alarm/arrival at scene/EMS personnel
  leaving the scene/arrival in hospital/first CT scan/until
  first key emergency intervention: ± 10 min.

All other variables (e.g. ISS, NISS, intervention etc.)
were only assessed with exact agreement which therefore
equals the correlation.

**Correlation** of the variables in SweTrau and the re-reg-
istration was calculated with either Cohen’s Kappa (cate-
gorical, qualitative data) or Pearson’s correlation coef-
ficient (numerical, quantitative data). The correlation was
determined as either excellent (≥ 0.8), strong (0.6–0.79),
moderate (0.4–0.59) or weak (<0.4).

**Data completeness** was calculated by checking the miss-
ing data in SweTrau, after adjusting for when a variable is
not applicable (some variables in SweTrau are mutually
exclusive, for example Respiratory rate upon arrival in hos-
pital and Respiratory rate clinical category upon arrival in
hospital).

**Case completeness** was determined by searching the
hospitals’ individual emergency ledgers for two randomly
selected weeks during 2018. The charts of the patients that
might fulfil the inclusion criteria for SweTrau were exam-
ined and the patients that should have been registered in
SweTrau were then checked to see if they had indeed been
included, and the percentage was calculated.

**Accuracy, correctness, data completeness and case com-
pleteness** were determined as either good (≥ 85%), adequate
(70–84%) or poor (<70%).

**Timeliness** (efficiency) was recorded by comparing the
date of trauma with the date of the signed registration in
SweTrau. The earliest possible registration in SweTrau is 31 days after the trauma (unless the patient dies before that), due to the 30-day mortality variable.

Comparability was assessed by comparing the variables in SweTrau with the Utstein Template of Trauma [17, 21], an international consensus document regarding trauma registry variables.

Validation of ISS and NISS

The ISS/NISS-registrations were validated in three different ways. Firstly, by comparing the exact ISS/NISS score. Secondly, by dividing the score into intervals: ISS/NISS 0–8 (mild injury), 9–15 (moderate injury), 16–24 (severe injury) and > 25 (very severe injury) as a modification of the six Copes’ categories [25, 26]. The ISS/NISS score were deemed correct if the original registration and the re-registration were scored in the same interval. Finally, by dividing and comparing the ISS/NISS score with a cut-off of ISS/NISS 0–15 (not severe injury) and ISS/NISS > 15 (severe injury) respectively.

Statistics

Statistical analyses were performed with IBM SPSS Statistics, version 26 (IBM Corp., Armonk, N.Y., USA), and with Microsoft Excel for Mac, version 16.16.22. Categorical data were analyzed with Chi-squared test. The level of significance was set at a p value less than 0.05.

Results

Overall demographics of the study population compared to all patients in SweTrau 2018 is presented in Table 1. There was no difference between the groups. The majority of the patients were male (68.3%) and had suffered a blunt trauma (90.0%). Most of them were relatively healthy with an ASA score 1–2 (85.8%). The mean and median of age was 44 and 43 years, while the mean and median with an ASA score 1–2 (85.8%). The mean and median trauma (90.0%). Most of them were relatively healthy with an ASA score 1–2 (85.8%).

There was no difference between the groups. The majority of the variables (87.5%, 42 of 48 variables) had an excellent (≥ 0.8) or strong correlation (0.6–0.79) between the original registration and the re-registration (Table 2). Six variables showed moderate correlation (0.4–0.59): SBP clinical category upon arrival of EMS personnel at scene (0.46), Pre-injury ASA physical status classification (0.49), Trauma call re-prioritized (0.49), Glasgow Outcome Scale (GOS) at discharge from reporting hospital (0.51), Type of airway management (0.57), Highest level of pre-hospital care provided (0.59). No variable had a weak correlation (< 0.4).

All variables of SweTrau except the individual AIS-codes were examined, rendering 48 individual variables and four groups of variables to be validated (Table 2). None of the patients with NISS < 15 died. Two patients (1.7%) had a NISS < 15 at the initial registration but had a missed injury that led to NISS > 15 at re-registration. One patient (0.8%) was determined severely injured (NISS > 15) at the initial registration but the NISS was reduced to < 15 at the re-registration. For the rest if the patients, the NISS score was either an absolute agreement between the initial registration and the re-registration, or differed upward or downward but without affecting the limit of NISS < 15.}

Accuracy

Overall accuracy was 85.8%. Out of 48 variables, 41 exhibited good (≥ 85%, 31 variables) or adequate accuracy (70–84%, 10 variables) (Table 2). Regarding NISS and ISS, they showed good accuracy when grouped by < 15 (< 97.5% and 92.5%), as well as grouped by 1–8, 9–15, 16–24 and 25–75 (85.0% and 81.7%), although their individual accuracy was poor (NISS 38.3% and ISS 48.3%). Five additional variables had poor accuracy (< 70%): Time of first CT scan (39.6%), Time until first key emergency intervention (47.4%), Time of trauma (60.0%), Systolic Blood Pressure (SBP) upon arrival of EMS personnel at scene (64.8%) and Pre-injury ASA physical status classification (68.1%).

Correlation

The majority of the variables (87.5%, 42 of 48 variables) had an excellent (≥ 0.8) or strong correlation (0.6–0.79) between the original registration and the re-registration (Table 2). Six variables showed moderate correlation (0.4–0.59): SBP clinical category upon arrival of EMS personnel at scene (0.46), Pre-injury ASA physical status classification (0.49), Trauma call re-prioritized (0.49), Glasgow Outcome Scale (GOS) at discharge from reporting hospital (0.51), Type of airway management (0.57), Highest level of pre-hospital care provided (0.59). No variable had a weak correlation (< 0.4).

Correctness

Overall correctness was 89.7%. Of the individual variables, 44 of 48 (91.7%) had a good (≥ 85) or adequate (70–84%) correctness, as well as all the groups of ISS and NISS (Fig. 2). Four variables exhibited poor correctness (< 70%): NISS (38.3%), ISS (48.3%), Time until first key emergency
### Table 2: Accuracy, correlation and comparability

