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Berg von Linde, Maria

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

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MARIA BERG VON LINDE

DEPARTMENT OF CLINICAL SCIENCES, MALMÖ | FACULTY OF MEDICINE | LUND UNIVERSITY

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An evidence-based approach to forensic assessments of single stab injuries to the trunk

Maria Berg von Linde
Medical doctor

DOCTORAL DISSERTATION

Doctoral dissertation for the degree of Doctor of Philosophy (PhD) at the Faculty of Medicine at Lund University to be publicly defended on 26 of February 2026, at 13.00 in Belfragesalen, Klinikgatan 32, Lund.

Faculty opponent
Professor Dr. Benjamin Ondruschka
Universitätsklinikum Hamburg-Eppendorf, Hamburg, Germany

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Abstract:

This thesis aims to strengthen the scientific basis for forensic assessments of single stab injuries to the trunk, which have traditionally been based upon professional experience rather than scientifically evaluated evidence. Using nationwide registries maintained by the Swedish National Board of Forensic Medicine, we conducted five studies including both fatalities and survivors of sharp force trauma, with the objectives of characterising injury patterns related to the injury causation (assaults or self-inflicted), grading injury severity, and develop systematic approaches to provide evidence-based forensic evaluations.

Most homicide victims were young males (odds ratio [OR] 4.2, 95 % confidence interval [CI] 1.7–10.4), typically found outdoors (OR 18.6, 95 % CI 6.6–52.2), being under the influence of alcohol (OR 7.1, 95 % CI 2.9–17.7) or illicit narcotics (OR 4.3, 95 % CI 1.5–11.9), and mostly transported to hospital before death (56.4 %). In contrast, suicides mainly died in their homes (79.5 %), and some cases due to only minor injuries (NISS ≤ 8) (8.9 %).

Based on the findings associated with homicides and suicides, respectively, we developed the *Manner of Death in Stab Injuries to the Trunk (MODSIT) score*, an evidence-based tool that in four models showed good to excellent performance in distinguishing manner of death. Receiver Operating Characteristic (ROC) analysis demonstrated excellent discriminatory ability (Area Under the Curve [AUC] 0.99, 95 % CI 0.97–1.00) for MODSIT score model 3 (injury characteristics, alcohol exposure and scene circumstances) distinguishing homicide from suicide.

To reduce the risk of classification bias inherent in research of fatalities, survived assaults verified by perpetrator confession or witness testimony were also analysed. Compared to homicides, survivors of assaults more often sustained stab wounds to the abdomen (OR 1.9, 95 % CI 1.1–3.1), left axillary region (OR 3.7, 95 % CI 1.5–8.8), or back (OR 3.7, 95 % CI 1.9–7.2), but less frequently to the ribcage (OR 0.2, 95 % CI 0.1–0.3).

Finally, we demonstrated in a ROC analysis that the trauma scoring system *New Injury Severity Score (NISS)* provided excellent predictive performance (AUC 0.94, 95 % CI 0.92–0.96) discriminating fatal from non-fatal injuries in the absence of life-saving intervention, supporting its potential application as a systematic tool in forensic life-threat assessments.

Together, these contributions provide characteristic findings and methodological tools that can complement expert opinion in forensic medicine. This thesis advances forensic medicine towards more consistent and evidence-based practice with the potential to strengthen fairness and reliability in the legal system.

Key words: Forensic pathology, Forensic Medicine, Autopsy, Sharp force, Stab injury, Single stab, Homicide, Suicide, Assault, Self-inflicted injury, Trauma score, New Injury Severity Score

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Maria Berg von Linde, M.D.

LUND UNIVERSITY

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Faculty of Medicine
Department of Clinical Sciences, Malmö

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“A mind needs books as a sword needs a whetstone, if it is to keep its edge.”

Tyrion Lannister, Game of Thrones.

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Article and manuscript overview

The thesis is based on the following original papers, which will be referred to in the text by their corresponding Roman numerals (**I–V**):

Paper I: Berg von Linde M, Acosta S, Khoshnood AM, Wingren CJ. A Swedish nationwide forensic study of the manner of death in single stab injuries to the trunk. *Forensic Sci Int*. 2024 Jan;354:111910. doi: 10.1016/j.forsciint.2023.111910. Epub 2023 Dec 10. PMID: 38096751.

Paper II: Berg von Linde M, Acosta S, Khoshnood AM, Wingren CJ. Lethal injuries in single stabs to the trunk - A study on homicides and suicides in Sweden. *Injury*. 2024 Aug;55(8):111694. doi: 10.1016/j.injury.2024.111694. Epub 2024 Jun 21. PMID: 38943797.

Paper III: Berg von Linde M, Acosta S, Khoshnood AM, Wingren CJ. A scoring system for assessing the Manner of Death in Stab Injuries to the Trunk (The MODSIT score). *Forensic Sci Int*. 2025 Sep 22;377:112666. doi: 10.1016/j.forsciint.2025.112666. Epub ahead of print. PMID: 41014683.

Paper IV: Berg von Linde M, Acosta S, Khoshnood AM, Wingren CJ. Single stab injuries to the trunk in survivors of corroborated assaults. *Int J Legal Med*. 2025 Oct 23. doi: 10.1007/s00414-025-03629-5. Epub ahead of print. PMID: 41125970.

Paper V: Berg von Linde M, Acosta S, Khoshnood AM, Wingren CJ. Forensic life-threat assessments using trauma scoring in single stabs to the trunk. *Manuscript submitted in September 2025.*

Relevant article not included in this thesis:

Berg von Linde M, Wingren CJ. Single stab injuries to the trunk - A meta-analysis on two recently published articles. Leg Med (Tokyo). 2024 Jul;69:102439. doi: 10.1016/j.legalmed.2024.102439. Epub 2024 Mar 26. PMID: 38547643.

Abstract

This thesis aims to strengthen the scientific basis for forensic assessments of single stab injuries to the trunk, which have traditionally been based upon professional experience rather than scientifically evaluated evidence. Using nationwide registries maintained by the Swedish National Board of Forensic Medicine, we conducted five studies including both fatalities and survivors of sharp force trauma, with the objectives of characterising injury patterns related to the injury causation (assaults or self-inflicted), grading injury severity, and develop systematic approaches to provide evidence-based forensic evaluations.

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Together, these contributions provide characteristic findings and methodological tools that can complement expert opinion in forensic medicine. This thesis advances forensic medicine towards more consistent and evidence-based practice with the potential to strengthen fairness and reliability in the legal system.

Overview of paper I-V

	Paper I	Paper II	Paper III	Paper IV	Paper V
Aim	Identifying forensic characteristics that differentiate homicidal from suicidal stabs	Evaluating injury severity and internal in homicidal and suicidal stabs	Develop an evidence-based composite score that predicts the manner of death in stab injuries	Revisiting forensic characteristics associated with stabs in assaulted survivors	Finding a systematic evidence-based tool that defines life-threatening injuries
Study group	Homicides and suicides	Homicides and suicides	Homicides and suicides	Assaults and homicides	Fatalities and survivors
Variables	Age, sex, context at the death scene, injury characteristics, toxicological results	Age, sex, organ and vessel damage, AIS, NISS, medical care	Age, sex, context at the death scene, injury characteristics, alcohol	Age, sex, context at the scene, injury characteristics, toxicological results	Age, sex, organ and vessel damage, NISS, medical interventions
Statistical methods	Fisher's exact test, logistic regression	Fisher's exact test	ROC analysis	Fisher's exact test, logistic regression	Chi-square test, ROC analysis
Highlight	Typical homicide victims were young, intoxicated males found outdoors	Suicides mainly died at the scene, a few from minor injuries, whereas homicides mostly died in hospital	The score models showed good to excellent performance in predicting manner of death	Assaulted and homicide victims had similar demographics and injury characteristics, but more stabs to the bones of the ribcage in homicides	NISS showed excellent performance in predicting fatal outcomes without lifesaving intervention

AIS, Abbreviated Injury Scale; NISS, New Injury Severity Score; ROC, receiver operating characteristic.

Populärvetenskaplig sammanfattning på svenska

Rättsläkare är experter på att bedöma hur skador uppstått, om de varit livshotande och vilken skada som orsakat ett dödsfall. Vid en obduktion förväntas rättsläkaren dessutom ta ställning till om dödsfallet är ett mord, självmord, olycka eller en följd av sjukdom. När brottsoffer som överlevt ett överfall undersöks ska skadorna dokumenteras och bedömas i ett rättsintyg. De rättsmedicinska utlåtandena i obduktionsrapporter och rättsintyg kan sedan användas som bevis i rättsprocessen och kan få en avgörande betydelse för både skuldfrågan och straffets längd. Trots detta bygger rättsmedicinska bedömningar som regel på rättsläkarens erfarenhet och intuition, snarare än på etablerade metoder baserat på forskning. Detta kan leda till variationer av utlåtanden mellan olika rättsläkare och därmed en risk för orättvisa i rättsprocessen.

Denna avhandling syftar till att skapa vetenskapligt underlag och utifrån dessa ta fram nya metoder som kan användas för att skapa mer enhetliga rättsmedicinska bedömningar, med fokus på en särskilt svårbedömd skadebild – enskilda stickskador på bålen. Dessa kan uppstå både genom självtillfogade handlingar och genom våld av annan person, och i sällsynta fall genom olyckor. Att skilja mellan dessa uppkomstsätt kan bli särskilt utmanande för rättsläkaren då det endast finns en skada att utgå ifrån.

Genom fem delstudier har vi analyserat skademönster, omständigheter vid platsen för händelsen och den medicinska vård som givits, både hos avlidna och överlevda fall med enskilda stickskador på bålen.

I **Delstudie I** kartlades skillnader mellan mord och självmord utifrån omständigheter vid skadeplatsen, obduktionsfynd, och analysresultat av alkohol och narkotika. Vi upptäckte följande skillnader: mordoffer var oftare unga män, påträffades utomhus med alkohol i kroppen och hade stickskadorna utspridda på hela bålen, medan de flesta självmordsoffer hittades i hemmet med skador på bröstet eller buken.

I **Delstudie II** jämförde vi inre skador, medicinsk behandling och skadornas svårighetsgrad mellan mord och självmord. Vi använde ett internationellt etablerat poängsystem som utvecklats för att mäta skadors svårighetsgrad. Det visade sig att de flesta självmordsoffer dog på skadeplatsen, ofta med skador på hjärtat samt ett fåtal fall som avlidit till följd relativt lindriga skador, och som förmodligen hade överlevts om vård hade tillkallats i tid. Mordfallen däremot, avled oftast på sjukhus till följd av skador på stora kärl trots akut behandling.

I **Delstudie III** utvecklade vi ett poängsystem som väger samman flera olika fynd – skademönster, omständigheter vid skadeplatsens, alkoholpåverkan, och demografi – för att systematiskt kunna skilja mellan mord och självmord. Verktyget visade god till utmärkt träffsäkerhet.

I **Delstudie IV** granskades överlevda fall med särskilt fokus på de fall där det var bekräftat att skadan orsakats av en annan person, antingen genom att gärningspersonen erkänt eller att händelsen bevittnats. Detta ökade studiens tillförlitlighet, eftersom det med hög säkerhet kunde fastställas att skadorna orsakats av annan person till skillnad från studier som endast utgår från rättsläkarens bedömning. Vi jämförde även överlevande offer med dödliga mordfall. Det visade sig att överlevda fall oftare hade skador på buken, vänster sida av bålen och ryggen, medan mordoffer oftare hade skador genom bröstkorgens skelettdelar.

I **Delstudie V** undersökte vi hur väl det system som poängsätter skadors svårighetsgrad, som även användes i delstudie II, kan förutsäga risken att en person dör av sina skador om ingen livräddande behandling ges. Resultaten visade att poängsystemet har utmärkt träffsäkerhet, vilket påvisar dess potential som stöd i rättsmedicinska bedömningar av livshot. Sammanfattningsvis visar resultaten hur rättsmedicinska utlåtanden vid enskilda stickskador i bålen kan göras mer grundat baserad på forskning. Genom att använda systematiska verktyg skulle rättsläkare, utöver sin erfarenhet, kunna stödja sina bedömningar på objektiva och kvantifierbara kriterier när de ska avgöra hur en skada uppkommit och om den varit livshotande. Denna avhandling bidrar därmed inte bara till att utveckla nya metoder för att bedöma just enskilda stickskador på bålen, utan representerar ett principiellt viktigt steg mot en mer enhetlig och vetenskapligt grundad rättsmedicin.

Populärwissenschaftliche Zusammenfassung auf Deutsch

Rechtsmediziner:innen sind Expert:innen darin, zu beurteilen, wie Verletzungen entstanden sind, ob sie lebensbedrohlich waren und welche Verletzung letztlich zum Tod geführt hat. Bei einer Obduktion wird zudem erwartet, dass der/die Rechtsmediziner:in im Obduktionsbericht festhält, ob der Tod auf einen Mord, einen Selbstmord, einen Unfall oder eine Krankheit zurückzuführen ist. Bei der Untersuchung lebender Gewaltopfer werden die Verletzungen untersucht, dokumentiert und in einem rechtsmedizinischen Gutachten beurteilt. Die rechtsmedizinischen Stellungnahmen in Obduktionsberichten und Gutachten können anschließend als Beweismittel in Gerichtsverfahren verwendet werden und können entscheidenden Einfluss sowohl auf die Schuldfrage als auch auf das Strafmaß haben. Die heutigen rechtsmedizinischen Beurteilungen beruhen in der Regel eher auf der Erfahrung und Intuition der Rechtsmediziner:innen als auf etablierten, wissenschaftlich fundierten Methoden. Dies kann zu Unterschieden zwischen den Beurteilungen verschiedener Fachpersonen führen und damit ein Risiko für Ungerechtigkeit im Rechtsprozess darstellen.

Diese Dissertation hat zum Ziel, eine wissenschaftliche Grundlage zu schaffen und darauf aufbauend neue Methoden zu entwickeln, die zu einheitlicheren rechtsmedizinischen Beurteilungen beitragen können. Der Fokus liegt dabei auf einem besonders schwer zu beurteilenden Verletzungstyp – einzelne Stichverletzungen am Rumpf. Solche Verletzungen können sowohl durch selbst ausgeführte Handlungen als auch durch Gewalt durch andere Personen und in seltenen Fällen durch Unfälle entstehen. Zwischen diesen Entstehungsweisen zu unterscheiden, kann für die Rechtsmedizin insbesondere dann eine Herausforderung sein, wenn nur eine einzige Verletzung als Ausgangspunkt vorliegt.

In fünf Teilstudien wurden Verletzungsmuster, Umstände am Ereignisort und die geleistete medizinische Versorgung sowohl bei Verstorbenen als auch bei Überlebenden mit einzelnen Stichverletzungen am Rumpf analysiert.

In **Teilstudie I** wurden Unterschiede zwischen Mord und Selbstmord anhand der Umstände am Ereignisort, der Obduktionsbefunde, sowie der Analyseergebnisse von Alkohol und Betäubungsmitteln untersucht. Dabei zeigten sich folgende Unterschiede: Mordopfer waren häufiger junge Männer, wurden im Freien mit Alkohol im Blut aufgefunden und wiesen über den gesamten Rumpf verstreute Verletzungen auf, während die meisten Selbstmordopfer zu Hause mit Verletzungen im Bereich von Brustkorb oder Bauch gefunden wurden.