<table>
<thead>
<tr>
<th>No</th>
<th>Variable</th>
<th>Accuracy</th>
<th>Pearson’s $r$ or Cohen’s kappa</th>
<th>Comparability</th>
</tr>
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<tr>
<td>1</td>
<td>Type of transportation</td>
<td>0.97</td>
<td>0.90</td>
<td>X</td>
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<tr>
<td>2</td>
<td>Glasgow Coma Scale (GCS) upon arrival of EMS personnel at scene</td>
<td>0.87</td>
<td>0.96</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>GCS motor component upon arrival of EMS personnel at scene</td>
<td>0.97</td>
<td>0.82</td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>Systolic blood pressure (SBP) upon arrival of EMS personnel at scene</td>
<td>0.65</td>
<td>0.87</td>
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<td>5</td>
<td>SBP clinical category upon arrival of EMS personnel at scene</td>
<td>0.83</td>
<td>0.46</td>
<td>X</td>
</tr>
<tr>
<td>6</td>
<td>Respiratory rate (RR) upon arrival of EMS personnel at scene</td>
<td>0.83</td>
<td>0.95</td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>RR clinical category upon arrival of EMS personnel at scene</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td>Pre-hospital cardiac arrest</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>9</td>
<td>Pre-hospital airway management</td>
<td>0.99</td>
<td>0.85</td>
<td>X</td>
</tr>
<tr>
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<td>Type of pre-hospital airway management</td>
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<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>11</td>
<td>Highest level of pre-hospital care provided</td>
<td>0.86</td>
<td>0.59</td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>Time of trauma</td>
<td>0.61</td>
<td>0.86</td>
<td>Z</td>
</tr>
<tr>
<td>13</td>
<td>Time of alarm</td>
<td>0.80</td>
<td>1.00</td>
<td>T</td>
</tr>
<tr>
<td>14</td>
<td>Time of arrival at scene</td>
<td>0.78</td>
<td>1.00</td>
<td>S</td>
</tr>
<tr>
<td>15</td>
<td>Time of EMS personnel leaving the scene</td>
<td>0.89</td>
<td>1.00</td>
<td>S</td>
</tr>
<tr>
<td>16</td>
<td>Time of arrival in hospital</td>
<td>0.70</td>
<td>1.00</td>
<td>T</td>
</tr>
<tr>
<td>17</td>
<td>Type of trauma criteria</td>
<td>0.99</td>
<td>0.66</td>
<td>S</td>
</tr>
<tr>
<td>18</td>
<td>Activation of the trauma team</td>
<td>0.89</td>
<td>0.81</td>
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</tr>
<tr>
<td>19</td>
<td>Trauma call re-prioritized</td>
<td>0.97</td>
<td>0.49</td>
<td>S</td>
</tr>
<tr>
<td>20</td>
<td>GCS upon arrival in hospital</td>
<td>0.88</td>
<td>0.93</td>
<td>X</td>
</tr>
<tr>
<td>21</td>
<td>GCS motor component upon arrival in hospital</td>
<td>0.98</td>
<td>0.74</td>
<td>X</td>
</tr>
<tr>
<td>22</td>
<td>SBP upon arrival in hospital</td>
<td>0.68</td>
<td>0.88</td>
<td>X</td>
</tr>
<tr>
<td>23</td>
<td>SBP clinical category upon arrival in hospital</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>24</td>
<td>RR upon arrival in hospital</td>
<td>0.85</td>
<td>0.71</td>
<td>X</td>
</tr>
<tr>
<td>25</td>
<td>RR clinical category upon arrival in hospital</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>26</td>
<td>Dominating type of injury</td>
<td>0.98</td>
<td>0.90</td>
<td>X</td>
</tr>
<tr>
<td>27</td>
<td>Pre-injury ASA physical status classification</td>
<td>0.68</td>
<td>0.49</td>
<td>X</td>
</tr>
<tr>
<td>28</td>
<td>Mechanism of injury</td>
<td>0.88</td>
<td>0.86</td>
<td>X</td>
</tr>
<tr>
<td>29</td>
<td>Intention of injury</td>
<td>0.99</td>
<td>0.96</td>
<td>X</td>
</tr>
<tr>
<td>30</td>
<td>First key emergency intervention</td>
<td>0.91</td>
<td>0.70</td>
<td>X</td>
</tr>
<tr>
<td>31</td>
<td>Type of first key emergency intervention</td>
<td>0.83</td>
<td>0.71</td>
<td>X</td>
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<tr>
<td>32</td>
<td>Base excess</td>
<td>0.97</td>
<td>1.00</td>
<td>Y</td>
</tr>
<tr>
<td>33</td>
<td>Coagulation: INR</td>
<td>1.00</td>
<td>1.00</td>
<td>X</td>
</tr>
<tr>
<td>34</td>
<td>Hospital airway management</td>
<td>0.98</td>
<td>0.79</td>
<td>X</td>
</tr>
<tr>
<td>35</td>
<td>Type of hospital airway management</td>
<td>0.83</td>
<td>0.57</td>
<td>X</td>
</tr>
<tr>
<td>36</td>
<td>Time until normal base excess</td>
<td>1.00</td>
<td>1.00</td>
<td>Y</td>
</tr>
<tr>
<td>37</td>
<td>Time of first CT scan</td>
<td>0.43</td>
<td>0.85</td>
<td>X</td>
</tr>
<tr>
<td>38</td>
<td>Time until first key emergency intervention</td>
<td>0.47</td>
<td>0.99</td>
<td>X</td>
</tr>
<tr>
<td>39</td>
<td>ISS</td>
<td>0.48</td>
<td>0.91</td>
<td>X</td>
</tr>
<tr>
<td>40</td>
<td>NISS</td>
<td>0.38</td>
<td>0.92</td>
<td>X</td>
</tr>
<tr>
<td>41</td>
<td>Survival status (30-day mortality)</td>
<td>0.99</td>
<td>0.80</td>
<td>X</td>
</tr>
<tr>
<td>42</td>
<td>Glasgow Outcome Scale (GOS) at discharge from reporting hospital</td>
<td>0.70</td>
<td>0.51</td>
<td>X</td>
</tr>
<tr>
<td>43</td>
<td>Number of days on ventilator</td>
<td>0.88</td>
<td>0.94</td>
<td>X</td>
</tr>
<tr>
<td>44</td>
<td>Date of discharge</td>
<td>0.79</td>
<td>0.95</td>
<td>Z</td>
</tr>
<tr>
<td>45</td>
<td>Highest level of in-hospital care</td>
<td>0.93</td>
<td>0.90</td>
<td>X</td>
</tr>
<tr>
<td>46</td>
<td>Discharge destination</td>
<td>0.91</td>
<td>0.83</td>
<td>X</td>
</tr>
<tr>
<td>47</td>
<td>Inter-hospital transfer</td>
<td>0.98</td>
<td>0.96</td>
<td>X</td>
</tr>
<tr>
<td>48</td>
<td>Mortality conference</td>
<td>1.00</td>
<td>1.00</td>
<td>S</td>
</tr>
</tbody>
</table>

NISS grouped by 1-8, 9-15, 16-24 & 25-75: 0.85  
ISS, grouped by <15: 0.93  
NISS, grouped by <15: 0.98  
ISS grouped by 1-8, 9-15, 16-24 & 25-75: 0.82
Table 2 (continued)

$S =$ variables exclusive to SweTrau $(n = 5)$. $T =$ time of alarm and time of arrival in hospital instead of time from alarm to hospital arrival $(n = 2)$. $X =$ exact agreement $(n = 37)$. $Y =$ venous or arterial blood

### Accuracy and correctness of variables

| Variable                                                                 | Mortality conference | Time until normal base excess | Congestion: INR | RR clinical category upon arrival in hospital | SBP clinical category upon arrival in hospital | Type of pre-hospital airway management | Pre-hospital cardiac arrest | RR clinical category upon arrival of EMS personnel at scene | Type of trauma criteria | Survival status (30-day mortality) | Intention of injury | Pre-hospital airway management | Inter-hospital transfer | Dominating type of injury | GCS motor component upon arrival in hospital | NISS, grouped by $< 12$ | Hospital airway management | GCS upon arrival in hospital | Base excess | Glasgow Coma Scale (GCS) upon arrival of EMS personnel at scene | GCS motor component upon arrival of EMS personnel at scene | Type of transportation | Trauma call re-prioritized | Respiratory rate (RR) upon arrival of EMS personnel at scene | RR upon arrival in hospital | Number of days on ventilator | Time of EMS personnel leaving the scene | Highest level of in-hospital care | Systolic blood pressure (SBP) upon arrival of EMS personnel at scene | Time of alarm | ISS, grouped by $< 12$ | Discharge destination | First key emergency intervention | Time of arrival in hospital | Time of arrival at scene | Activation of the trauma team | Mechanism of injury | SBP upon arrival in hospital | Highest level of pre-hospital care provided | NISS grouped by 1, 8, 9, 15, 16-24 & 25-75 | Time of first CT scan | Type of hospital airway management | Type of first key emergency intervention | SBP clinical category upon arrival of EMS personnel at scene | ISS, grouped by 1, 8, 9, 15, 16-24 & 25-75 | Date of discharge | Time of trauma | Glasgow Outcome Scale (GOS) at discharge from reporting hospital | Pre-injury ASA physical status classification | Time until first key emergency intervention | ISS | NISS |
|-------------------------------------------------------------------------|----------------------|--------------------------------|----------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------|-------------------------|----------------------------------------------------|---------------------|-----------------------------------------------|---------------------|-----------------------------------------------|-------------------------|---------------------------------|-----------------------------------------------|---------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------|----------------------------------|------------------------------------------------|---------------------------------|--------------------------------|----------------------|-----------------------|---------------------------------|---------------------------------|----------------|----------------|

![Fig. 2 Accuracy and correctness of variables. RR respiratory rate, EMS emergency medical services, NISS New Injury Severity Score, GCS Glasgow Coma Scale, SBP systolic blood pressure, GOS Glasgow Outcome Scale](image-url)
intervention (52.6%), Pre-injury ASA physical status classification (68.1%).

Data completeness

Overall data completeness was 88.5%. Most variables (41/48) exhibited a good (≥ 85%) or adequate (70–84%) data completeness (Fig. 3). Seven variables showed poor completeness < 70%: RR clinical category upon arrival of EMS personnel at scene (20.0%), Time until normal base excess (27.3%), Base excess (28.3%), RR clinical category upon arrival in hospital (50.0%), Time of trauma (55.0%), Coagulation: INR (66.4%), SBP clinical category upon arrival of EMS personnel at scene (66.7%).

Case completeness

A total of 44.3% of the identified trauma patients eligible for inclusion in SweTrau were registered (39/88). None of the missed patients were severely injured (NISS > 15) or had initiated the highest level of trauma call (Trauma
Alert). The missed patients were evenly dispersed among the validated hospitals.

Timelines

One year (365 days) after the trauma date 84.2% of the patients were registered. Median time from trauma date and registration in SweTrau was just over 4.5 months (139 days, Fig. 4). Some 5.8% (7/120) of the patients were registered within 30 days after the trauma, which is too early for registering the Survival status (30-day mortality) since all seven patients were registered as survivors.

Comparability

Some 89.6% (43/48 variables) were identical with the Utstein Template of Trauma (n = 37) or displayed minor variations (n = 6) (Table 2). Five variables were exclusive to SweTrau: Time of arrival at scene, time of EMS personnel leaving the scene, Type of trauma criteria, Trauma call re-prioritized, Mortality conference.

Discussion

This first validation of the Swedish Trauma Registry (SweTrau) confirms that the registry has a high validity, even though there are some areas of improvement that need to be addressed; such as the completion of registration of certain variables. The validated population shows the same properties (approximate median age, predominately male patients, a majority of blunt trauma) as other studies made on trauma populations in Sweden [27, 28] which indicates a representative sample of patients. In the vast majority of cases where an adjustment of NISS score was made at re-registration, this did not lead to the patient being considered severely injured, i.e. no change in morbidity in a significant way. Only three patients (2.5%) had a modification in NISS that actually affected the limit of NISS < 15 < (two altered to > 15 and one to < 15) which is a better result than reported in a Norwegian study [5] (5.6% had a change that affected the ISS < 15 <). This indicates that a cut-off of NISS > 15 for severely injured patients in SweTrau is valid. Although overall accuracy, correlation, correctness and data completeness showed good results (85.8–89.7%), this still means that roughly ten percent of the data in SweTrau does not match when compared between two independent registrars. This is important to remember when conducting and interpreting research based on SweTrau, in addition to the common limitations with registry data.

Accuracy, correlation and correctness

We found only one study calculating overall accuracy in a trauma registry, also reporting a good result (94.3% [6], compared to 85.8% in our study). Survival status was one of the variables in our study with very high accuracy (99%) and excellent correlation (0.8), which is in concordance with a Dutch study (accuracy 99%, correlation 0.82 [18]). Regarding overall correctness, we identified two additional studies from regional trauma registries that had good (> 85%) correctness as well: 98% [23] (Spanish study evaluating 42