In **Teilstudie II** wurden innere Verletzungen, medizinische Behandlung und der Schweregrad der Verletzungen zwischen Mord- und Selbstmordfällen verglichen. Zur Bestimmung des Schweregrades der Verletzungen wurde ein international etabliertes Punktesystem zur Bewertung der Verletzungsschwere verwendet. Es zeigte sich, dass die meisten Selbstmordopfer am Ereignisort verstarben, häufig mit Herzverletzungen, und dass es einige Fälle mit relativ geringfügigen Verletzungen gab, die vermutlich überlebt hätten, wenn rechtzeitig medizinische Hilfe in Anspruch genommen worden wäre. Die Mordopfer hingegen verstarben überwiegend im Krankenhaus infolge von Verletzungen großer Gefäße trotz sofort eingeleiteter Notfallbehandlung.

In **Teilstudie III** wurde ein Punktesystem entwickelt, das mehrere verschiedene Befunde – Verletzungsmuster, Umstände am Ereignisort, Alkoholeinfluss und demografische Faktoren – zusammenführt, um systematisch zwischen Mord und Selbstmord unterscheiden zu können. Dieses Instrument zeigte eine gute bis ausgezeichnete Treffsicherheit.

In **Teilstudie IV** wurden überlebende Fälle untersucht mit besonderem Fokus auf diejenigen, bei denen bestätigt war, dass die Verletzung von einer anderen Person verursacht worden war, etwa durch ein Geständnis des/der Täter:in oder durch Zeugenaussagen. Auf diese Weise erhöhte sich die Verlässlichkeit der Studie, da die Entstehungsweise der Verletzungen mit hoher Sicherheit festgestellt werden konnte, im Gegensatz zu Studien, die sich ausschließlich auf rechtsmedizinische Einschätzungen stützen. Außerdem wurden überlebende Opfer mit tödlich verlaufenen Mordfällen verglichen. Es zeigte sich, dass Überlebende häufiger Verletzungen im Bauch, an der linken Rumpfseite und am Rücken aufwiesen, während Mordopfer häufiger Verletzungen durch knöcherne Strukturen des Brustkorbs hatten.

In **Teilstudie V** wurde untersucht, wie gut das Punktesystem zur Bewertung der Verletzungsschwere, das auch in Teilstudie II verwendet wurde, die Sterblichkeit prognostizieren kann, wenn keine lebensrettenden Maßnahmen ergriffen werden. Die Ergebnisse zeigten, eine ausgezeichnete Vorhersagegenauigkeit und unterstreichen das Potenzial dieses Systems als Unterstützung bei rechtsmedizinischen Beurteilungen des Lebensbedrohlichkeitsgrades von Verletzungen.

Zusammenfassend zeigen die Ergebnisse der Studien, wie rechtsmedizinische Gutachten bei einzelnen Stichverletzungen am Rumpf stärker auf wissenschaftlicher Grundlage durchgeführt werden können. Durch den Einsatz systematischer Instrumente könnten Rechtsmediziner:innen sich neben ihrer Erfahrung zusätzlich auf objektive und quantifizierbare Kriterien stützen – sowohl bei der Beurteilung der Entstehungsweise als auch des Schweregrades von Verletzungen. Diese Dissertation trägt somit nicht nur zur Entwicklung neuer Methoden zur Beurteilung einzelner Stichverletzungen am Rumpf bei, sondern stellt auch einen grundsätzlich wichtigen Schritt hin zu einer einheitlicheren und wissenschaftlich fundierteren Rechtsmedizin dar.

Abbreviations

AIS	Abbreviated Injury Score
AUC	Area Under the Curve
CI	Confidence Intervals
ICC	Intra-class Correlation Coefficient
ICD	International Classification of Diseases
IQR	Interquartile Range
ISS	Injury Severity Score
MODSIT	Manner of Death in Stab Injuries to the Trunk
NISS	New Injury Severity Score
OR	Odds Ratio
Ref	Reference
ROC	Receiver Operating Characteristic

Introduction

Causation of sharp force injuries

Sharp force violence remains the predominant mechanism of fatal interpersonal violence in Europe (1–3) which could be a result of the restrictive firearm legislation (4–6). In Sweden however, sharp force violence has been the second most common cause of homicide since the late 2010s, surpassed by the rise in firearm-related fatalities (7–9). Nevertheless, when adjusted for population size, the proportion of fatal sharp force injuries in Sweden remains comparable to that reported in Denmark, Norway, and other Western European countries (10). Although suicides involving sharp objects constitute only a few percentages of all suicidal deaths (11,12), self-inflicted sharp force injuries account for a substantial share, comprising 15–24 %, of all patients treated for sharp force trauma in clinical settings (13–15).

Forensic pathologists are tasked with determining the causation of injuries, whether these are self-inflicted or inflicted in an assault, which can be challenging in cases of stab injuries if the injury pattern or the contextual circumstances are lacking or ambiguous (16–22). Previous studies have identified injury characteristics typically associated with assault, such as defensive injuries on the ulnar sides of the forearms or on the on the palms, reflecting attempts to ward off the attacker, stab injuries located in the back, vertical oriented entrance wounds and injuries to the bones or cartilage of the ribcage (23–36). In contrast, hesitation injuries, which are typically superficial, parallel incisions located on the flexor sides of the forearms or around the primary wound, stab wounds located in the left precordial region, horizontally oriented entrance wounds, and injuries through the intercostal space are associated with suicide (26–34,37,38). In addition to injury characteristics, contextual findings at the scene have also been investigated. In homicide cases, the stab is typically inflicted through clothing and the perpetrator usually disposes the weapon, whereas in suicides the victim often inflicts the wound while exposing the skin of the stabbing area (24,26,29,31,32,34,39). Assaulted victims are often attacked outdoors under influence of alcohol, while suicide victims are most commonly found in their own homes (15,26,29,33,37,39,40).

Although these studies provide some guidance, their rather small sample sizes and limited specificity of most observed injury characteristics and contextual findings, restrict their usefulness in distinguishing between manners of death (Table 1). Also, the assessments of injury characteristics and scene circumstances, rely largely on the professional experience of the forensic pathologists rather than evidence-based data (41), which risks inconsistency across cases (42). Efforts have been made to rank the strength of association of individual variables (26), but to our knowledge no previous study has systematically scaled the assessment of manner of death by combining these variables (Table 1).

Secondly, it should be noticed that previous studies within the area are almost exclusively based on autopsy populations. The restriction to autopsy cases does not just introduce a selection bias by excluding the variation of survived injuries but are also limited by potential circular reasoning since the manner of death is defined by the forensic pathologists which possibly introduces misclassification. In other areas of forensic medicine, this issue has been addressed by including cases with greater certainty regarding the causation of injuries, by accounting for those in which the perpetrator confessed, the event was witnessed, or the act was filmed (43,44). Such cases increase the robustness of evidence-based forensic medicine, as the forensic pathologist's assessment is corroborated by external evidence and this approach can therefore be considered as gold standard (Table 1).

Injury severity

Forensic pathologists are expected to assess which injuries that are 'fatal' in autopsy cases of traumatic deaths and if injuries in cases of survivals of violent crimes are considered 'life-threatening injuries'. A fatal injury is the one injury that has caused death, either by a direct causal link such as a stab lesion resulting in fatal hemorrhage, or by initiating the causal chain leading to death, such as a stab injury resulting in an infection as a secondary complication (45). In some cases, several injuries may each have been sufficient to cause fatal outcomes independently, whereas in others, the injuries may be considered fatal only in combination. The presence of multiple independently fatal injuries, may support legal interpretations of sustained or excessive violence, whereas less severe injuries that are fatal only when combined might suggest a lower degree of force or intent (46,47). A life-threatening injury is forensically defined as an injury that carries a considerable risk of death in the natural course if left without medical treatment (41,48). Such assessments are key factors in determining the seriousness of assaults in both fatalities and survivors, thereby influencing the legal classification of the crime, which in turn affects the allocation of judicial resources and the sentencing of the offender (49,50).

According to national and international consensus, life-threatening injuries include perforations of the pleura with associated pneumothorax, injuries to thoracic or abdominal organs, and lacerations of major vessels (51,52), or injuries that require emergency treatment including surgery or blood transfusion (49). However, these consensus statements are largely based on expert opinions and include general criteria that are not entirely equivalent in their definitions. Consequently, despite their comprehensiveness, they lack the reproducibility and quantifiable precision required for consistent application in forensic assessments. This underscores the need for evidence-based research to establish systematic and verifiable methods for assessing life-threatening and fatal injuries, thereby promoting fairness in judicial outcomes.

Trauma scoring systems, originally developed for trauma management, have been applied in forensic autopsy populations (46,47,53–57) and in forensic clinical settings (51,58,59) to systematically determine injury severity. Nevertheless, the challenge remains to adapt the trauma scores, which are developed and validated in hospitalised trauma populations (60–68), to assess the natural course of injuries. Still, these studies illustrate how scoring systems, such as New Injury Severity Score (NISS), can systematize and quantify forensic assessments, thereby systematize assessments of injury severity (Table 1).

Single stab injuries to the trunk

This thesis focuses on single stab injuries to the trunk as a model for developing evidence-based approaches in forensic medicine. Even if this particular injury pattern remains comparatively underexplored, with only a few previous studies based on small sample sizes (69–71), such a clearly delineated population provides an opportunity to explore the principles of systematic and reproducible forensic assessment of sharp force trauma. The rationale for studying this specific injury pattern is twofold. First, single stab injuries can be particularly challenging in forensic assessment of the causation, whether an assault or self-inflicted act, since the anatomical distribution and injury characteristics can be evaluated based on a single injury. Second, limiting the study to isolated stab wounds to the thorax and/or abdomen reduces potential confounding factors introduced by multiple injuries, by involvement of different anatomical locations and by diverse mechanisms of trauma. This focused approach not only enables more precise comparisons of injury severity and characteristics but also serves as a foundation for building broader, evidence-based knowledge applicable to the forensic assessment of sharp force injuries in general.

Use of artificial intelligence

The author of this dissertation has utilised the generative artificial intelligence model ChatGPT-5.1 solely as a support tool for English language assistance. Following its use, the author reviewed and edited all text and takes full responsibility for the content of the dissertation.

Aims

The overall aim of this thesis was to strengthen the scientific basis for forensic assessments by using single stab injuries to the trunk as a model for developing evidence-based approaches in forensic medicine. By integrating survivors and fatalities, incorporating corroborated cases to reduce misclassification bias, and developing and evaluating structured tools such as scoring systems, the thesis seeks to promote greater uniformity in forensic assessments and thereby reinforce the rule of law (Table 1). Specifically, the objectives were to:

I. Identify injury characteristics and circumstances at the death scene that distinguish homicides from suicides, thereby strengthening the evidence basis for manner of death assessments.

II. Examine differences in internal injuries, NISS, and medical care between homicides and suicides, to clarify if variables related to injury severity are also associated with the manner of death.

III. Develop a systematic and reproducible scoring tool by integrating variables characteristic of homicides and suicides – the Manner of Death in Stab Injuries to the Trunk (MODSIT) score – with the aim of improving consistency in manner of death assessments.

IV. Investigate whether injury characteristic and scene circumstances observed in homicides are generalisable to survivors of assaults, focusing on confessed and/or witnessed assaults to reduce possible misclassification.

V. Evaluate the predictive performance of NISS for estimating fatal injuries in the absence of life-saving interventions, with the aim of adapting a trauma scoring system to use as a quantifiable tool in forensic life-threat assessments.

Table 1. Forensic assessments, established findings and remaining knowledge gaps addressed in this thesis

Forensic assessment	Established findings	Knowledge gaps and limitations	Addressed in Thesis (Paper I–V)
Manner of death	Autopsy studies describe injury characteristics and contextual findings typical for homicide/suicide.	Circular reasoning. Rather small sample sizes. Lack of systematic combination of variables into a reproducible tool	Paper I (injury and contextual characteristics). Paper III (MODSIT score – systematic tool).
Causation of survived injuries	Few forensic studies on surviving victims.	Reliance on findings from autopsy cases. Circular reasoning with lack of gold standard as reference cases.	Paper IV (survivors of assault with focus on confession/witnessed cases).
Injury severity	Consensus statements defining life-threatening injuries. Trauma scoring systems widely used for trauma management to quantify severity.	No standardised method for assessments. Trauma scores are designed for treated trauma patients, not for natural course of untreated injuries.	Paper II (application of NISS in autopsies). Paper V (NISS adapted for forensic life-threat assessments).

Summary of key areas relevant to forensic assessment of sharp force injuries to the trunk. The table outlines established findings from previous research, identifies remaining limitations and knowledge gaps, and indicates how these were addressed through the five studies included in this thesis (Papers I–V).

MODSIT, Manner of Death in Stab Injuries to the Trunk; NISS, New Injury Severity Score

Materials and methods

Study population

This thesis is based on five retrospective studies (Papers I–V), all conducted using data, documents and image material available from registries maintained by the Swedish National Board of Forensic Medicine, encompassing all six forensic institutions in Sweden. The studies cover the period between 2010 and 2021 for fatalities, and 2016 to 2021 for survivors.

The forensic autopsy register, including all forensic autopsies performed in Sweden, was used to identify fatalities due to single stabs to the stunk. We applied the International Classification of Diseases 9th edition (ICD-9) codes for sharp force injuries and causes of death ascribed to injuries to the trunk for a primary selection of relevant cases before reviewing the cases manually. Homicidal and suicidal victims aged at least 15 years with a single stab injury to the trunk as primary cause of death were included. Cases of accidental or undetermined deaths, and cases in which the number of stab injuries could not be determined, because of decomposition or severe fire damage, were excluded. In total, 139 fatalities met the inclusion criteria.

The registry of clinical forensic examinations covers all police-requested forensic examinations of surviving victims nationwide. Each such examination results in a clinical forensic report written by forensic pathologists based on injuries observed during the forensic body examinations, in photographs of injuries and/or in medical records. We searched the reports using various Swedish terms describing stab injuries (e.g., the Swedish equivalents of stab wound, knife stab, sharp-edged), after which all cases were manually reviewed. Survivors aged fifteen years or older with a single stab injury to the trunk were included, yielding a total of 408 cases.

Across the five studies, different subsets of these two populations of fatalities and survivors were analysed (Table 2). **Paper I–III** were all based on the fatalities, including 94 homicides and 45 suicides. **Paper IV** focused on 385 survivors of assault. These assaults were stratified into corroborated cases, defined by the presence of a perpetrator's confession and/or eyewitness testimony, and non-corroborated cases. Additional subgroup analyses were performed for assaults that were exclusively either confessed or witnessed (but not both). A homicide reference group was included for comparison. **Paper V** combined the populations of fatalities (n = 139) and survivors (n = 408). Fatalities were stratified by whether the victim was found within 24 hours of the stabbing event or later, while survivors were stratified according to the complexity of medical interventions: no or minimal interventions, moderate interventions, and life-saving interventions (the definitions of these subgroups are specified under the headline *variables*). In addition, fatal injuries were defined as survived injuries requiring life-saving interventions or autopsy cases where the victim was found dead within 24 hours of the stabbing, or non-fatal, defined as survived injuries requiring no, minimal, or moderate interventions (similar definitions of fatal and non-fatal injuries were previously described by Wingren CJ (41)).