![Fig. 4 Days between trauma date and registration date in SweTrau. Min = 2 days, Max = 516 days, Median = 139 days](image-url)
variables) and 97.1% [6] (Finnish study evaluating 32 variables), in relation to 89.7% in our study (evaluating 48 variables and four groups of variables). When the re-registration was made, we found that some data (systolic blood pressure for example) had been rounded in the original registration, which possibly could explain some discrepancies in accuracy and correlation. This is taken into consideration when calculating correctness. Among the seven variables that had poor accuracy, four also showed poor correctness: NISS, ISS, Time until first key emergency intervention and Pre-injury ASA physical status classification. Additionally, Pre-injury ASA physical status classification had only moderate correlation, indicating that more instructions for assessing ASA score may be needed. For example, we found that BMI and smoking were judged in different ways when assessing the ASA score. The individual results of NISS and ISS may also seem problematic, however, NISS and ISS performed well when analyzed as grouped by <15 and grouped by 1–8, 9–15, 16–24 and 25–75 with both good accuracy and correlation. Since most studies group the patients in some way, we believe that the discrepancies of the individual scores have less clinical relevance. The low performance of accuracy of ISS is also shown in a Dutch study [18] (63%), where the correlation of ISS was slightly lower than in our study (0.84 vs 0.91), although still considered excellent (≥0.8), similar to another study from the Netherlands [19] (0.81 vs. 0.91 in our study). The calculation of NISS and ISS is furthermore complicated by the fact that the registrars often have to interpret radiology reports which do not specify the extent of the injury (e.g. should a “minor cerebral contusion” be assessed as “tiny <1 cm” or “small 1–4 cm”? ). This assessment might be more concordant if registrars would have the possibility to perform local validations of a number of patients each year. Time until first key emergency intervention may finally be hard to register because of the hospitals’ multiple ways of recording data in patient charts; many times in several different modules that may or may not be linked. A national coherent system of recording in patient charts may improve this.

### Timeliness and case completeness

Ideally, the timeliness should be 31 days post trauma date, however, our study showed a median time from trauma date to registration of approximately 4.5 months. The delay could in isolated cases be due to waiting for post-mortem protocols, although this concerns a very small portion of the patients. This lead us to suggest that more focus should be directed towards improving timeliness in SweTrau so that complete and reliable data could be extracted and interpreted in a timely manner. Of the validated hospitals, only two had registered patients before the mortality variable should be recorded (i.e. too early) which might be improved by more information about the importance of waiting 30 days after the trauma before finalizing the registration.

In the literature, we have found only two studies regarding case completeness, with very diverse results: 97.1% [6] and 60.1% [22], respectively. The case completeness in this study (44.3%) should also be interpreted with caution since the patient sample became too small to properly analyze. It is nevertheless an indication that particularly the lowest level of trauma calls (i.e. Trauma Responses) are not being fully covered by SweTrau since all the missing patients consisted of Trauma Responses, making the case completeness for patients with NISS > 15 100%. This suggest that analysis of severely injured patients in SweTrau is reliable while the cohort of patients with minor injuries might not be representative, possible due to not being prioritized during registration.

Because case completeness is dependent on the registry’s inclusion criteria (in SweTrau “all trauma calls”) this also relies on finding all Trauma Responses, instead of only Trauma Alerts and patients with NISS > 15. Today, SweTrau has adopted a way to approximate case completeness by comparing its registered cases with the Swedish Intensive Care Registry, which is possible due to the unique personal identification number that everyone in Sweden have. This, however, focuses mainly on finding patients with NISS > 15 and Trauma Alerts and is tainted with several problems (not all intensive care wards are affiliated, a trauma patient can have several different registrations for the same trauma etc.).

A way to increase this precision would be to simultaneously compare the patients with The Cause of Death Registry, as well as pinpointing a certain number of trauma diagnoses and compare these patients with the Patient Registry, where all diagnoses in Sweden are registered, but there is no absolute correlation between a certain ICD-10, chapter 19, (S00-T98) diagnosis and the inclusion criteria for SweTrau. Also, the issue with finding all Trauma Responses remains to improve case completeness. We found this to be virtually impossible without comparing the emergency ledgers at each individual hospital, as is done in this study.

### Data completeness

Data completeness of SweTrau seems to be in line with the few studies that exists: slightly lower than in two regional trauma center studies (88.5% vs 93.4% [6] and 92.8% [23]) but higher than in a large study by Ringdal et al. (81.3% of the variables in our study had >80% data completeness compared to 78% in the multicenter study [20]). RR clinical category upon arrival of EMS personnel at scene, RR clinical category upon arrival in hospital and SBP clinical category upon arrival of EMS personnel at scene all had poor data completeness (<70%). The clinical category is an estimation which is used when there is no specific value recorded.
(for example, respiratory rate (RR) can be “normal”, “fast”, “slow”, “gasp” or “no respiration”). However, this is not always noted on the patient chart which could be a reason, we believe, for missing data. Making these parameters mandatory before signing the patient charts could improve compliance. Blood tests, such as Base excess, Time until normal base excess and Coagulation: INR also exhibited poor data completeness. Some of these missing values are unavoidable since not all trauma patients (especially not Trauma Responses) get blood tests taken. Moreover, the issue with missing data on Base excess and Time until normal base excess, as well as pre-hospital recordings on RR and SBP, has also been noted in an international multicenter study by Ringdal et al. [20]. Lastly, Time of trauma was missing in almost 50% of the cases—somewhat understandable since the time of trauma in many cases is unknown and this variable should consequently be judged with caution.

Comparability

The minor variations of the Utstein Template of Trauma variables consisted of recording time of alarm and time of arrival in hospital instead of time from alarm to hospital arrival, as well as recording time of trauma and date of discharge instead of length of stay. Moreover, SweTrau uses either venous or arterial blood gas for base excess, while the Utstein Template states arterial blood gas—a disparity which should not affect the result in a significant way. In summary; with the vast majority of the variables being consistent with the Utstein Template of Trauma, we deem that the data in SweTrau is comparable to other trauma registries using the Utstein Template of Trauma.

Limitations and strengths

Due to the COVID-19 pandemic the examined patient population became considerably smaller than intended, which is a major limitation of this study. Despite several attempts, we were not allowed to visit several hospitals due to visitor restrictions, and exemptions were not made since validation was not considered a priority under the circumstances. The loss of hospitals was, however, random and we therefore still consider the population to be representative, although the sample size is less than desired. One of the strengths of this study is that the data is from 2018 which therefore reflects the actual situation for the trauma registrars before the additional cut-down in time and resources following the outbreak of the COVID-19 pandemic. Another strength is that we have validated each case on-site at the actual hospital—which certainly is a very time consuming way to validate but as a result gave us the exact same prerequisites as the local registrars.

Conclusion

This study shows that the overall data validity of SweTrau is high; with good accuracy (85.8%), correctness (89.7%) and data completeness (88.5%), as well as strong or excellent correlation (87.5%). The data in SweTrau is comparable to other trauma registries that use the Utstein Template of Trauma. Areas of improvement are, however, timeliness and case completeness. The authors would like to recommend SweTrau to continuously perform regular validations on-site in the future.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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2. Moberger P. Sköldberg F. Birgisson H. Evaluation of the Swedish Colorectal Cancer Registry: an overview of
Penetrating Trauma on the Rise
– Nine-year Trends of Severe Trauma in Sweden

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Abstract

Purpose

Sweden has an established trauma system involving national trauma criteria and a registry, SweTrau, since over a decade. Meanwhile, the injury panorama has evolved, with an increase in gang-related violence in the Swedish community. In this study, we aimed to investigate long-term trends in mortality, management and trauma type in two major Swedish trauma centers over a nine-year period.