Table 2. Study populations of Paper I–V

	Paper I	Paper II	Paper III	Paper IV	Paper V
Registry	Autopsy registry (2010–2021)	Autopsy registry (2010–2021)	Autopsy registry (2010–2021)	Clinical registry (2016–2021)	Autopsy (2010–2021) and clinical registry (2016–2021)
Sample size	n = 139	n = 139	n = 139	n = 385	n = 547
Study groups	Homicide and suicide victims	Homicide and suicide victims	Homicide and suicide victims	Assaulted survivors (homicides as reference)	Fatalities and survivors
Analyses in subgroups	-	-	-	Corroborated and non-corroborated assaults. Confessed assaults only. Witnessed assaults only.	Fatalities found within or more than 24 hours after the stab. Survivors with no/minimal, moderate or life-saving interventions. Fatal and non-fatal injuries.

Overview of data sources, sample sizes, study groups, and subgroup stratifications across the five studies.

Variables

Across the five studies, variables were extracted from material available from the registries, including autopsy reports, forensic documentation of the scene, clinical forensic reports, police records, medical, psychiatric and ambulance records, and photographic documentation. The variables fell into the following main categories: demographics, psychiatric history, scene circumstances, toxicology, injury characteristics, injury severity, and medical care. All variables, their subcategories, and data source is provided in Table S1 (supplementary table) and described below.

Demographic variables included age, as a continuous variable and categorically whether < 30 years or ≥ 30 years, and sex (male or female). These variables were extracted from the personal identity number stated in the registries.

Information on presence of any psychiatric diagnosis was collected from medical records among survivors and psychiatric records among the fatalities.

Variables describing the contextual circumstances were based on police reports, forensic examination of the scene, photographic documentation and ambulance records. Scene of event was classified as the victim's home, other indoor location (such as stairwell, workplace, public indoor area), or outdoors (including courtyards and gardens). The alleged sharp weapon was categorised into found in situ in the body, found elsewhere at the scene, or not found. If no information was available about if the weapon was obtained, the variable was categorised as not found. Injury through clothing described whether the stab perforated the victim's clothing, absence of injury in clothing, or if the victims did not wear clothing at the upper body. Suicide note was recorded as present when any written message indicating suicidal intent was documented at the scene.

Toxicological variables were extracted from forensic toxicology records (among fatalities) or hospital records (among survivors). Influence of alcohol and/or illicit narcotics (amphetamine, cocaine, tetrahydrocannabinol, heroin) were defined as any detection of these substances or self-reported consumption in connection with the stabbing event.

Information on the anatomical and morphological characteristics of the stab injuries and presence of defensive and/or hesitation injuries was extracted from autopsy and clinical forensic reports, medical records and photographic documentation. Anatomical location of the entrance wound was partitioned into different categories, including thorax or abdomen, anterior trunk, right axillary region, left axillary region, or posterior trunk and midline and left side of the thorax at the frontal trunk or other area at the frontal trunk.

Penetration into the thoracic and/or abdominal cavity was recorded as present or absent. Stabs penetrating the thoracic wall were also defined whether the stab involved any bony or cartilaginous structures (ribs, sternum, scapula) or passed through the intercostal space. Orientation of entrance wound was categorised as horizontal, vertical, diagonally downward-right, or diagonally downward-left. Length of the injury channel was recorded in cm. Orientation of injury channel was recorded in the sagittal plane (cranial, caudal, or horizontal) and the horizontal plane (medial, lateral, or straight sagittal).

Defensive injuries were defined as present when typical appearance of such injuries were seen or described, such as fresh sharp force injuries on the palms or ulnar aspects of the forearms. Hesitation injuries were defined as present if characteristic self-inflicted injuries were identified, such as superficial, parallel, incisions located near the stab wound or on the flexor side of the forearms.

Injury severity was assessed by trauma scoring using the NISS and classification of the damaged organs and vessels, which were obtained from autopsy and clinical forensic reports, and medical records.

NISS is a modification of the Injury Severity Score (ISS) and is designed to quantify anatomical injury severity by summing the squared Abbreviated Injury Scale (AIS) scores (72) of the three most severely injured body structures, irrespective of body region (73,74). NISS was categorised into intervals of potential survivable (NISS < 75) or unsurvivable injuries (NISS = 75), and also minor (NISS ≤ 8), moderate (NISS 9–15), severe (NISS 16–24), or critical injuries (NISS 25–74). Organ injuries specified involvement of heart, lung(s), liver, spleen, pancreas, stomach and/or intestines, or urogenital system. Injuries to all anatomically named vessels were recorded.

The time from the stabbing event until death among the fatalities was collected from the police reports and was based on the time when the victims were last seen unharmed and when the victim was found dead. These cases were categorised into victims found ≤ 24 hours after the stabbing event or found > 24 hours after the event.

Information on medical care was extracted from medical and ambulance records. Type of care received was classified as hospital care, including medical interventions such as surgery, thoracic drainage, blood transfusion, prehospital care only, or no medical care in cases where the bodies are found dead at the scene. The complexity of medical interventions was classified as no/minimal, moderate, or life-saving interventions. No or minimal interventions encompassed cases with no treatment, suturing of injuries, prophylactic antibiotics, or exploratory surgery without therapeutic intervention. Moderate interventions included interventional surgery, endovascular therapy, or blood transfusion in the absence of major bleeding, major haemothorax, or tension pneumothorax. Life-saving interventions were defined as cases with immediate life-threatening conditions including major bleeding, major haemothorax, or tension pneumothorax that required surgical intervention and/or endovascular therapy.

In all the papers (**Paper I–V**), variables concerning demographics were included, psychiatric history was included in **Paper I and IV**, circumstances at the scene, toxicology and injury characteristics were included in **Paper I, III and IV**, and injury severity and medical care were included in **Paper II and V** (Table 3).

Table 3. Variables included in Paper I–V

Variables	Paper I	Paper II	Paper III	Paper IV	Paper V
Demographics					
Age	X	X	X	X	X
Sex	X	X	X	X	X
Psychiatric history					
Psychiatric diagnosis	X			X	
Circumstances					
Death scene	X		X	X	
Object found	X		X	X	
Stab through clothing	X			X	
Suicide letter	X		X		
Toxicological analyses					
Alcohol	X		X	X	
Illicit drugs	X			X	
Injury characteristics					
Anatomical location	X		X	X	
Penetrating the thoracic and/or abdominal cavity	X			X	
Injury to the thoracic wall	X		X	X	
Orientation of the entrance wound	X		X	X	
Length of the injury channel	X			X	
Orientation of injury channel	X			X	
Defensive injuries	X		X	X	
Hesitation injuries	X		X		
Severity					
Organ and vessel injuries		X			
NISS		X			X
Time until death					X
Medical care					
Type of care		X			
Complexity of medical interventions					X

Overview of variables extracted across the five studies, grouped into demographics, circumstances at the scene, toxicology, injury characteristics, injury severity, and medical care.

NISS, New Injury Severity Score

Statistical analyses

Descriptive statistics were applied to summarise demographics, contextual circumstances, injury characteristics, toxicology, injury severity, and medical care variables across the study populations (**Paper I–V)**. Categorical variables were presented as numbers and percentages, while continuous variables were reported as medians with ranges. Comparisons between groups were performed using Chi-square or Fisher's exact test for categorical variables and the Mann–Whitney U test for comparisons between two groups or Kruskal–Wallis test for comparisons involving more than two groups for continuous variables. A p-value of <0.05 was considered statistically significant.

In **Paper I, IV and V**, univariable logistic regression models were applied to evaluate associations between variables and outcomes such as manner of death (homicide vs. suicide, Paper I), assault classification (corroborated vs. non-corroborated, assaulted survivors vs. homicide, Paper IV) and mortality in the natural course of injuries (fatal vs. non-fatal injuries, Paper V). The multivariable regression analyses included gender, age, psychiatric history, and abuse of alcohol and/or narcotics as covariates when examining associations between the variables and outcomes related to injury causation (manner of death and assault classification). Age and gender were included as covariates when examining associations between NISS categories and mortality in the natural course of injuries. Covariates were excluded from the multivariable analysis if > 50 % of the data were missing within any outcome group. Odds ratios (OR) were reported with 95% confidence intervals (CI).

In **Paper III**, a new tool for manner of death assessment, the *MODSIT score*, was developed. Variables found to be significantly associated with homicide or suicide in Paper I were combined into score models. Variables significantly associated with homicide were assigned positive point values, while variables associated with suicide were assigned negative values. Variables with ≤ 90% specificity for homicide were assigned 1 point, those in the range between > 90% and ≤ 95% specificity were assigned 2 points, and those with > 95% specificity were assigned 3 points. The same logic was applied to variables associated with suicide, which were given –1, –2, or –3 points depending on their specificity. The following four score models were built: model 1 including only autopsy findings, model 2 including autopsy and alcohol findings, model 3 including autopsy, alcohol and scene circumstantial findings and model 4 including autopsy, alcohol and scene circumstantial findings and demographics. Variables in Paper I with more than 30 % missing data were excluded from the score models. Additionally, we did not include influence of illicit narcotics because it was deemed too context-specific, reflecting the local patterns of substance use within a particular period of time (75–78), thereby limiting its transferability to other forensic populations. Diagnostic performance was evaluated for each score model using Receiver Operating Characteristic (ROC) analysis to calculate the Area Under the Curve (AUC). The interpretation of AUC values followed established conventions, with scores of 0.90–1.00 considered excellent, 0.80–0.90 good, 0.70–0.80 fair, 0.60–0.70 poor, and 0.50–0.60 indicative of failed discrimination (79). Sensitivity, specificity, accuracy and Youden's Index were calculated for the cut-off scores of the model with the best diagnostic performance after cross-tabulation against previously assessed homicide and suicide cases (Figure 1) (80).

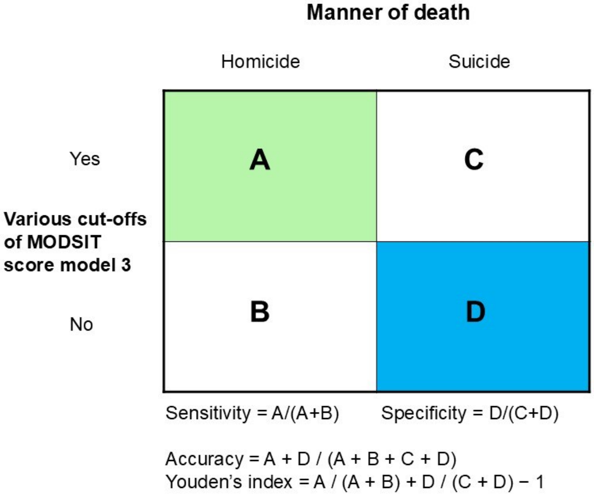

Figure 1. Four-field contingency table illustrating the calculation of sensitivity, specificity, accuracy and Youden's Index for cut-offs from the MODSIT score model with the best diagnostic performance in predicting manner of death.
Cells represent homicides meeting the score cut-off (A), homicides not meeting the score cut-off (B), suicides meeting the score cut-off (C), and suicides not meeting the score cut-off (D).
MODSIT, Manner of Death in Stab Injuries to the Trunk

The MODSIT score models were validated in the population of survivors of corroborated and non-corroborated assaults. Score distributions were presented using boxplots visualizing median values, minimum, maximum, and interquartile ranges (IQRs). We also calculated the number and percentage of the corroborated and non-corroborated assaults that met the optimal threshold score from the score model with the highest diagnostic performance in predicting homicides from the autopsy population.

In **Paper II and V**, the cases were scored according to NISS by the first author during residency in forensic pathology. To assess inter-rater reliability, 20 autopsy cases were randomly selected and independently scored by a second rater, a co-author and board-certified specialist in emergency medicine. Prior to scoring, detailed criteria for all relevant AIS codes were agreed upon (81). Inter-rater reliability of NISS was evaluated using the intra-class correlation coefficient (ICC) with 95% CI. An ICC > 0.70 was considered acceptable (82).

In **Paper V**, predictive performance of the NISS to estimate fatal injuries in the natural course was evaluated using ROC analysis to calculate the AUC. Sensitivity, specificity, accuracy and Youden's Index were calculated for all possible cut-off scores (Figure 2) (80).

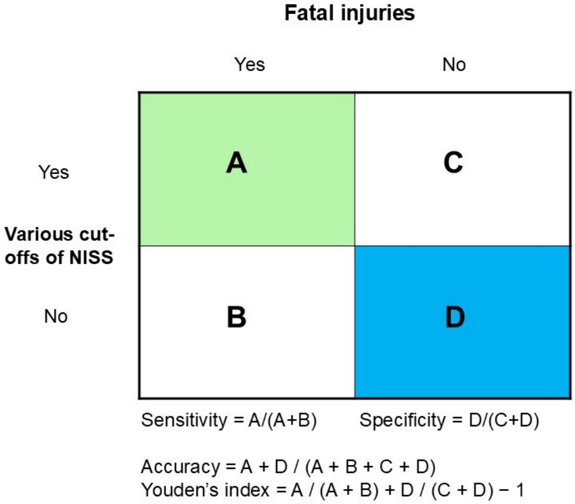

Figure 2. Four-field contingency table illustrating the calculation of sensitivity, specificity, accuracy and Youden's Index for NISS cut-offs in predicitng fatal injuries in the natural course. Cells represent fatal injuires meeting the NISS cut-off (A), fatal injuires not meeting the NISS cut-off (B), non-fatal injuries meeting the NISS cut-off (C), and non-fatal injuries not meeting the NISS cut-off (D). NISS, New Injury Severity Score

Together, these statistical approaches enabled systematic evaluation of differences between homicides and suicides (**Papers I–III**), comparability of survivors of assaults and fatal assaults (**Paper IV**), and application of trauma scoring as a method to predict fatal injuries in the natural course (**Paper V**).

All statistical analyses, except for calculation of sensitivity, specificity, accuracy and Youden's Index, were conducted using IBM SPSS Statistics Premium version 28 (SPSS, Chicago, IL, USA).

Ethical approval

All studies were approved by the Swedish Ethical Review Authority (Dnr 2022–04847–01, approved 2022-10-05). The studies were retrospective based solely on existing data, whereupon informed consent was not required according to the ethical approval.

Results

Demographics of the study population

The fatalities caused by a single stab injury to the trunk, which constitute the study population of **Paper I–III** and **Paper V**, comprises 94 homicides and 45 suicides (Table 4). The survivors with single stab injuries to the trunk constitute the study population of **Paper IV**, involving corroborated (n = 162) and non-corroborated assaults (n = 223), and **Paper V**, involving all survivors regardless of causation (n = 408) (Table 4).

The majority of both homicide and suicide victims were male, yet the proportion of males was higher among homicides (92.6%) than suicides (82.2%). Homicide victims were significantly younger, with a median age of 33 years compared to 52 years among suicide victims (p < 0.001). The assaulted victims showed similar proportions of male domination (93.2 % in corroborated and 94.2 % in non-corroborated assaults) and similar median age (32 years in corroborated and 29 years in non-corroborated assaulted victims) as in homicide victims.

Table 4. Demographics of fatalities and survivors

	Fatalities (n = 139)			**Survivors (n = 408)**			
	Homicides (n = 94), n (%)	**Suicides (n = 45), n (%)**	**P-value**	**Survived corroborated assaults (n =162), n (%)**	**Survived non-corroborated assaults (n = 223), n (%)**	**Survived self-inflicted, accidental and undetermined (n = 23), n (%)**	**P-value**
Males	87 (92.6)	37 (82.2)		151 (93.2)	210 (94.2)	16 (69.6)	
Females	7 (7.4)	8 (17.8)	0.08	11 (6.8)	13 (5.8)	7 (30.4)	< 0.001
Age, median of years (range)	33.0 (15-84)	52.0 (15-90)	< 0.001	32 (15–79)*	29 (15–76)	32.0 (19–61)	0.09

Descriptive analyses of demographics among homicides, suicides, survivors of corroborated and non-corroborated assaults and other groups of survivors of single stabs to the trunk.
*Missing values: age among corroborated assaults n = 1 (0.6 %).