Methods

All trauma patients with a New Injury Score (NISS)>15 or a Trauma Alert call during 2013-2021 were identified in the participating centers’ SweTrau registries. Data were analysed regarding mortality, proportion of emergency interventions, intensive care unit (ICU) admissions, mechanism of injury and type of trauma (penetrating or blunt). To assess trends, Chi-Squared test for trend and JoinPoint regression method were used.

Results

A total of 10585 patients were included in the study. Mortality remained unchanged over time in patients with NISS>15 (10.0% - 10.9%, p=0.963) but increased in NISS<15 (1.3% - 2.7%, p=0.005), partly comprising penetrating trauma, suicides and traumatic cardiac arrests. For NISS>15, the proportion undergoing emergency interventions was stable (53.9%-48.8%, p=0.297) while ICU admissions declined (62.1%-45.7%, p<0.001). Penetrating trauma increased (12.4%-19.6%, p<0.001), including knife (10.0%-15.7%, p<0.001) and gunshot wounds (2.3%-3.8%, p<0.001), whereas accidents involving motorcycles (8.8%-7.0%, p=0.004) and pedestrians (5.3%-2.2%, p<0.001) decreased.

Conclusions

In this trend analysis at two major Swedish trauma centers during 2013-2021, penetrating trauma increased with over 50% while traffic injuries decreased. The rise in mortality in patients with NISS<15 is concerning and requires further evaluation, as do the reduction in ICU admissions.
Introduction

Trauma is affecting all ages throughout the population and is a significant burden to society. The occurrence of trauma in a population is affected by societal changes, and such changes may also affect the management algorithm for trauma as well as trauma outcome. Over the past decades in Sweden, there has been a 2-fold increase in deadly violence due to firearms [1]. During the years 2000-2019, Sweden has climbed from the bottom to the top of gunshot wound homicides in Europe, with the absolute majority of cases being gang-related and linked to illicit drugs, illegal weapons and socially disadvantaged areas [2]. This dramatic (and in Europe previously unseen) increase takes off steeply from 2013 and onward, with Sweden leading the list since 2018. The worrisome development calls for an urgent need to identify where the most potential of improvement in trauma care lies, by mapping changes and trends in the trauma panorama.

In order to safely modify the way to prepare for, treat and prevent trauma, it is important to have reliable data and research to base such recommendations on. In Sweden, a uniform system for trauma call activation exists; the Swedish National Trauma Triage Criteria (SNTTC) [3], with two levels of trauma call: Trauma Alert (TA, highest) and Trauma Response (TR, lowest). Furthermore, there is a national trauma registry (SweTrau), implemented in 2011 [4] with variables based on the internationally acknowledged consensus document “The Utstein Template of Trauma” [5, 6]. SweTrau includes all trauma patients with a trauma call (either a TA or TR) or a NISS>15. Moreover, the registry has recently been validated [7]. All these parts of the Swedish trauma system make up a solid foundation for studying trends of trauma.

The current paper aims to assess changes in trauma care and trauma patterns in Sweden over a nine-year period, using data from SweTrau at two major trauma centers.
Material & Methods

Study population and study questions

All trauma patients with NISS>15 or a TA (regardless of NISS) from two Swedish trauma centers (Karolinska university hospital in Stockholm and Uppsala university hospital in Uppsala) between the years 2013 to 2021 were examined. These trauma units serve a primary catchment area of 2.8 million inhabitants in central Sweden, comprising about 27% of the total Swedish population. Both centers offer comprehensive trauma care including all trauma subspecialties, and have a tertiary care status for treatment of complex trauma patients within their respective regions (total population catchment area approximately 4.6 million). The selection of inclusion criteria was to ensure that all severely injured trauma patients would be captured, so that for example patients with penetrating trauma that did not reach NISS>15 but still required an emergency intervention were not missed. The choice of NISS over Injury Severity Score (ISS) \cite{8} was made on the basis of NISS being an inclusion criteria of SweTrau, as well as being better at describing penetrating injuries \cite{9}, in-hospital mortality \cite{10} and post-trauma multiorgan failure \cite{11}. The population was then divided into groups (NISS<15, NISS>15, penetrating and blunt trauma) during the analysis of the study questions. The primary study question was how the outcome of trauma care, defined as 30-day mortality after severe trauma, had changed over time in the trauma cohort. Secondary study questions included analysis of outcome for patients with NISS>15 and those with NISS<15 separately, the proportion of patients with severe trauma and an emergency intervention or an admission to the intensive care unit (ICU), and changes in the patterns of mechanisms of injury (including penetrating vs blunt trauma).

Data sources

The time period of the study was selected to include data from the complete inception of the SweTrau registry (initiation phase in 2011 to 2012 with fully established registry from 2013). SweTrau contains patient characteristics, such as social security number, age, sex and American Society of Anesthesiologists (ASA) physical status score, as well as pre-hospital and in-hospital data on injuries and performed emergency interventions. These are defined as thoracotomy, laparotomy, pelvic packing, revascularization, endovascular intervention, craniotomy, intracranial pressure measurement or other (chest tube, external fixation of fracture, major surgery of fractures or wound revision in the operating room). The registry also records days on ventilator in the ICU, if the injury was penetrating (e.g. penetrates through the tissue) or blunt (injury resulting from a person being hit by or hitting another object) and discharge destination (home, rehabilitation, other care facility, morgue etc.). The 30-day mortality variable is verified during the registration in SweTrau via each hospitals
electronic records which are linked to the Swedish Tax Agency that files all death certificates in Sweden, thus ensuring 100% accuracy for Swedish citizens.

Statistics

Statistical analyses were performed with IBM SPSS Statistics, version 28.0.1.0 (IBM Corp., Armonk, N.Y., USA), JoinPoint Regression Program, version 5.0.2 (Statistical Methodology and Applications Branch, Surveillance Research Program, National Cancer Institute) and with Microsoft Excel for Mac, version 16.74. Medcalc.org was used to obtain the confidence intervals for the incidence rate in Supplemental material 1. Categorical data were analyzed with Chi-Squared test and numerical data with Mann-Whitney U test (two groups) or Kruskal-Wallis test (more than two groups). Trends were analyzed with Chi-Squared test for trend and JoinPoint regression model, resulting in an annual average percent change (AAPC). The level of significance was set at a p-value <0.05.
Results

The eligible number of patients was 10816 which, after exclusion due to missing data, led to a study population of 10585 patients (Figure 1). Patient characteristics of the population, as well as for the groups NISS>15, NISS<15, penetrating trauma and blunt trauma is presented in Table 1. The group of penetrating trauma was younger and had a higher proportion of males and less comorbidities, as well as a lower NISS score, than the overall study population. Patients with NISS<15 experienced more penetrating trauma than patients with NISS>15, while also being younger and having a lower ASA and NISS score.