Characteristics of homicides, suicides and survivors of assaults

In **Papers I and IV**, we present the same set of variables in both papers, including victim profiles, contextual circumstances at the scene, toxicological findings, anatomical location of the stab injury and injury characteristics. **Paper I** defined variables that distinguish homicides from suicides among single stabs to the trunk, while **Paper IV** applies the same framework to investigate if variables characteristic for homicides were transferable to survivors of assaults.

Victims profile

Males under the age of 30 years were at higher risk of being victims of homicides (OR 4.2, 95% CI 1.7–10.4), using suicide cases as references (Table 5). The prevalence of males under 30 years did not significantly differ between survivors of assault and homicide victims. Psychiatric diagnoses and history of abuse of alcohol and/or narcotics were conclusively less common among survivors of assault (OR 0.05, 95 % CI 0.01–0.1 and OR 0.08, 95 % CI 0.03–0.2, respectively), using homicide victims as reference.

Circumstances at the scene

Homicide victims were most frequently found outdoors (54.3 %) or in another indoor location outside of the home (28.7 %), while suicide victims were predominantly found in their own homes (79.5 %) (Table 6). Survivors of corroborated assault, which involved a perpetrator confession or an eyewitness, were frequently assaulted outdoors, and survivors of non-corroborated assaults were to an even greater extent assaulted outdoors (46.0 % vs. 60.2 %, $p = 0.008$). In contrast, survivors of corroborated assaults were more commonly assaulted at an indoor location other than their home compared to survivors of non-corroborated assaults (29.8 % vs. 19.4 %, $p = 0.03$).

In homicides, the weapon was mostly absent from the crime scene (69. 1%), whereas finding the weapon in situ of the body or elsewhere at the death scene were conclusively less common in homicides compared to suicides (OR 0.008, 95 % CI 0.001–0.05 and OR 0.03, 95 % CI 0.006–0.1, respectively). In survivors of assault the weapons were also mostly not found, and in non-corroborated cases of assault the weapon was more frequently not found than in corroborated cases of assault (73.1 % vs. 52.5 %, $p < 0.001$),

Among the fatalities in which the clothing was examined, 75.0 % of homicide victims had defects in the clothing close to the stab wound compared to 32.0 % of suicide victims. Among survivors of assaults, nearly all cases in which clothing were examined had defects, with a few cases with no defects in the clothing among corroborated (3.7 %) and non-corroborated assaults (8.0 %).

Suicide notes were found in 24.4% of suicides.

Table 5. Victims profile among different categories of fatalities and survived assaults

	Fatalities				Assaults				
	Homicides, n (%)	**Suicides, n (%)**	**P-value**	**Homicides (Ref suicides), OR (95% CI)**	**Survived corroborated assaults, n (%)**	**Survived non-corroborated assaults, n (%)**	**P-value**	**Survived corroborated assaults (Ref survived non-corroborated), OR (95% CI)**	**Survived assaults (Ref homicides), OR (95% CI)**
Males aged < 30 years	41 (43.6)	7 (15.6)		4.2 (1.7–10.4)	64/161 (39.8)*	109 (48.9)		0.7 (0.1–1.0)	1.1 (0.7–1.7)
Males aged ≥ 30 years and females	53 (56.4)	38 (84.4)	< 0.001	Ref	97/161 (60.2)*	114 (51.1)	0.08	Ref	Ref
Psychiatric diagnosis	12/16 (75.0)*	21/28 (75.0)*		1.0 (0.2–4.1)	22/161 (13.7)	24/218 (11.0)		1.3 (0.7–2.4)	0.05 (0.01–0.1)
No psychiatric diagnosis	4/16 (25.0)*	7/28 (25.0)*	1.0	Ref	139/161 (86.3)	194/218 (89.0)	0.4	Ref	Ref
Abuse	20/25 (80.0)	11/21 (52.4)		3.6 (0.9–13.4)	35/161 (21.7)	54/218 (24.8)		0.8 (0.5–1.4)	0.08 (0.03–0.2)
No abuse	2/25 (20.0)	10/21 (47.6)	0.06	Ref	126/161 (78.3)	164/218 (75.2)	0.5	Ref	Ref

Descriptive and univariable logistic regression analyses of victims profile among homicides, suicides and survived corroborated and non-corroborated assaults of single stabs to the trunk.

*Missing values: psychiatric diagnosis among homicides n = 78 (83.0 %), psychiatric diagnosis among suicides n = 17 (37.8 %), abuse among homicides n = 69 (73.4), abuse among suicides n = 24 (53.3), age among survived corroborated assaults n = 1 (0.6 %), psychiatric diagnosis among survived corroborated assaults n = 1 (0.6 %), psychiatric diagnosis among survived non-corroborated assaults n = 5 (2.2 %), abuse among survived corroborated assaults n = 1 (0.6), abuse among survived non-corroborated assaults n = 5 (2.2).

Ref, Reference; OR, Odds Ratio; CI, Confidence Interval

Table 6. Contextual scene circumstances among different categories of fatalities and survived assaults

	Fatalities				Assaults				
	Homicides, n (%)	**Suicides, n (%)**	**P-value**	**Homicides (Ref suicides), OR (95% CI)**	**Survived corroborated assaults, n (%)**	**Survived non-corroborated assaults, n (%)**	**P-value**	**Survived corroborated assaults (Ref survived non-corroborated) , OR (95% CI)**	**Survived assaults (Ref homicides), OR (95% CI)**
Other indoor location than home	27 (28.7)	3/44 (6.8)*	0.004	19.7 (5.2–74.5)	48/161 (29.8)*	39/201 (19.4)*	0.03	1.3 (0.7–2.4)	0.6 (0.3–1.3)
Outdoor location	51 (54.3)	6/44 (13.6)*	< 0.001	18.6 (6.6–52.2)	74/161 (46.0)*	121/201 (60.2)*	0.008	0.6 (0.4–1.1)	0.8 (0.4–1.4)
At home	16 (17.0)	35/44 (79.5)*	< 0.001	Ref	39/161 (24.2)*	41/201 (20.4)*	0.4	Ref	Ref
Weapon found in situ	3 (3.2)	12 (26.7)	< 0.001	0.008 (0.001–0.05)	≤3 (1.2)	6 (2.7)	0.5	0.6 (0.1–3.2)	0.7 (0.2–2.7)
Weapon found elsewhere	26 (27.7)	31 (68.9)	< 0.001	0.03 (0.006–0.1)	75 (46.3)	54 (24.2)	< 0.001	2.7 (1.7–4.1)	1.3 (0.8–2.2)
No weapon found	65 (69.1)	2 (4.4)	< 0.001	Ref	85 (52.5)	163 (73.1)	< 0.001	Ref	Ref
Defect in clothing	15/20 (75.0)*	8/25 (32.0)*	0.007	4.2 (0.9–18.1)	26/27 (96.3)*	23/25 (92.0)*	0.6	2.3 (0.2–26.6)	1.5 (0.1–17.2)
No clothing	4/20 (20.0)*	9/25 (36.0)*	0.3	0.3 (0.03–3.1)	0/27 (0)*	0/25 (0)*	–	error	error
No defect in clothing	≤3/20 (5.0)*	8/25 (32.0)*	0.03	Ref	≤3/27 (3.7)*	≤3/25 (8.0)*	0.6	Ref	Ref
Suicide note	0 (0)	11 (24.4)		error	0 (0)	0 (0)			
No suicide note	94 (100)	34 (75.6)	< 0.001	Ref	0 (0)	0 (0)	–		

Descriptive and univariable logistic regression analyses of contextual circumstances at the scene among homicides, suicides and survived corroborated and non-corroborated assaults of single stabs to the trunk.

*Missing values: scene location among suicides n = 1 (2.2 %), scene location among survived corroborated assaults n = 1 (0.6), scene location among survived non-corroborated assaults n = 22 (9.9 %), information on clothes among homicides n = 74 (78.7 %), information on clothes among suicides n = 20 (44.4 %), information on clothes among survived corroborated assaults n = 135 (83.3 %), information on clothes among survived non-corroborated assaults n = 198 (88.8 %).

Ref, Reference; OR, Odds Ratio; CI, Confidence Interval

Toxicological findings

Most homicide victims were inebriated with alcohol at the stabbing event, in contrast to suicide victims (58.1 % vs. 16.3 %, $p < 0.001$) (Table 7). Survivors of assault were also to a lesser extent inebriated with alcohol compared to homicide victims (OR 0.3, 95 % CI 0.2–0.4). Alcohol inebriation was also conclusively more frequent among survivors of corroborated assaults using non-corroborated assaults as reference (OR 1.8, 95% CI 1.1–2.8).

Influence of illicit narcotics was conclusively more common among homicide victims using suicide victims as reference (OR 4.3 95 % CI 1.5–11.9) (Table 7). Influence of illicit narcotics was conclusively less common among survivors of assault when using homicide victims as reference (OR 0.1, 95% CI 0.04–0.4).

Anatomical location of the stab injury

Most of the homicidal stabs (77.7 %) and all suicidal stabs were located in the anterior trunk (Figure 3). In suicide victims, the stabs were consistently located at or medial to the midclavicular line, while stabs in homicide victims demonstrated a more variable distribution, including injuries to the back (11.7 %), and right and left axillary regions (4.3 % and 6.4 %, respectively). The stabs in suicide victims were clustered at the left side of the thorax and in the midline (93.3 %), whereas stabs located at the frontal trunk in other areas than the left side of the thorax or midline were conclusively more frequent in homicide victims (OR 5.3, 95 % CI 1.5–19.0) (Table 8).

Most stab wounds in survivors of assault were also located in the frontal trunk (Figure 4), with 46.2 % of the corroborated cases and 54.2% of the non-corroborated cases. In survivors of corroborated assault, 27.8% of the stab wounds were located in the back and 5.6% in the right axillary region, with similar proportions in the non-corroborated assaults. The left axillary region significantly differed between corroborated and non-corroborated assaults (20.4 % vs. 11.7 %, $p = 0.02$) (Table 8).

Survivors of assaults had conclusively more injuries to the abdomen rather than in the thorax (OR 1.9, 95 % CI 1.1–3.1), in the frontal trunk in other areas than the left side of the thorax or midline (OR 3.7, 95 % CI 2.0–6.6), to the back (OR 3.7, 95 % CI 1.9–7.2) and in the left axillary region of the trunk (OR 3.7, 95 % CI 1.5–8.8), compared to homicide victims (Table 8).

Table 7. Toxicological findings among different categories of fatalities and survived assaults

	Fatalities				Assaults				
	Homicides, n (%)	**Suicides, n (%)**	**P-value**	**Homicides (Ref suicides), OR (95% CI)**	**Survived corroborated assaults, n (%)**	**Survived non-corroborated assaults, n (%)**	**P-value**	**Survived corroborated assaults (Ref survived non-corroborated) , OR (95% CI)**	**Survived assaults (Ref homicides), OR (95% CI)**
Alcohol	54/93 (58.1)	7/43 (16.3)		7.1 (2.9–17.7)	52 (32.1)	47 (21.3)		1.8 (1.1–2.8)	0.3 (0.2–0.4)
No alcohol	39/93 (41.9)	36/43 (83.7)	< 0.001	Ref	110 (67.9)	176 (78.9)	0.02	Ref	Ref
Illicit narcotics	33/93 (35.5)	5/44 (11.4)		4.3 (1.5–11.9)	9 (5.6)	14 (6.3)		1.9 (0.3–10.0)	0.1 (0.04–0.4)
No illicit narcotics	60/93 (65.5)	39/44 (88.6)	0.007	Ref	153 (94.4)	209 (93.7)	0.8	Ref	Ref

Descriptive and univariable logistic regression analyses of toxicological findings among homicides, suicides and survived corroborated and non-corroborated assaults of single stabs to the trunk.

*Missing values: alcohol among homicides n = ≤3 (1.1 %), alcohol among suicides n = ≤3 (2.2 %), illicit narcotics among homicides n = ≤3 (1.1 %), illicit narcotics among suicides n = ≤3 (2.2 %).

Ref, Reference; OR, Odds Ratio; CI, Confidence Interval

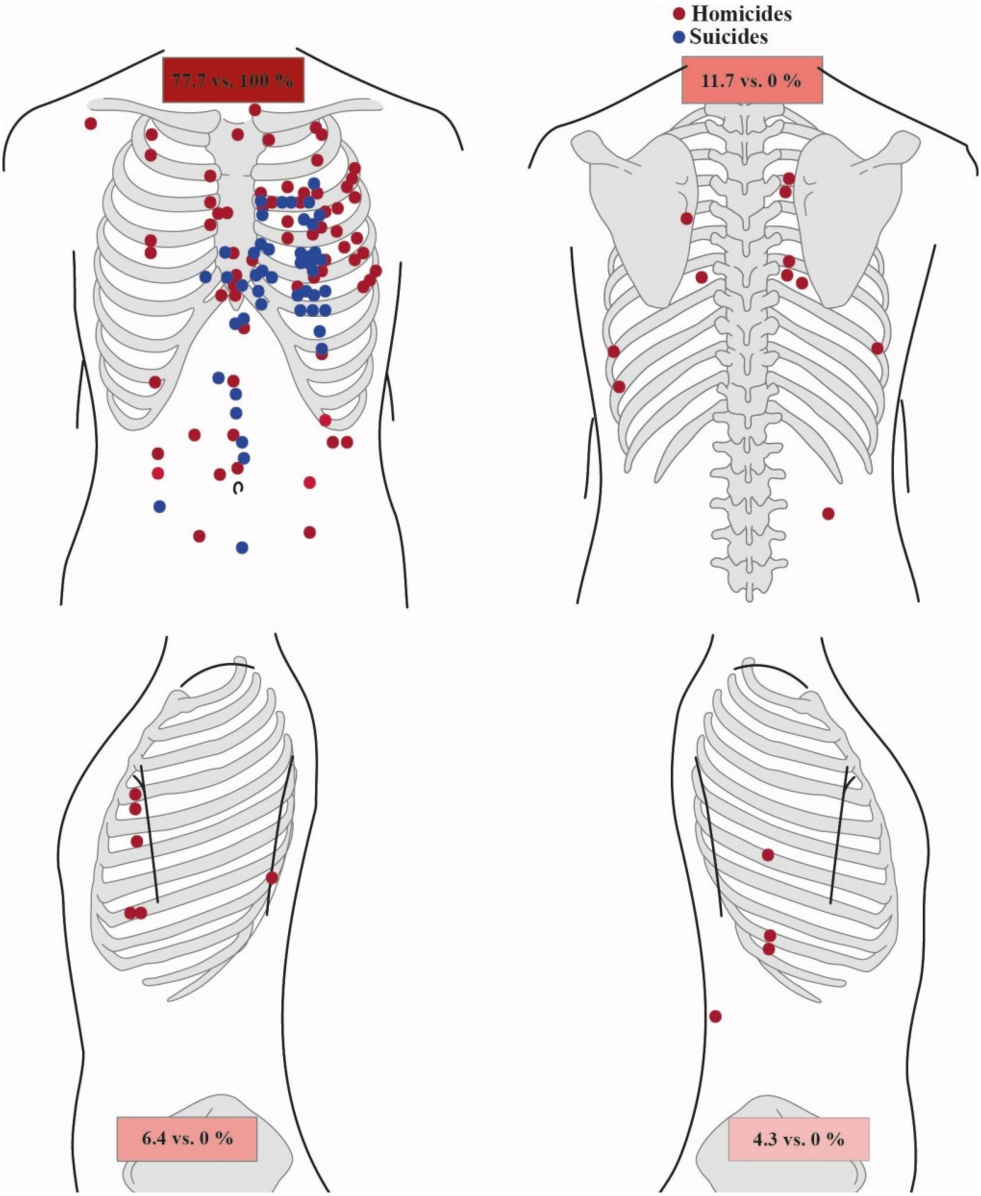

Figure 3. Anatomical distribution of stab injuries in homicides and suicides. The red spots represent the entrance of homicidal stab wounds and the blue spots represent the entrance of suicidal stab wounds.