Mortality

The overall 30-day mortality in the population was 7.8 %, with a significantly higher mortality for patients with NISS>15 than NISS<15 (13.0 % vs 1.7 %, p<0.001, Table 1). The mortality remained unchanged for the groups penetrating trauma, blunt trauma and NISS>15 (Table 2 and Figure 2), while it increased for patients with NISS<15 (1.3 % to 2.7 %, p=0.005). The majority of deaths in the group NISS<15 (52.4 %, 44 of 84 patients) occurred during the last third of the study period, between 2019-2021. Among these 44 patients there were seven deaths from knife injuries and gunshot wounds (GSW) (compared to only two during the first six year of the study), and suicide from blunt trauma accounted for five deaths during this period, as opposed to one during 2013-2018. Furthermore, although there were no deaths in the emergency department (ED) in the first six years of the study, thirteen patients with NISS<15 died in the ED during 2019-2021. Eleven of these patients had experienced a pre-hospital cardiac arrest, comprising one young man with a GSW and ten patients categorized as blunt trauma, aged between 51-67 years.

Emergency Intervention

The rate of emergency interventions for NISS>15 remained around 50 % (Figure 3a). The four most common emergency interventions in the groups NISS>15 and blunt trauma were the same: craniotomy, major surgery of fractures, chest tube and intracranial pressure measurement. Penetrating trauma and NISS<15 shared three out of the four most common emergency interventions: wound revision in the operating room, laparotomy and chest tube, with thoracotomy being in the top four with penetrating trauma as opposed to major surgery of fractures in patients with NISS<15. Overall, there were no significant trends in the rate of emergency interventions for patients with NISS>15, nor for patients with penetrating or blunt trauma. For patients with NISS<15, the two statistical methods had divergent findings, with Chi-Squared test for trend suggesting a significant change in emergency interventions rate over time (14.8 % to 16.7 %, p=0.029), whilst this change was not significant when
assessed with JoinPoint regression (AAPC 1.51; CI -0.73, 4.21, Table 2). The graphic changes in the rate of emergency interventions per year are visualized in Figure 2.

**Intensive Care Unit**

Figure 4 shows the rate of admission to ICU after trauma. Admissions to the ICU decreased for patients with NISS>15 (62.1 % to 45.7 %, p<0.001), whilst it was stable for NISS<15 (Table 2). When assessing rate of ICU admission for blunt and penetrating trauma, a clear decrease in admissions in both groups was observed from 2020 and onwards (Figure 4b and Table 2).

**Mechanisms of injury**

The rate of mechanisms of injury per year are presented in Figure 5. This figure focuses on mechanisms of injury with a significant change over time when analyzed with both Chi-Squared test for trend and JoinPoint regression (Table 2). Assaults with knife (10.0 % to 15.7 %, p<0.001), GSW (2.3 % to 3.8 %, p<0.001) and hit by blunt object (8.1 % to 10.5 %, p=0.006) increased, while traffic accidents involving motorcycles (MCC) (8.8 % to 7.0 %, p=0.004) and pedestrians (5.3 % to 2.2 %, p<0.001) decreased.

**Penetrating trauma, gender proportion and NISS**

Table 3 displays trends in penetrating and blunt trauma. The proportion of patients subjected to penetrating trauma increased from 12.4 % to 19.6 % (p<0.001). There was no change in laparotomy or thoracotomy rates among those with penetrating trauma. The fraction of male patients remained stable at approximately 90 % for penetrating trauma and 70 % for blunt trauma, while a median of NISS 13 was maintained for penetrating trauma and 17 for blunt trauma, even though there were some fluctuations for penetrating trauma (Table 3).

**Incidence of severe trauma**

The number of severe trauma patients per year during 2013 to 2021 increased with 20.5 %, while the population of the catchment area grew with 12.0 % during the same period, as seen in Supplemental material 1. During the years of 2020-2021, the main increase in trauma (15.4 %) occurred. The incidence of trauma varied from 41 to 48 per 100 000 inhabitants with partially overlapping 95 % confidence intervals.
Discussion

Interpretation of mortality trends

Our study, examining 10587 patients for a time period of nearly a decade, is to our knowledge the largest study in Sweden reporting trends in trauma. Overall mortality in the group of NISS>15 was 13.0 % – less than in studies from Denmark [12], the USA [13] and Japan [14] but comparable to a previous Swedish study [3]. The mortality also compares very well when looking at SweTrau’s annual reports, were the mortality in the group NISS>15 between the years 2013-2021 varies from 14 to 20 %, with a mean of around 17 %. However, the mortality in SweTrau reflects a mixture of university hospitals and regional hospitals, in contrast to our study’s two major university trauma centers, which could possibly explain the higher mortality rate in SweTrau. Further, our results are similar to an Australian study that showed no significant changes in mortality during the years 2006-2016 [15], with one worrisome exception in our study; the group NISS<15 where mortality has risen from 1.3 % to 2.7 %.

The increase in mortality for NISS<15 is visible from 2019 and onward. An important proportion of this increase was related to patients that died in the ED. It should be noted that in 2017, the previously mentioned new Swedish trauma call system (SNTTC) was introduced. One could hypothesize that the implementation of the SNTTC could have led to a more stringent use of the highest trauma call (TA), possibly resulting in a change of presentation of injured patients with NISS<15 to ED:s and thus explaining part of this observed increase in mortality among NISS<15 patients. However, in a Swedish study from 2019 [16], it was shown that both the number of TA:s and the proportion of patients with ISS<15 among TA:s were the same before and after the implementation of the new criteria, which do not support this idea. Moreover, on closer examination of the NISS<15 group, there was a striking difference in the number of deaths from knife injuries, GSW, and suicides from blunt trauma during the study period, resulting in twelve fatalities during the last three years (2019-2021), compared to only three during the first six years (2013-2018).