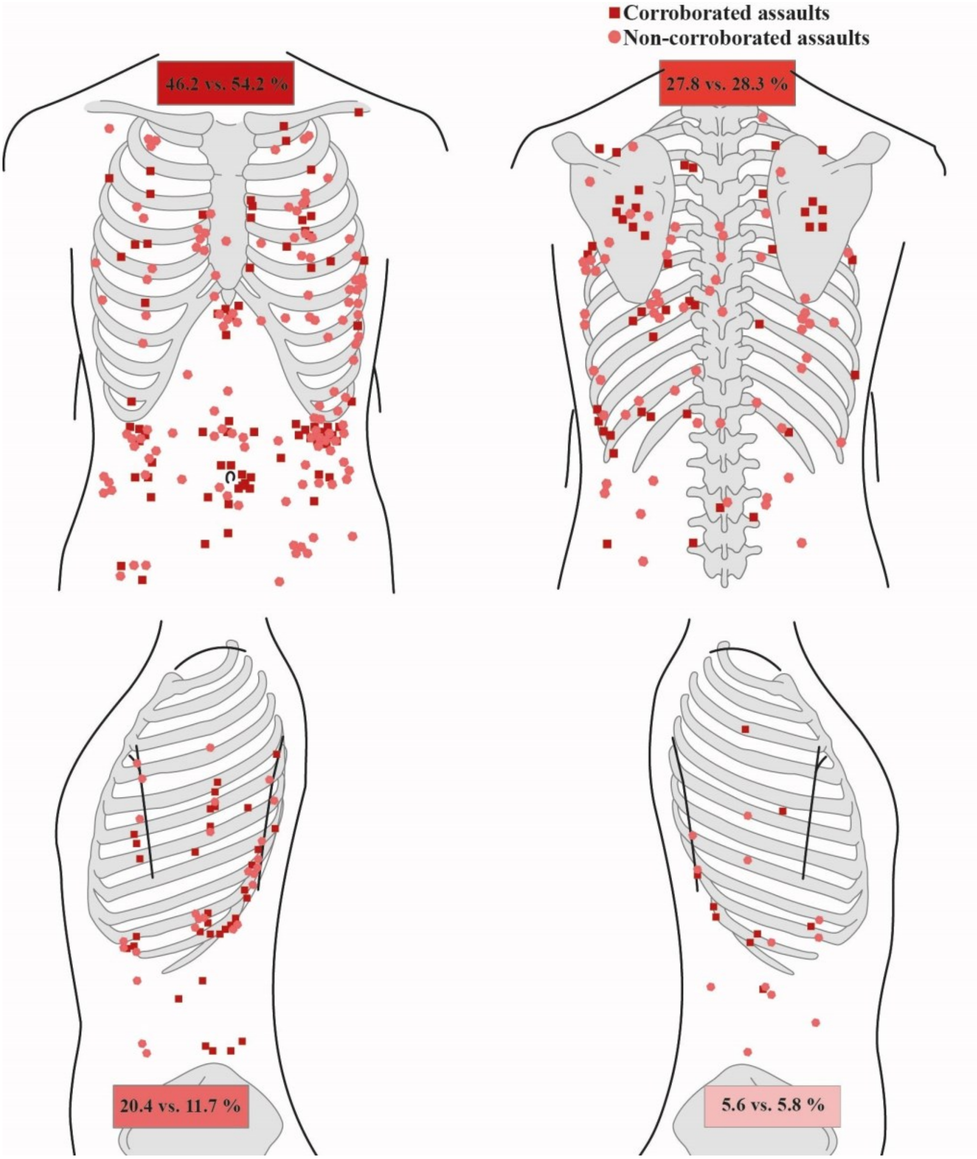

Figure 4. Anatomical distribution of stab injuries in survivors of corroborated and non-corroborated assaults. The dark red squares represent the entrance of stab wounds in corroborated cases and the light red squares represent the entrance of stab wounds in non-corroborated cases.

Table 8. Anatomical location of the stab injury among different categories of fatalities and survived assaults

	Fatalities				Assaults				
	Homicides, n (%)	**Suicides, n (%)**	**P-value**	**Homicides (Ref suicides), OR (95% CI)**	**Survived corroborated assaults, n (%)**	**Survived non-corroborated assaults, n (%)**	**P-value**	**Survived corroborated assaults (Ref survived non-corroborated) , OR (95% CI)**	**Survived assaults (Ref homicides), OR (95% CI)**
Abdomen	22 (23.4)	10 (22.2)		1.1 (0.5–2.5)	63 (38.9)	77 (34.5)		1.2 (0.8–1.8)	1.9 (1.1–3.1)
Thorax	72 (76.6)	35 (77.8)	1.0	Ref	99 (61.1)	146 (65.5)	0.4	Ref	Ref
The back	11 (11.7)	0 (0)	0.02	–	45 (27.8)	63 (28.3)	0.1	1.2 (0.7–1.9)	3.7 (1.9–7.2)
Right axillary region	4 (4.3)	0 (0)	0.3	–	9 (5.6)	13 (5.8)	0.1	1.1 (0.5–2.7)	2.1 (0.7–6.1)
Left axillary region	6 (6.4)	0 (0)	0.2	–	33 (20.4)	26 (11.7)	0.02	2.0 (1.1–3.7)	3.7 (1.5–8.8)
Frontal trunk	73 (77.7)	45 (100)	< 0.001	Ref	75 (46.2)	121 (54.2)	0.1	Ref	Ref
Area other than the midline and left thorax at the frontal trunk	20/73 (27.4)	3/45 (6.7)		5.3 (1.5–19.0)	44/75 (58.7)	70/121 (57.9)		1.0 (0.6–1.9)	3.7 (2.0–6.6)
Midline and left thorax at the frontal trunk	53/73 (72.6)	42/45 (93.3)	< 0.001	Ref	31/75 (41.3)	51/121 (42.1)	0.4	Ref	Ref

Descriptive and univariable logistic regression analyses of anatomical location of the stab injury among homicides, suicides and survived corroborated and non-corroborated assaults of single stabs to the trunk.

Ref, Reference; OR, Odds Ratio; CI, Confidence Interval

Table 9. Characteristics of the stab injury among different categories of fatalities and survived assaults

	Fatalities				Assaults				
	Homicides, n (%)	**Suicides, n (%)**	**P-value**	**Homicides (Ref suicides), OR (95% CI)**	**Survived corroborated assaults, n (%)**	**Survived non-corroborated assaults, n (%)**	**P-value**	**Survived corroborated assaults (Ref survived non-corroborated), OR (95% CI)**	**Survived assaults (Ref homicides), OR (95% CI)**
Penetrating	94 (100)	45 (100)			108 (76.1)	115 (59.0)		2.2 (1.4–3.6)	
Non-penetrating	0 (0)	0 (0)	1.0		34 (23.9)	80 (41.0)	0.001	Ref	
Bones/cartilage of the ribcage	62/77 (80.5)*	18/36 (50.0)*		4.1 (1.7–9.8)	22/55 (40.0)*	24/65 (36.9)*		1.3 (0.7–2.4)	0.2 (0.1–0.3)
Intercostal space	15/77 (19.5)*	18/36 (50.0)*	0.004	Ref	33/55 (60.0)*	41/65 (63.1)*	0.4	Ref	Ref
Vertical oriented entrance wound	23/86 (26.7)*	4/44 (9.1)*	0.02	5.5 (1.6–18.7)	27/86 (31.4)*	27/128 (21.1)*	0.1	2.0 (0.9–4.1)	0.7 (0.4–1.4)
Down–right-oriented entrance wound	28/86 (32.6)*	10/44 (22.7)*	0.2	2.7 (1.04–6.9)	15/86 (17.4)*	28/128 (21.9)*	0.5	1.0 (0.5–2.3)	0.5 (0.2–0.9)
Down–left-oriented entrance wound	14/86 (16.3)*	10/44 (22.7)*	0.2	1.3 (0.5–3.7)	21/86 (24.4)*	28/128 (21.9)*	0.7	1.5 (0.7–3.1)	1.1 (0.5–2.3)
Horizontal oriented entrance wound	21/86 (24.4)*	20/44 (45.5)*	0.02	Ref	23/86 (26.7)*	45/128 (35.2)*	0.2	Ref	Ref
Length of the injury channel*, median (range) (cm)	11.0 (5-22.5)*	10.0 (6-17)*	0.4	1.1 (0.9–1.3)	5.5 (0.3–17.5)*	4.5 (0.6–23.0)*	0.05	1.1 (0.9–1.2)	0.7 (0.6–0.8)
	n = 53	n = 11			n = 33	n = 43			
Cranial injury channel	18/68 (26.5)*	11/27 (40.7)*	0.02	0.3 (0.1–0.8)	12/37 (32.4)*	11/45 (24.4)*	0.5	1.5 (0.6–4.1)	1.1 (0.5–2.3)
Straight horizontal injury channel	4/68 (5.9)*	2/27 (7.4)*	0.7	0.5 (0.07–2.8)	0/37 (0)*	≤3/45 (2.2)*	1.0	error	0.2 (0.02–2.1)
Caudal injury channel	48/68 (70.6)*	14/27 (51.9)*	0.02	Ref	25/37 (67.6)*	33/45 (73.3)*	0.6	Ref	Ref
Lateral injury channel	11/69 (15.9)*	9/22 (40.9)*	0.02	0.2 (0.08–0.7)	5/42 (11.9)*	6/43 (14.0)*	1.0	0.9 (0.2–3.1)	0.8 (0.3–1.9)
Straight sagittal injury channel	3/69 (4.3)*	2/22 (9.1)*	0.6	0.3 (0.05–2.0)	≤ 3/42 (2.4)*	0/43 (0)*	0.5	error	0.3 (0.03–2.5)
Medial injury channel	55/69 (79.7)*	11/22 (50.0)*	0.01	Ref	36/42 (85.7)*	37/43 (86.0)*	1.0	Ref	Ref

Table 9: Descriptive and univariable logistic regression analyses of injury characteristics among homicides, suicides and survived corroborated and non-corroborated assaults of single stabs to the trunk.

*Missing values: injury to the ribcage among homicides n = 17 (18.1 %), injury to the ribcage among suicides n = 9 (20.0 %), injury to the ribcage among survived corroborated assaults n = 107 (66.0 %), injury to the ribcage among survived non-corroborated assaults n = 158 (70.9 %), orientation of the entrance wound among homicides n = 8 (8.5 %), orientation of the entrance wound among suicides n = 1 (2.2 %), orientation of the entrance wound among survived corroborated assaults n = 76 (46.9 %), orientation of the entrance wound among survived non-corroborated assaults n = 95 (42.6 %), length of the injury channel among homicides n = 41 (43.2 %), length of the injury channel among suicides n 34 = (75.6 %), length of the injury channel among survived corroborated assaults n = 129 (79.6 %), length of the injury channel among survived non-corroborated assaults n = 180 (80.7 %), orientation of the injury channel, sagittal plane among homicides n = 26 (27.7 %), orientation of the injury channel, sagittal plane among suicides n = 18 (40.0 %), orientation of the injury channel, sagittal plane among survived corroborated assaults n = 125 (77.2 %), orientation of the injury channel, sagittal plane among survived non-corroborated assaults n = 178 (79.8 %), orientation of the injury channel, horizontal plane among homicides n = 25 (26.6 %), orientation of the injury channel, horizontal plane among suicides n = 23 (51.1 %), orientation of the injury channel, horizontal plane among survived corroborated assaults n = 120 (74.1 %), orientation of the injury channel, horizontal plane among survived non-corroborated assaults n = 180 (80.7 %).

Ref, Reference; OR, Odds Ratio; CI, Confidence Interval

Table 10. Defensive and hesitation wounds among different categories of fatalities and survived assaults

	Fatalities				**Assaults**				
	Homicides, n (%)	**Suicides, n (%)**	**P-value**	**Homicides (Ref suicides), OR (95% CI)**	**Survived corroborated assaults, n (%)**	**Survived non-corroborated assaults, n (%)**	**P-value**	**Survived corroborated assaults (Ref survived non-corroborated) , OR (95% CI)**	**Survived assaults (Ref homicides), OR (95% CI)**
Defensive wounds	10 (10.6)	≤3 (2.2)		7.0 (0.8–64.8)	7 (4.3)	21 (9.4)		0.4 (0.2–1.0)	0.7 (0.3–1.4)
No defensive wounds	84 (89.4)	44 (97.8)	0.1	Ref	155 (95.7)	202 (90.6)	0.07	Ref	Ref
Hesitation wounds	0 (0)	13 (28.9)		error	0 (0)	≤3 (0.4)			
No hesitation wounds	94/94 (100)	32 (71.1)	< 0.001	Ref	162 (100)	222 (99.6)	1.0		

Descriptive and univariable logistic regression analyses of defensive and hesitation wounds among homicides, suicides and survived corroborated and non-corroborated assaults of single stabs to the trunk.

Ref, Reference; OR, Odds Ratio; CI, Confidence Interval

Characteristics of the stab injuries

A substantial amount of the survivors of assaults had superficial stab wounds that did not penetrate the thoracic or the abdominal cavities (Table 9). Penetrating stabs were more common in survivors of corroborated assaults compared to non-corroborated assault (76.1 % vs. 59.0 %, $p = 0.001$). The length of the injury channel was conclusively shorter in survivors of assault compared to homicide victims (OR 0.7, 95 % CI 0.6–0.8).

Penetration of the bony part of the ribcage was more frequently observed in homicide victims than in suicide victims (80.5 % vs. 50.0 %, $p = 0.004$) (Table 9). Survivors of assaults had conclusively less stabs penetrating the bony parts of the ribcage compared to homicide victims (OR 0.2, 95 % CI 0.1–0.3).

Entrance wounds with vertically running orientation (OR 5.5, 95 % CI 1.6–18.7) or down-right running orientation (OR 2.7, 95 % CI 1.04–6.9) were conclusively more common in homicide victims compared to suicide victims using horizontally running entrance wounds as reference (Table 9). A down-right oriented entrance wound was also conclusively less common in survivors of assault compared to in homicide victims (OR 0.5, 95 % CI 0.2–0.9).

Stabs with injury channels oriented laterally were conclusively less common in homicide victims compared to suicide victims (OR 0.2, 95 % CI 0.08–0.7), using medially running channel as reference (Table 9). Also, injury channels oriented cranially were conclusively more frequent in suicide victims (OR 0.3, 95 % CI 0.1–0.8) when caudally running injury channels were used as reference.

Defensive and hesitation wounds

Injuries with characteristics of defence were observed in 10.6% of homicide victims and in ≤3 of the suicide victims (Table 10). In fatal cases, hesitation wounds were documented exclusively in suicides (28.9 %, $p < 0.001$).

Defensive injuries were also documented in survivors of assaults, with 4.3 % in the corroborated and 9.4 % in the non-corroborated cases. Among the survivors of non-corroborated assaults, ≤3 cases had hesitation wounds.

Adjustment for confounders

The results of the multivariable logistic regression analyses, adjusting for gender and age, showed associations between contextual circumstances, toxicological findings, anatomical location of the stab injury, other characteristics of the stab injury and defensive wounds and the classification of homicides (suicides as reference) and all survivors of assault (homicides as reference) that were similar to the associations found in the univariable logistic regression (Table S2).

The analyses of multivariable logistic regression, adjusting for gender, age, psychiatric history and alcohol and/or narcotic abuse, presented associations between contextual circumstances, toxicological findings, anatomical location of the stab injury, other characteristics of the stab injury and defensive wounds and survivors of corroborated assaults (survivors of non-corroborated assaults as reference) were similar to the associations found in the univariable logistic regression (Table S2).

Development of a scoring system to differentiate the manner of death

Four score models

In **Paper III**, we developed an evidence-based scoring system for assessing the manner of death in stab injuries to the trunk – the *MODSIT* score. The model was based on characteristics previously identified as conclusively associated with either suicides or homicides (Paper I).

Variables representing injury characteristics, toxicology, contextual circumstances at the death scene, and demographics were incorporated into the scoring system (Table 11). Each variable was assigned positive or negative points depending on whether it was associated with homicide or suicide, respectively, with the weighting determined by the specificity for the manner of death. Variables associated with homicidal stabs included injury to the back or axillary region (+3), ribcage injury (+1), vertical wound orientation (+1), defensive wounds (+3), alcohol detection (+1), injured outside home (+1) absence of the weapon (+3), and males aged < 30 years (+1). Variables associated with suicidal stabs included intercostal injury (–1), horizontal entrance wound (–1), hesitation wounds (–3), injury at home (–1), weapon in situ of the body (–3), and presence of a suicide letter (–3). This structure produced a score where negative scores indicated suicide and positive scores indicated homicide.

Table 11. Variables included in the MODSIT score

	Association	Specificity (%)	Score points
Injury characteristics			
Injury located to the back or axillary region	Homicide	100	+3
Frontal trunk, location other than midline and left thorax	Homicide	93.3	+2
Injury to the ribcage	Homicide	50.0	+1
Intercostal injury	Suicide	80.5	–1
Vertical entrance wound	Homicide	83.3	+1
Horizontal entrance wound	Suicide	52.3	–1
Defensive wounds	Homicide	97.8	+3
Hesitation wounds	Suicide	100	–3
Toxicology			
Alcohol	Homicide	83.7	+1
Circumstances			
Not injured at home	Homicide	79.6	+1
Injured at home	Suicide	83.0	–1
No weapon found	Homicide	95.6	+3
Weapon found in situ	Suicide	96.8	–3
Suicide letter	Suicide	100	–3
Demographics			
Males aged < 30 years	Homicide	84.4	+1

Overview of variables significantly associated with homicide or suicide in Paper I that were incorporated into the MODSIT score. Variables were weighted according to their specificity in logistic regression analyses, with positive points assigned for homicide-associated variables and negative points for suicide-associated variables.

Four models of the MODSIT score were constructed based on different categories of variables, accordingly:

- Score model 1 included injury characteristics only.
- Score model 2 included injury characteristics and toxicology.
- Score model 3 included injury characteristics and toxicology and scene circumstances.
- Score model 4 included injury characteristics and toxicology, scene circumstances and demographics.

Performance of the score models

ROC analyses demonstrated good to excellent discriminatory ability for the score models (Figure 5). The AUC ranged from 0.86 (95 % CI 0.79–0.93) for model 1 to 0.99 (95 % CI 0.97–1.00) for model 3 which showed the best diagnostic performance among the score models, indicating nearly perfect discrimination between homicide and suicide.

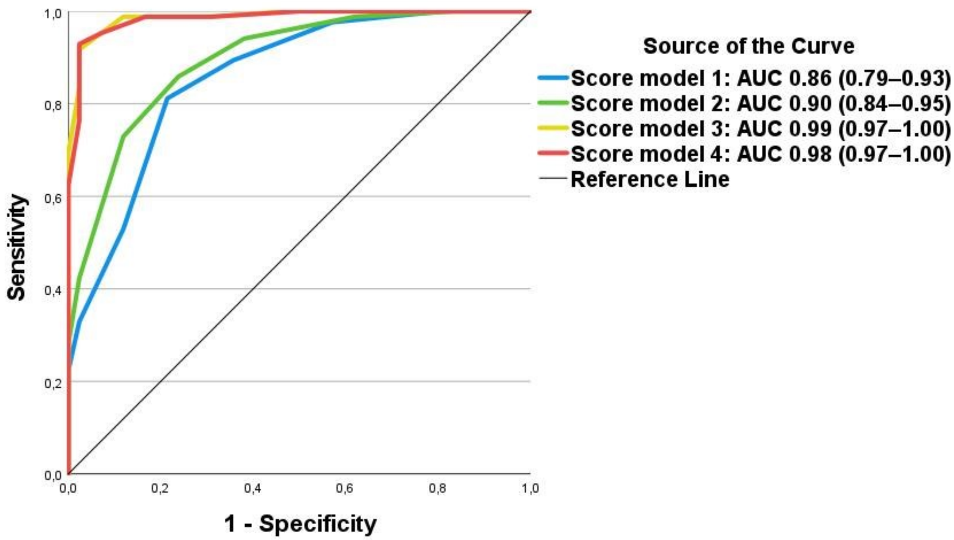

Figure 5. Diagnostic performance of the MODSIT score models evaluated by ROC analysis. AUC, Area Under the Curve

Cut-off points in score model 3

Model 3 was selected as the optimal score model due to showing the highest AUC among the different models and was therefore examined across all possible cut-off points for predicting homicide (Table 12). Some overlap between homicides and suicides was observed within the intermediate score range (–2 to +3), meaning that a threshold of ≥ +4 yielded 100 % specificity for identifying homicides and scores of ≤ –3 demonstrated 100 % specificity for suicides. The threshold with the highest Youden's Index (89.4, 95 % CI 81.9–96.8), representing the optimal balance between sensitivity and specificity, was set at 2 points.

Table 12. Diagnostic performance of score model 3 for predicting homicide

Cut-off point	Sensitivity (%) (95 % CI)	Specificity (%) (95 % CI)	Accuracy (%) (95 % CI)	Youden's Index (%) (95 % CI)
≤–9	100.0 (95.8–100.0)	0.0 (0.0–8.4)	66.9 (58.0–75.0)	0.0 (0.0–0.0)
–8	100.0 (95.8–100.0)	2.4 (0.1–12.6)	67.7 (58.9–75.7)	2.4 (0.0–9.2)
–7	100.0 (95.8–100.0)	7.1 (1.5–19.5)	69.3 (60.5–77.2)	7.1 (0.0–20.1)
–6	100.0 (95.8–100.0)	11.9 (4.0–25.6)	70.9 (62.2–78.5)	11.9 (0.0–29.9)
–5	100.0 (95.8–100.0)	19.1 (8.6–34.1)	73.2 (64.7–80.7)	19.0 (5.8–32.2)
–4	100.0 (95.8–100.0)	28.6 (15.7–44.6)	76.4 (68.0–83.5)	28.6 (12.5–44.6)
–3	100.0 (95.8–100.0)	40.5 (25.6–56.7)	80.3 (72.3–86.8)	40.5 (21.9–61.2)
–2	100.0 (95.8–100.0)	52.4 (36.4–68.0)	84.3 (76.7–90.1)	52.4 (37.3–67.5)
–1	98.8 (93.6–100.0)	69.1 (52.1–82.4)	89.0 (82.2–93.8)	67.9 (53.7–82.0)
0	98.8 (93.6–100.0)	88.1 (74.4–96.0)	95.3 (90.0–98.3)	86.9 (76.9–97.0)
1	95.3 (88.4–98.7)	92.9 (80.5–98.5)	94.5 (89.0–97.8)	88.2 (79.2–97.1)
2	91.8 (83.8–96.6)	97.6 (87.4–99.9)	93.7 (88.0–97.2)	89.4 (81.9–96.8)
3	83.5 (73.9–90.7)	97.6 (87.4–99.9)	88.2 (81.3–93.2)	81.1 (72.0–90.3)
4	69.4 (58.5–78.9)	100.0 (91.6–100.0)	79.5 (71.5–86.2)	69.4 (59.6–79.2)
5	60.0 (48.8–70.5)	100.0 (91.6–100.0)	73.2 (64.7–80.7)	60.0 (49.6–70.4)
6	50.6 (39.5–61.6)	100.0 (91.6–100.0)	66.9 (58.0–75.0)	50.6 (40.0–61.2)
7	31.8 (22.1–42.8)	100.0 (91.6–100.0)	54.3 (45.3–63.2)	31.8 (21.9–41.7)
8	21.2 (13.1–31.4)	100.0 (91.6–100.0)	47.2 (38.3–56.3)	21.2 (12.5–29.9)
9	12.9 (6.6–22.0)	100.0 (91.6–100.0)	41.7 (33.1–50.8)	12.9 (5.8–20.1)
10	4.7 (1.3–11.6)	100.0 (91.6–100.0)	36.2 (27.9–45.2)	4.7 (0.2–9.2)
11	1.2 (0.03–6.4)	100.0 (91.6–100.0)	33.9 (25.7–42.8)	1.2 (–1.1–3.5)
≥12	0.0 (0.0–4.3)	100.0 (91.6–100.0)	33.1 (25.0–42.0)	0.0 (0.0–0.0)

Sensitivity, specificity, and accuracy across all possible cut-off points of the MODSIT score model 3.

CI, Confidence Interval

Application of the MODSIT score in survivors of assault

To explore its external applicability, the MODSIT score was applied to survivors of corroborated and non-corroborated assaults of single stabs to the trunk (Paper IV). All four score models demonstrated distributions dominated by positive score values (Figure 6), consistent with the score values of homicidal stabs.

When applying the optimal cut-off in model 3 for predicting homicide (≥ 2 points), 85.3% of the corroborated assaulted survivors met this threshold.

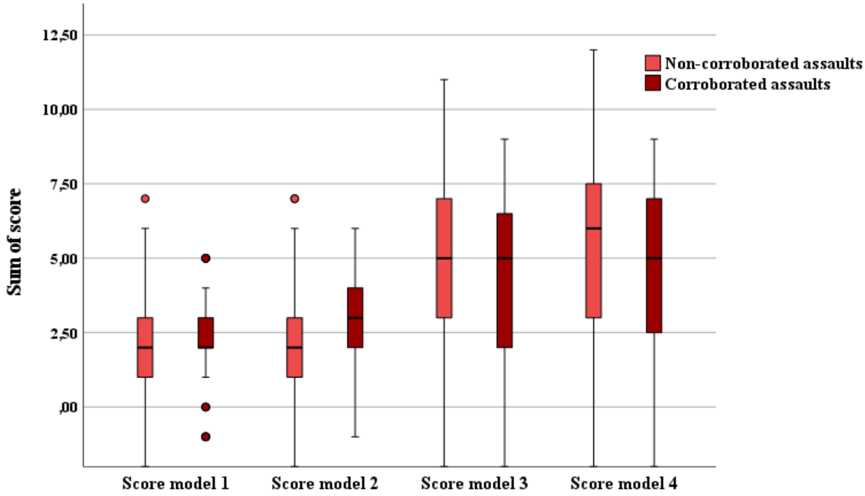

Figure 6. Distribution of the sum of scores for the four different MODSIT score models in categories of corroborated assaults and non-corroborated assaults.
Boxplot graph showing median scores and interquartile ranges (IQRs). Lines across the boxes indicate the median, boxes represent IQR, and the whiskers are lines that extent from the box edge to the highest and lowest values, excluding outliers and extremes. The small, filled circles represent outliers.

Use of trauma scoring in forensic populations

Inter-rater reliability of NISS between raters

The inter-rater reliability between the two NISS raters after having decided on detailed definitions of the NISS codes (81), showed an ICC of 0.87 (95% CI 0.68–0.95).

Differences in injury severity between homicidal and suicidal stabs

In **Paper II**, we investigated differences in internal injuries, injury severity, and medical care between homicidal and suicidal single stab injuries to the trunk.

Cardiac injuries were significantly more frequent in suicides than in homicides (68.9 % vs. 46.8 %, $p = 0.02$), while vessel injuries were more common in homicides (52.1 % vs. 13.3 %, $p < 0.001$) (Table 13). Other internal injuries, involving lungs, liver, pancreas and stomach and intestines did not show significant differences between homicidal and suicidal stab injuries.

Table 13. Internal organ and vessel injuries due to homicidal and suicidal stabs

	Homicide, n (%)	Suicide, n (%)	P-value
Heart	44 (46.8)	31 (68.9)	0.02
Vessels(s)	49 (52.1)	6 (13.3)	< 0.001
Lung(s)	47 (50.0)	17 (37.8)	0.2
Liver	13 (13.8)	5 (11.1)	0.8
Pancreas	2 (2.2)	0 (0)	1.0
Stomach and intestines	17 (18.1)	2 (4.4)	0.03

Distribution of cavity penetration and internal injuries among homicidal and suicidal single stabs to the trunk.

Injury severity caused by homicidal and suicidal stabs, assessed using NISS, did not show significant difference in median scores between the groups (58 vs. 75, $p = 0.5$) (Table 14). The category of unsurvivable injuries (NISS = 75) were significantly more common in suicides than in homicides (66.7 % vs. 46.8 %, $p = 0.03$), even if the majority of both groups sustained injuries categorized as (NISS 25–75). Minor injuries (NISS ≤ 8) were observed only among suicides (8.9 %, $p = 0.01$).

Table 14. NISS in homicide and suicide victims

	Homicide, n (%)	Suicide, n (%)	P-value
NISS (median, IQR)	58, 34–75	75, 29–75	0.5
Potential survivable injury (NISS < 75)	50 (53.2)	15 (33.3)	
Unsurvivable injury (NISS = 75)	44 (46.8)	30 (66.7)	0.03
Minor injury (NISS ≤ 8)	0 (0)	4 (8.9)	0.01
Moderate injury (NISS 9–15)	1 (1.1)	1 (2.2)	0.5
Severe injury (NISS 16–24)	5 (5.3)	3 (6.7)	0.7
Critical injury (NISS 25–75)	88 (93.6)	37 (82.2)	0.07

Distribution of NISS among homicidal and suicidal single stabs to the trunk.
NISS, New Injury Severity Score

More than half of the homicide victims (56.4 %) made it to the hospital where interventional therapy was started before they were declared dead compared with only 8.9 % of suicides ($p < 0.001$) (Table 15). Most suicide victims (55.6 %) were found dead at the scene compared with 14.9 % of homicides ($p < 0.001$). A further 28.7 % of homicide victims and 35.6 % of suicides received prehospital care only, before being declared dead.

Table 15. Medical care and interventions in homicide and suicide victims

	Homicide, n (%)	Suicide, n (%)	P-value
Hospital care with interventional therapy	53 (56.4)	4 (8.9)	< 0.001
Prehospital care only	27 (28.7)	16 (35.6)	0.4
Dead at the scene	14 (14.9)	25 (55.6)	< 0.001

Distribution of medical care among homicidal and suicidal single stabs to the trunk.