Adding the deaths from penetrating trauma and suicides, together with the patients who died in the ED, this constitutes more than half of the deceased patients with NISS<15 during 2019-2021, coinciding with the increase in mortality in this group. The change in the trauma panorama in Sweden thus can have contributed to this outcome.
Emergency Intervention & Intensive Care Unit

Emergency interventions did not change during the study period, underlined by the fact that laparotomy and thoracotomy in penetrating trauma showed no significant trends. The overall decrease in ICU admissions is however of interest, with an even sharper decline during the COVID-19 pandemic years of 2020-2021. This does not correspond to findings from other international studies [17, 18], where the ICU proportions of patients requiring ICU admission was unchanged during COVID-19. Furthermore, the number of trauma patients in our study actually increased during the years 2020-2021, unlike many other countries that practiced lockdown [17-20], and the increase in severe trauma cannot be explained in its entirety by a rise in population. This could be interpreted as a very concerning finding, indicating that trauma patients in Sweden were down-prioritized from the ICU during COVID-19. Nonetheless, as earlier discussed there was no increase in mortality during the study period except for the group NISS<15 and, on closer examination, there was no decrease in proportions of ICU admissions in deceased patients with NISS<15. This indicates that even if fewer trauma patients were indeed admitted to the ICU, patient safety was still maintained. The current data therefore suggests that a larger proportion of patients with severe trauma could be managed at a somewhat lower care level with the same result.

Mechanisms of injury

During the study period, we found that “being hit by a blunt object” increased as a mechanism of injury, together with other assaults (knife-inflicted trauma and GSW) – in contrast to the findings of a study from the USA between 2005-2014 [21] but consistent with a Danish study between 2010-2019 [12]. We also found that traffic injuries such as MCC and pedestrian accidents decreased, in line with other studies [12, 14, 21]. These changes could be interpreted as a shift towards violence being a more prevalent cause of injury while traffic related trauma decreases, indicating areas to focus on when discussing trauma prevention. Of note, we could not see a significant change in fall injuries, contrary to other studies that have reported a trend of higher incidence of falls [12, 14, 21, 22]. One possible explanation to this could be that this study only examines severe trauma, not the whole trauma population.

Penetrating trauma

The proportion of penetrating trauma increased with more than 50 percent during the study period (12.4 % to 19.6 %, p<0.001), but the mortality remained at just below six percent with some variations over the years. The increase in penetrating trauma in Sweden is also supported by other studies [23, 24]. Moreover, one has to remember that patients that are pronounced dead at scene are not included in SweTrau, which can lead to false
low mortality numbers, as showed in a Swedish study [23] where death due to violence was increased but not in-hospital mortality for penetrating trauma.

**Strengths and limitations**

The major strengths of our study are the substantial size of the population and the extensive time period examined, as well as the inclusion of two out of in total seven university hospitals in Sweden. Using two different statistical methods (JoinPoint regression [25] and Chi-Squared test for trend) also strengthens the validity of the results. JoinPoint is a common way to describe trends in incidence [21, 26] and includes the advantage of a measurement (AAPC) that is easy to comprehend and compare.

The retrospective nature of this paper carries the usual limitations of a registry based study, which makes more in-depth analyses of individual cases difficult. Also, any international comparisons of the results should be done with the Swedish context of our study in mind. A possible bias is the excluded patients; however, these were scarce (about 2 %) and the potential impact should therefore be minimal. Finally, since patients that die on the scene of trauma are not included in SweTrau, the mortality rate needs to be interpreted considering this, and our study therefore only reflects the in-hospital mortality.
Conclusion

Penetrating trauma with knife injuries and GSW increased with more than 50% at two major Swedish trauma centers during 2013-2021, with decreasing traffic related injuries such as MCC and pedestrian accidents. While no trend was seen in the proportion of emergency interventions performed, the group NISS<15 displayed a troublesome finding of a more than doubled mortality, primarily during 2019-2021. This could possibly be related to the increase in penetrating violence, as well as changes in presentation of trauma patients to the ED, and would merit further investigation aiming for improved outcomes. Additionally, a clear decrease in ICU admissions was noted, although not correlated with the increased mortality in NISS<15, indicating that a lower care level may be safe for a larger proportion of trauma patients.

Statements and Declarations

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Conflict of interest

The authors have no competing interest to declare that are relevant to the content of this article.

Availability of data

Data available from the authors upon reasonable request.

Authors contribution

LH contributed to the literature search, study design, data collection, data analysis and interpretation and writing. AW, CW and FL contributed to study design and critical revision. HA and KM contributed to study design, data interpretation and critical revision. All authors have read and approved the manuscript.

Ethics approval

The study was approved by the Regional Ethics Review Board in Uppsala, Sweden (Dnr 2014/250 and Dnr 2022-03417-02).
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2. The Swedish National Council for Crime Prevention, Gun homicide in Sweden and other European countries.


Patients with NISS>15 and/or Trauma Alert during 2013-2021 at included hospitals

Eligible patients (n=10816)

Excluded (n=229)
* Missing data on mortality (n=52)
* Missing data on emergency intervention (n=2)
* Missing data on injury mechanism (n=113)
* Missing data on ASA score (n=62)

Study population (n=10587)

Figure 1. Flowchart of patient population.
Figure 2a&b. Trends in mortality for the groups NISS>15 vs NISS<15 and penetrating trauma vs blunt trauma.

Figure 3a&b. Trends in emergency intervention for the groups NISS>15 vs NISS<15 and penetrating trauma vs blunt trauma.
Figure 4a&b. Trends in intensive care unit admissions for the groups NISS>15 vs NISS<15 and penetrating trauma vs blunt trauma.