Application of NISS to predict fatal injuries in the natural course

Building on the findings from Paper II, which applied the NISS to identify differences in injury severity between homicides and suicides, **Paper V** extended the use of the NISS to evaluate its predictive performance for fatal outcome in the natural course of the injuries using a material that combines fatalities and survivors with single stab injuries to the trunk.

Distribution of NISS values was observed across increasing levels of intervention complexity in survivors and time to death in fatalities (Table 16). Among the survivors representing non-fatal injuries, the median NISS rose from 1 (IQR 1–4) in cases with no or minimal interventions, to 13 (IQR 8–18) in those requiring moderate interventions. Among the cases representing fatal injuries in the natural course and survivors whose injuries required life-saving interventions the median NISS was 20 (IQR 13–27). Fatalities found within 24 hours after the stabbing event showed NISS values with a median of 75 (IQR 34–75).

Injuries reaching the maximum value of NISS (NISS = 75), categorized as unsurvivable, constituted 54.8 % of fatalities found within 24 hours and 45.8 % of those found after 24 hours (Table 16).

The proportion of minor injuries (NISS ≤ 8) decreased with the increasing need for intervention complexity among the survivors, with 88.3 % of the cases with no/minimal interventions, 30.0 % of those that required moderate interventions, and 8.5 % of those requiring life-saving interventions. The minor injuries leading to major bleedings that required life-saving interventions included stab injuries with lacerations to the pectoral muscle, omentum, liver and the spleen. In each of the two subgroups of the fatalities, ≤3 cases fell into the category of minor injuries.

Critical injuries (NISS 25–75) rose from none in the group of survivors with no/minimal intervention, 7.1 % of survivors with moderate interventions to 37.3 % in survivors requiring life-saving intervention. Among fatalities, most cases found within 24 hours (92.2 %) and also after 24 hours (79.2 %) were categorised as critical injuries.

Table 16. NISS distribution by intervention among survivors and time to death among fatalities

	Non-fatal injuries		Fatal injuries			
	Survivors with no/minimal interventions (n = 179), n (%)	**Survivors with moderate interventions (n = 170), n (%)**	**Survivors with life-saving interventions (n = 59), n (%)**	**Fatalities found within 24h (n = 115), n (%)**	**Fatalities found after 24h (n = 24), n (%)**	**P-value**
NISS (median, IQR)	1 (1–4)	13 (8–18)	20 (13–27)	75 (34–75)	50 (27.5–75)	< 0.001
NISS < 75	179 (100)	170 (100)	59 (100)	52 (45.2)	13 (54.2)	
NISS = 75	0 (0)	0 (0)	0 (0)	63 (54.8)	11 (45.8)	< 0.001
NISS ≤ 8	158 (88.3)	51 (30.0)	5 (8.5)	≤3 (≤2.6)	≤3 (12.5)	
NISS 9−15	14 (7.8)	59 (34.7)	13 (22.0)	≤3 (≤2.6)	≤3 (12.5)	
NISS 16−24	7 (3.9)	48 (28.2)	19 (32.2)	7 (6.1)	≤3 (12.5)	
NISS 25−75	0 (0)	12 (7.1)	22 (37.3)	106 (92.2)	19 (79.2)	< 0.001

NISS median values and categories among survivors stratified by intervention level (no/minimal, moderate, or life-saving) and fatalities stratified by time to death after the stabbing (≤ 24 h or > 24 h).
NISS, New Injury Severity Score;IQR, Interquartile Range

The categories of moderate (NISS 9−15), severe (NISS 16−24), and critical injuries (NISS 25−75) were all conclusively associated with fatal injuries, using minor injuries (NISS ≤8) as a reference in a univariable regression model and a multivariable regression model adjusted for age and gender (Table 17).

Table 17. Logistic regression analyses presenting associations between the NISS categories and fatal injuries

	Fatal injuries (Ref non-fatal injuries), OR (95%CI)	
NISS categories	Univariable model	Multivariable model, adjusted for age and gender
NISS 25−75	76.6 (24.7−237.7)	369.5 (134.2−1017.4)
NISS 16−24	14.4 (5.2−40.4)	16.6 (6.5−42.5)
NISS 9−15	7.4 (2.6−21.6)	6.5 (2.4−17.7)
NISS ≤ 8	Ref	Ref

Univariable and multivariable logistic regression models, adjusting for age and gender, presenting associations between the NISS categories fatal injuries in the natural course

Ref, Reference; OR, Odds Ratio; CI, Confidence Interval, NISS; New Injury Severity Score.

The ROC analysis demonstrated that NISS discriminated fatal from non-fatal injuries in the natural course with excellent performance (AUC 0.94, 95 % CI 0.92–0.96) (Figure 7). The optimal balance between sensitivity and specificity was achieved at NISS ≥ 20, yielding sensitivity 81.0 % (95 % CI 74.4–86.6 %) and specificity 91.1 % (95 % CI 87.6–93.9 %), with a Youden's Index of 72.1 % (95 % CI 61.9–80.6 %) (Table 18). Higher thresholds increased specificity but reduced sensitivity, where NISS ≥ 34 reached 100 % specificity for identifying fatal injuries in the natural course with a sensitivity of 59.2 % (95 % CI 51.5–66.6 %).

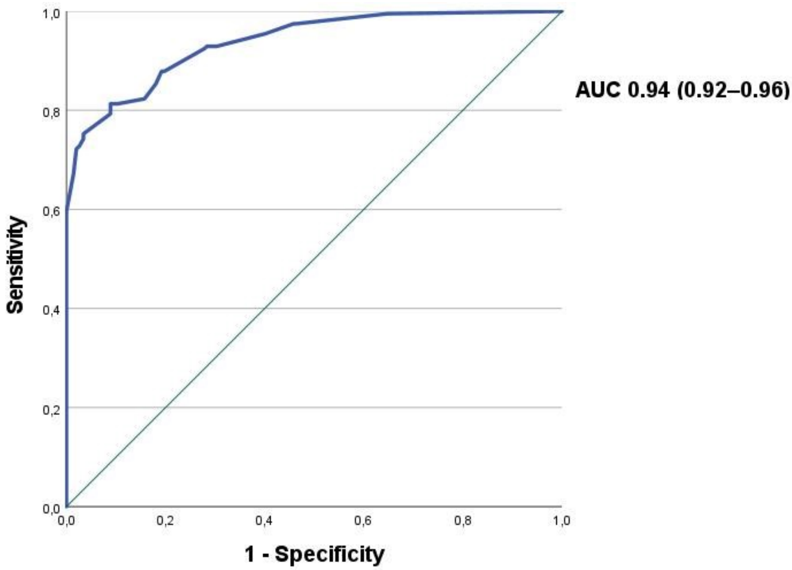

Figure 7. ROC curve for NISS predicting fatal injuries.
The ROC curve demonstrates the diagnostic performance of the NISS for distinguishing fatal from non-fatal single stab injuries to the trunk. The AUC was 0.94 (95 % CI 0.92–0.96, $p < 0.001$), indicating excellent discriminatory ability.
AUC, Area Under the Curve

Table 18. Diagnostic performance of NISS cut-offs for predicting fatal injuries in the natural course

NISS cut-off point	Sensitivity (%) (95 % CI)	Specificity (%) (95 % CI)	Accuracy (%) (95 % CI)	Youden´s Index (%) (95 % CI)
1	100.0 (97.9–100.0)	0.0 (0.0–1.1)	36.2 (32.2–40.4)	0.0 (–2.1–1.1)
4	100.0 (97.9–100.0)	35.2 (30.2–40.5)	58.5 (54.2–62.7)	35.2 (28.1–40.5)
5	98.3 (95.0–99.6)	53.6 (48.2–58.9)	69.5 (65.4–73.3)	51.9 (43.2–58.5)
8	98.3 (95.0–99.6)	54.2 (48.8–59.5)	69.8 (65.8–73.7)	52.5 (43.8–59.1)
9	96.6 (92.7–98.7)	59.9 (54.5–65.1)	72.8 (68.8–76.5)	56.5 (47.2–63.8)
10	94.3 (89.7–97.2)	63.9 (58.6–68.9)	78.1 (74.4–81.5)	58.2 (48.3–66.1)
12	94.3 (89.7–97.2)	71.6 (66.6–76.3)	79.3 (75.7–82.7)	65.9 (56.3–73.5)
13	93.7 (89.0–96.8)	72.2 (67.2–76.8)	79.5 (75.9–82.8)	65.9 (56.2–73.6)
14	88.5 (82.8–92.8)	80.2 (75.7–84.3)	83.0 (79.6–86.1)	68.7 (58.5–77.1)
16	88.5 (82.8–92.8)	80.8 (76.3–84.8)	83.4 (80.0–86.4)	69.3 (59.1–77.6)
17	85.6 (79.5–90.5)	82.0 (77.5–85.8)	83.2 (79.8-86.2)	67.6 (57.0–75.8)
18	82.2 (75.7–87.6)	84.2 (80.0–87.9)	83.6 (80.2-86.6)	66.4 (55.7–74.9)
19	81.0 (74.4–86.6)	89.7 (86.0–92.7)	86.7 (83.5–89.4)	70.7 (60.4–79.3)
20	81.0 (74.4–86.6)	91.1 (87.6–93.9)	87.6 (84.5–90.2)	72.1 (61.9–80.6)
22	78.7 (71.9–84.6)	91.1 (87.6–93.9)	86.8 (83.7–89.6)	69.8 (59.4–78.5)
24	74.7 (67.6–81.0)	96.6 (94.1–98.2)	88.9 (85.9–91.4)	71.3 (60.7–80.1)
25	73.6 (66.4–80.0)	96.6 (94.1–98.2)	88.5 (85.5–91.0)	70.2 (59.6–79.0)
26	71.8 (64.5–78.4)	97.4 (95.2–98.8)	88.5 (85.5–91.0)	69.2 (58.4–78.0)
27	71.3 (63.9–77.9)	98.0 (95.9–99.2)	88.7 (85.7–91.2)	69.3 (58.4–78.5)
29	66.1 (58.5–73.1)	98.6 (96.7–99.5)	87.2 (84.1–89.9)	64.7 (53.6–74.0)
34	59.2 (51.5–66.6)	100.0 (99.0–100.0)	85.2 (81.9–88.1)	59.2 (48.0–66.6)
36	50.6 (42.9–58.2)	100.0 (99.0–100.0)	82.3 (78.8–85.4)	50.6 (39.5–58.2)
38	48.3 (40.7–56.0)	100.0 (99.0–100.0)	81.5 (78.0–84.7)	48.3 (37.2–56.0)
41	45.4 (37.9–53.1)	100.0 (99.0–100.0)	80.6 (77.1–83.9)	45.4 (34.3–53.1)
43	43.1 (35.6–50.8)	100.0 (99.0–100.0)	79.9 (76.3–83.2)	43.1 (32.0–50.8)
45	41.4 (34.0–49.1)	100.0 (99.0–100.0)	79.2 (75.5–82.5)	41.4 (30.3–49.1)
50	40.2 (32.9–47.9)	100.0 (99.0–100.0)	78.8 (75.1–82.2)	40.2 (29.1–47.9)
57	38.5 (31.2–46.2)	100.0 (99.0–100.0)	78.2 (74.6–81.6)	38.5 (27.4–46.2)
59	37.9 (30.7–45.6)	100.0 (99.0–100.0)	77.9 (74.2–81.3)	37.9 (26.8–45.6)
66	37.4 (30.2–45.0)	100.0 (99.0–100.0)	77.7 (74.0–81.1)	37.4 (26.3–45.0)
75	36.2 (29.1–43.8)	100.0 (99.0–100.0)	77.3 (73.6–80.8)	36.2 (25.1–43.8)

Sensitivity, specificity, and Youden's Index for all NISS cut-off points in distinguishing fatal from non-fatal stab injuries to the trunk.
NISS, New Injury Severity Score; CI, Confidence Interval

Discussion

Towards evidence-based forensic assessment

This thesis aimed to strengthen the scientific basis for forensic assessments, in which single stab injuries to the trunk was used as a model through five registry-based studies, by applying systematic, evidence-based methods that could supplement experience-based forensic evaluations to enhance consistency and reliability.

Paper I investigated characteristics associated with the manner of death among fatalities which extended previous research on sharp force violence, which has previously predominantly relied on descriptive data from smaller autopsy-based sample sizes (25–29,38,39). **Paper IV** evaluated the generalisation of homicide characteristics to survivors of assault and minimized classification bias by focusing on cases with external evidence that corroborated the assessment of injury causation made by the forensic pathologist, considered gold standard (43,44). Furthermore, **Paper III** developed an evidence-based reproducible tool based on combinations of variables associated with homicides and suicides, respectively. Finally, **Paper II and V** used the established trauma scoring system NISS (74) to quantify injury severity when comparing homicides to suicides and to predict fatal outcomes along the natural course of injuries.

Applications of the results in the forensic practice

The results of this thesis have direct applicability across the main stages of forensic practice, from the investigation of the death scene and review of the background material collected from the police to performing autopsies, forensic examinations of injury survivors, and the final forensic assessments of injury causation and severity.

First, the demographics of the victim and contextual findings from the scene of the injury event can assist the forensic pathologist and crime scene investigators in forming a structured assessment of whether the stab injury would more likely be caused by interpersonal violence or by self-harm. These indicators concerning age of the victim, location of the scene, presence of the weapon, and penetration of clothing could help prioritise investigative hypotheses and formalise evidence collection from an early stage of the investigation.

After having performed the autopsy and receiving results from the toxicology analysis, findings associated with the manner of death, like anatomical location of the stab wound, damage to the bony parts of the ribcage, orientation of the entrance wound, presence of defensive or hesitation wounds, and presence of alcohol should be clearly documented in the forensic autopsy report.

In a similar way, the findings characteristic for cases of survived assaults, involving stabs injuries located to the back or axillary regions, vertically oriented entrance wounds and defensive wounds, should be collected from clinical forensic body examinations and medical records and highlighted in the clinical forensic protocols to enable a transparent documentation process. Furthermore, accurate documentation of injured organs and vasculature in both survivors and fatalities enables application of NISS to assist the forensic assessments of injury severity.

At the last stage of forming forensic conclusions, MODSIT could be applied to support the forensic assessments of injury causation. The MODSIT score enables the forensic pathologist to combine and evaluate the evidential weight of various indicators for manner of death, in which higher score points indicate increased specificity for homicide and lower score points increased specificity for suicide. Although the inclusion of contextual variables from the death scene (score models 3 and 4) showed the best diagnostic performance of the MODSIT score, the models limited to autopsy findings alone (model 1) or autopsy findings combined with alcohol results (model 2) may be regarded as more objective and less prone to external influence or manipulation (83). Accordingly, models 1 and 2 could serve as valuable tools in cases where contextual information is inaccurate or unavailable.

Additionally, incorporating NISS into forensic assessments enables the forensic pathologist to provide a quantitative estimate of injury severity, reflecting the probability of a fatal outcome or need for life-saving intervention. It should, however, be recognised that in this thesis NISS predicted fatal injuries in the natural course (as in fatal outcome in the absence of medical treatment), rather than injuries carrying a significant risk of fatal outcome without intervention, which constitutes the forensic definition of a life-threatening injury. Application of these structured tools could ultimately strengthen the scientific credibility of forensic assessments and promote consistency and fairness in judicial proceedings.