Figure 5. Trends in mechanism of injury over the study period.
Table 1 – Characteristics. NISS = New Injury Severity Score. IQR = Interquartile range. ASA score = American Society of Anesthesiologists physical status score. 1Chi-Squared test. 2Mann-Whitney U test. * = p<0.05.
<table>
<thead>
<tr>
<th></th>
<th>Chi-Squared test for trend p-value</th>
<th>JoinPoint regression AAPC (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mortality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISS&gt;15</td>
<td>0.963</td>
<td>-0.75 (-5.17, 4.11)</td>
</tr>
<tr>
<td>NISS&lt;15</td>
<td>0.005*</td>
<td>12.24* (7.53, 18.36)</td>
</tr>
<tr>
<td>Penetrating trauma</td>
<td>0.465</td>
<td>-2.90 (-10.85, 7.33)</td>
</tr>
<tr>
<td>Blunt trauma</td>
<td>0.079</td>
<td>1.14 (-3.95, 8.82)</td>
</tr>
<tr>
<td><strong>Emergency Intervention</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISS&gt;15</td>
<td>0.297</td>
<td>-0.64 (-2.34, 1.15)</td>
</tr>
<tr>
<td>NISS&lt;15</td>
<td>0.029*</td>
<td>1.51 (-0.73, 4.21)</td>
</tr>
<tr>
<td>Penetrating trauma</td>
<td>0.221</td>
<td>0.01 (-2.22, 2.49)</td>
</tr>
<tr>
<td>Blunt trauma</td>
<td>0.909</td>
<td>-0.11 (-1.66, 1.51)</td>
</tr>
<tr>
<td><strong>ICU</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISS&gt;15</td>
<td>&lt;0.001*</td>
<td>-3.00* (-4.61, -1.38)</td>
</tr>
<tr>
<td>NISS&lt;15</td>
<td>0.993</td>
<td>-0.57 (-5.48, 5.50)</td>
</tr>
<tr>
<td>Penetrating trauma</td>
<td>0.001*</td>
<td>-7.23* (-8.47, -5.90)</td>
</tr>
<tr>
<td>Blunt trauma</td>
<td>0.030*</td>
<td>-1.93* (-3.22, -0.59)</td>
</tr>
<tr>
<td><strong>Increasing MOI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knife</td>
<td>&lt;0.001*</td>
<td>7.46* (4.82, 10.81)</td>
</tr>
<tr>
<td>Hit by blunt object</td>
<td>0.006*</td>
<td>3.32* (1.54, 5.35)</td>
</tr>
<tr>
<td>GSW</td>
<td>&lt;0.001*</td>
<td>7.12* (4.82, 9.97)</td>
</tr>
<tr>
<td><strong>Decreasing MOI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCC</td>
<td>0.004*</td>
<td>-3.57* (-5.89, -1.26)</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>&lt;0.001*</td>
<td>-8.84* (-15.14, -2.80)</td>
</tr>
</tbody>
</table>

Table 2 – Chi-Squared test for trend and Annual average percentage change. AAPC = Annual average percentage change. CI = Confidence interval. NISS = New Injury Severity Score. ICU = Intensive care unit. MOI = Mechanism of injury. GSW = Gunshot wound. MCC = Motorcycle crash. * = p<0.05.
<table>
<thead>
<tr>
<th></th>
<th>2013 (n=1122)</th>
<th>2014 (n=1060)</th>
<th>2015 (n=1060)</th>
<th>2016 (n=1182)</th>
<th>2017 (n=1172)</th>
<th>2018 (n=1132)</th>
<th>2019 (n=1172)</th>
<th>2020 (n=1335)</th>
<th>2021 (n=1352)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blunt, n (%)</td>
<td>983 (87.6)</td>
<td>941 (88.8)</td>
<td>901 (85.0)</td>
<td>1006 (85.1)</td>
<td>972 (82.9)</td>
<td>923 (81.5)</td>
<td>918 (78.3)</td>
<td>1060 (79.4)</td>
<td>1087 (80.4)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Male sex, n (%)</td>
<td>705 (71.7)</td>
<td>658 (69.9)</td>
<td>630 (69.9)</td>
<td>707 (70.3)</td>
<td>680 (70.0)</td>
<td>641 (69.4)</td>
<td>635 (69.2)</td>
<td>729 (68.8)</td>
<td>748 (68.8)</td>
<td>0.118</td>
</tr>
<tr>
<td>NISS median (IQR)</td>
<td>17 (6-27)</td>
<td>17 (6-29)</td>
<td>17 (6-27)</td>
<td>17 (6-27)</td>
<td>17 (9-27)</td>
<td>17 (6-27)</td>
<td>17 (6-27)</td>
<td>17 (6-27)</td>
<td>17 (6-27)</td>
<td>0.188</td>
</tr>
<tr>
<td>Penetrating, n (%)</td>
<td>139 (12.4)</td>
<td>119 (11.2)</td>
<td>159 (15.0)</td>
<td>176 (14.9)</td>
<td>200 (17.1)</td>
<td>209 (18.5)</td>
<td>254 (21.7)</td>
<td>275 (20.6)</td>
<td>265 (19.6)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Male sex, n (%)</td>
<td>130 (93.5)</td>
<td>108 (90.8)</td>
<td>139 (87.4)</td>
<td>165 (93.8)</td>
<td>184 (92.0)</td>
<td>188 (90.0)</td>
<td>223 (87.8)</td>
<td>250 (90.9)</td>
<td>232 (87.5)</td>
<td>0.0991</td>
</tr>
<tr>
<td>NISS median (IQR)</td>
<td>13 (2-17)</td>
<td>17 (2-22)</td>
<td>14 (3-18)</td>
<td>15 (2-22)</td>
<td>16 (3-22)</td>
<td>13 (2-18)</td>
<td>13 (3-19)</td>
<td>13 (3-18)</td>
<td>13 (2-18)</td>
<td>0.024*</td>
</tr>
<tr>
<td>Laparotomy, n (%)</td>
<td>7 (5.0)</td>
<td>7 (5.9)</td>
<td>7 (4.4)</td>
<td>9 (5.1)</td>
<td>9 (4.5)</td>
<td>8 (3.8)</td>
<td>8 (3.1)</td>
<td>10 (3.6)</td>
<td>8 (3.0)</td>
<td>0.0991</td>
</tr>
<tr>
<td>Thoracotomy, n (%)</td>
<td>16 (11.5)</td>
<td>23 (19.3)</td>
<td>19 (11.9)</td>
<td>15 (8.5)</td>
<td>17 (8.5)</td>
<td>22 (10.5)</td>
<td>34 (13.4)</td>
<td>32 (11.6)</td>
<td>38 (14.3)</td>
<td>0.810</td>
</tr>
</tbody>
</table>

Table 3 – Incidence of blunt and penetrating trauma. IQR = Interquartile range. 1Chi-Squared test for trend. 2Kruskal-Wallis test. * = p<0.05.
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Population catchment area, n</td>
<td>2 508 523</td>
<td>2 546 986</td>
<td>2 585 603</td>
<td>2 630 433</td>
<td>2 677 114</td>
<td>2 720 478</td>
<td>2 760 794</td>
<td>2 780 384</td>
<td>2 810 165</td>
</tr>
<tr>
<td>Severe trauma, n</td>
<td>1122</td>
<td>1060</td>
<td>1060</td>
<td>1382</td>
<td>1172</td>
<td>1132</td>
<td>1172</td>
<td>1335</td>
<td>1352</td>
</tr>
<tr>
<td>Incidence rate per 100000 (95% CI)</td>
<td>45 (42-48)</td>
<td>42 (40-45)</td>
<td>41 (38-43)</td>
<td>45 (43-48)</td>
<td>43 (41-46)</td>
<td>42 (40-44)</td>
<td>42 (39-44)</td>
<td>48 (45-50)</td>
<td>48 (46-51)</td>
</tr>
</tbody>
</table>