Generalisation of results

The findings in this thesis are based on cases involving single stab injuries to the trunk, which is a selected study population chosen to minimise confounding from varying injury numbers and locations. While this focused approach increases internal validity, its generalisability to populations with other injury patterns or injury types warrants consideration.

Homicide victims with a single stab injury have been overrepresented by male victims killed by a friend or acquaintance in an alcohol-related context (25,84–86). In contrast, homicides in domestic settings in which the perpetrator had a close relationship with the victim, have most commonly involved multiple stab wounds to the victims (25,84,85,87). These contextual differences were reflected in the death scene locations, whereas the homicide victims due to single stabs, as represented in this thesis, were predominantly found outdoors and victims due to multiple stabs found indoors (69,85,86). Still, stabbed victims found outdoors were more prevalent in homicide cases than suicide cases regardless of the number of stabs. Moreover, other typical contextual findings at the scene and also demographics and injury characteristics associated with a certain manner of death overlapped between population of single stabs (69–71) and multiple stabs (27–29,38,39,69,88).

The MODSIT score, which is based on variables associated with homicides and suicides, respectively, could therefore likely be adapted to cases involving multiple stab wounds, which would although require recalibrating the weighting of the variables to account for repeated stabbing. For example, anatomical distribution would need adjustment to reflect the heterogeneity of multiple homicidal stab injuries in comparison to the clustered patterns of suicidal stabs (29). Additionally, orientation of the entrance wounds and penetration of the bones and cartilage of the ribcage would require a modification adjusted for several injuries, for instance by including the most represented injury characteristics among the stabs. The death scene may also warrant a modified score weighing adjusted to the greater extent of domestic violence in homicidal multiple-stab cases (87). To summarise, the underlying framework of the MODSIT score remains relevant, but its adaptation to multiple stab injuries would require a structured re-evaluation of each variable.

Assaulted survivors of single stabs to the trunk, investigated in this thesis, also showed clear parallels in demographics, contextual circumstances and injury characteristics when compared to the fatal assaults due to single stabs (69–71). Yet differences in anatomical location of the single stab wounds, with less stabs to the thorax and to the bony parts of the ribcage in survived stabbing assaults (70,71,85), support a cautious but scientifically grounded approach when extrapolating from autopsy to clinical forensic populations. Although the MODSIT score was applied to survivors of assault to explore its external applicability, this validation was limited by the absence of a comparison group of survivors of self-inflicted stab injuries. This prevented evaluation of the discriminatory ability of the MODSIT score among survivors of stabbing victims.

Similarly, the adaptation of NISS for forensic use in evaluations of injury severity could be applied to varying numbers of stab wounds and also to other mechanisms of penetrating trauma, such as firearm-related violence. Nonetheless, the substantially greater kinetic energy and tissue destruction causes higher mortality in gunshot wounds compared to sharp force violence (89–91). Thereto, the type of gun and ammunition would have to be taken into account (92–94) in calibration of cut-off values to ensure accurate prediction of fatal outcomes in the natural course.

As trauma scores were used to estimate differences in injury severity between assaults and self-inflicted sharp force injuries regardless of the number of injuries, sharp force due to assaults were assessed with higher severity (13–15,27). However, this pattern could not be confirmed in this thesis, as our analyses were restricted to homicidal and suicidal single stabs to the trunk. The differences in severity stated in previous studies could reflect a higher number of stab wounds and more frequent involvement of vital structures, involving thoracic organs and vessels, among assaults (27–29,95). Moreover, this thesis demonstrated that minor injuries (NISS ≤ 8) to the abdomen were observed exclusively in suicide victims who did not receive hospital care. If these suicide victims with minor injuries had received timely hospital care, as most homicide victims did, they would with high probability have survived the stab (96,97). This observation is in line with previous studies on hospitalised patients showing no difference in mortality between treated self-inflicted and assault-related abdominal stab injuries (98,99), presupposing that urgent trauma care is the critical determinant of survival following penetrating injuries (100). Therefore, differences in injury severity due to homicidal and suicidal single stabs do not seem to be generalisable to cases with multiple stabs, stabs to heterogeneous anatomical locations or study populations restricted to hospital-treated patients (101).

To summarize, the specific findings of this thesis apply most directly to single stabs to the trunk, but the analytical approaches, including structured variable weighting, and use of trauma scoring to quantify severity, offer a framework with evidence-based methods that can be extended to more heterogeneous injury patterns, including multiple stab wounds and firearm injuries.

Circular reasoning

A central methodological weakness in forensic research lies in the potential of circular reasoning, which appears when the outcome being studied is defined by the same expert judgement that the research aims to evaluate (102). In previous studies of fatal sharp force injuries, the manner of death is routinely determined by the forensic pathologist (27–29,39), who based the assessment in whole or in part on the variables that are analysed. This creates a risk that the associations identified between these variables and the manner of death just reproduce the expert's original reasoning, rather than provide independent evidence for the association. It should, however, be acknowledged that forensic pathologists are experts in this field and whose determinations reflect the current state of knowledge.

The study results of **Paper I, II and III** relied on the classification of the manner of death determined by forensic pathologists. Even if forensic pathologists are experts in this manner and all such forensic assessments in Sweden are performed in agreement between two physicians, of which at least one is a board-certified forensic pathologist, the results must be interpreted with this methodological limitation in mind.

With this recognition, **Paper IV** was designed specifically to reduce the potential of circular reasoning. By focusing on corroborated assaults, verified through either a perpetrator's confession or eyewitness testimony, the study established an independent reference standard for the outcome classification. However, it should be noted that the corroborating evidence in Paper IV derived from the background material representing preliminary information from the police investigation, not from final court verdicts. The trustworthiness of the perpetrator confessions and witness statements were therefore not verified within the study. Still, this design could be expected to substantially reduce classification bias compared to the autopsy-based populations with no external evidence that support the manner of death determined by the forensic pathologist.

Strengths and limitations

A major strength of this thesis is the nationwide scope, which represent all forensic autopsies and clinical forensic examinations in Sweden, with access to detailed data, from the forensic registries. The inclusion of both fatal and surviving cases allowed the investigation of injury severity and fatal outcome in the natural course.

Although this thesis represents, to our knowledge, the largest cohort to date of single stab injuries aimed at differentiating between interpersonal and self-inflicted violence, the limited sample size has resulted in low statistical power, particularly in the multivariable logistic regression analyses. Additionally, the data did not allow adjustment for psychiatric history and abuse as confounders in the analyses using homicides as an outcome group, because of the relatively small sample size and high numbers of missing data. In more extended multivariable models, adjustment for ethnicity, socio-economic status and educational level of the victims would have been warranted when evaluating injury causation, as well as adjustment for comorbidity when predicting fatal injuries in the natural course. The limitation of the relatively small sample size reflects the broader challenge of studying infrequent injury patterns, such as single stabs to the trunk, which inherently generate small cohorts even when using nationwide data. As emphasised in a recent meta-analysis co-authored by myself and the main supervisor of this thesis (103), achieving scientific robustness in such narrowly defined fields will depend on cross-national collaboration and meta-analyses.

The retrospective design restricted access to certain detailed information, particularly contextual data occasionally missing from police records and descriptions of injury characteristics that were incomplete or missing in medical records. Using material exclusively from the forensic registries also introduced selection bias, primarily due to the exclusion of survivors who did not undergo forensic assessment. As a result, the study population of survivors involved only cases subjected to police investigation with a request for forensic assessment and may therefore have been biased toward more severe injuries, thus underrepresenting less severe cases. Also, a suitable comparison group of survivors with self-inflicted stab injuries could not be established, as too few such cases were available in the registry within the study period. Consequently, the analyses in Paper IV lacked a reference population that would have enabled direct comparison between assaults and self-inflicted stabbings among survivors. However, the nationwide scope of the study and the mandatory referral of traumatic deaths for forensic autopsy in Sweden minimise the risk of excluding fatal cases that would otherwise be excluded in studies relying on hospital data alone.

The application of the standardised scoring system NISS, ensured comparability with international trauma research, even if the score originated from hospital populations (104). In addition, performing inter-rater reliability testing of NISS between two raters independently, with satisfactory results, contributes to robust NISS data in Paper II and V. It should be acknowledged that the scoring system is based on anatomical injuries and does not account for other established predictors of fatal outcome, such as physiological derangement, age, or comorbidity (105,106). As a result, the generalisability of the findings may be limited in populations with markedly different age distributions or health profiles. Likewise, patterns of interpersonal violence, and access to timely healthcare vary internationally, which means that the characteristics of injury causation identified in this thesis may not be directly applicable to countries where the epidemiology of violence, weapon use, or healthcare delivery differs substantially from the Swedish context. Moreover, although both the MODSIT and NISS models exhibited excellent discriminatory performance within the studied populations, they were validated internally using the same datasets, which may have led to an overestimation of their predictive accuracy. Independent external validation, across different countries and age groups, is therefore necessary to confirm their discriminatory performance and applicability.

Conclusions

This thesis aimed to strengthen the scientific basis for forensic assessments of sharp force injuries by using single stab injuries to the trunk as a model for developing evidence-based approaches in forensic medicine. By using nationwide registry-based data from fatalities and survivors, and integrating scoring systems, the studies demonstrate how systematic, quantitative methods can complement expert interpretation in forensic practice. The papers of this thesis concluded:

I. Homicide victims were conclusively associated with male under 30 years outdoor death scene, absence of weapon, stab wound to the lateral or posterior trunk, penetrating the bones of the ribcage, vertically orientated entrance wound, defensive wounds, and alcohol influence. In contrast, suicide victims were associated with being found in their home, the weapon remaining in situ, suicide letter, with stab wound to the left side of the thorax or the frontal midline, intercostal injury, horizontally orientated entrance wound, and hesitation wounds.

II. Examination of internal injuries and severity revealed that suicides more often involved cardiac injuries, whereas homicides more commonly involved vascular injuries and higher rates of hospital treatment before death.

III. Based on the findings from paper I, the MODSIT score was developed. The score model 3, which combines injury, death scene, and toxicological variables, demonstrated excellent diagnostic performance in distinguishing homicides from suicides.

IV. While assault survivors shared several demographic, scene and injury characteristic with homicide victims, differences in anatomical distribution reflected the moderate influence of injury severity. Inclusion of corroborated assaults, verified through confessions or eyewitness testimony, reduced the risk of circular reasoning.

V. Applying NISS demonstrated an excellent performance in predicting fatal injuries in the natural course. The findings support its use as a quantitative complement to forensic assessments of life-threatening injuries.

The MODSIT score and NISS demonstrate how reproducible scoring systems hold potential to enhance consistency between forensic pathologists. By introducing measurable, validated methods into forensic practice, this thesis contributes to a more transparent and scientifically grounded approach to the evaluation of sharp force injuries, thereby emphasising reliability and fairness of the judicial process.

Future directions

This thesis has laid a foundation for more systematic and evidence-based approaches to the forensic assessments. However, several important areas for future research have been identified across this thesis.

To further minimise the potential for circular reasoning, future studies should incorporate judicial verdicts when classifying the causation of fatal and survived injuries. Using classifications based on verdicts, rather than relying on forensic assessments with or without corroborating evidence from an early stage of the police investigation, would strengthen the external validity.

The MODSIT score requires validation in larger and more diverse populations, including victims with various numbers of stabs injuries with both survived and fatal outcome, to confirm its diagnostic performance and establish its generalisability beyond single stab injuries to the trunk. Similarly, application of NISS in forensic populations should also be validated in larger populations, encompassing a broader spectrum of trauma mechanisms such as involvement of firearm injuries, and potentially also blunt violence. Such studies would hold potential to enable an evidence-based scale of diagnostic certainty, quantifying how different score intervals correspond to probabilities of injury causation and severity. Once validated, this approach could facilitate more standardised reporting and promote consistency across forensic studies.

Future forensic research on injury severity could explore the progression of minor injuries in patients that are admitted for observation at the hospital to determine the frequency of late complications such as rebleeding, expansion of pneumothoraxes or infection. Such longitudinal data could contribute to a more evidence-based estimation of risk in cases with penetrating injuries that initially required no or just minor medical interventions. Additionally, age, gender and comorbidity should be systematically investigated as potential confounders of fatal outcome or need for live-saving intentions, to clarify at what point these factors significantly impair the prognosis of injury severity.

Survivors of self-inflicted stab injuries, who would serve as relevant reference group for survivors of assault in clinical forensic research, rarely become subjects for forensic assessments and can thereby not serve as a representative study group if collected from the forensic registries. Therefore, prospective studies including patients from emergency departments would be preferable, ideally supplemented with full forensic examinations and detailed blood toxicology analyses.

In parallel with advancing research, there is a need to ensure that variables essential for assessing injury causation and severity are systematically documented in routine practice. Implementing nationwide structured reporting templates, and thereby ensuring consistent documentation by crime scene investigators, emergency physicians, and forensic pathologists, could improve data completeness and reduce inter-observer variability. Achieving this would require a collaboration between forensic medicine, emergency medicine, and the law enforcement, including agreement on the shared data standards. Such a collaboration could further create the opportunity of including data with forensic relevance to the Swedish Trauma register, which could not only facilitate the data collection for future forensic studies, but also enable inclusion of survivors of trauma that are not subjected to a police investigation. An integration of forensic research with routine trauma care would enable prospective collection of physiological data, treatment timelines, and early outcome measures that are difficult to reconstruct retrospectively. Large-scale initiatives such as the Violent Crimes in Skåne (ViCS) project demonstrate the feasibility of linking emergency, prehospital, and forensic medicine data to study injury mechanisms and outcomes in victims of violent crime (107). Extending similar multidisciplinary data-linkage approaches to prospective emergency department studies would strengthen the understanding of injury causation and severity while simultaneously allowing evaluation of emergency pathways, treatments and early predictors of mortality.

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Supplementary table

Table S1. Overview of collected variables, subcategories, and data sources

Variables	Subcategories	Data source
Demographics		
Age	Years (continuous), < 30 / ≥ 30 years	Registry data
Sex	Male / Female	Registry data
Psychiatric history		
Psychiatric diagnosis	Present / Absent	Medical or psychiatric records
Circumstances		
Scene	At home / Other indoor / Outdoors	Police report, forensic scene documentation
Object found	In situ / Found elsewhere / Not found	Police report, forensic scene documentation, ambulance records, photographs
Stab through clothing	Through clothing / No injury through clothing / No clothing	Police report, forensic scene documentation, photographs
Suicide letter	Present / Absent	Police report, forensic scene documentation
Toxicological analyses		
Alcohol	Present / Absent	Toxicology or medical records
Illicit drugs	Present / Absent	Toxicology or medical records
Injury characteristics		
Anatomical location	Thorax / Abdomen	Autopsy or clinical report, photographs
Anatomical location	Anterior / Right axillary / Left axillary / Posterior	Autopsy or clinical report, photographs
Anatomical location	Midline and left thorax at the frontal trunk / Other area at the frontal thorax	Autopsy or clinical report, photographs
Penetrating the thoracic and/or abdominal cavity	Present / Absent	Autopsy or clinical report, medical records
Injury to the thoracic wall	Bony part of the ribcage / Intercostal space	Autopsy or clinical report, medical records
Orientation of the entrance wound	Horizontal / Vertical / Diagonal down-right / Diagonal down-left	Autopsy or clinical report, photographs
Length of the injury channel	cm (continuous)	Autopsy or clinical report, medical records
Orientation of injury channel	Cranial / Caudal / Horizontal, Medial / Lateral / Sagittal	Autopsy or clinical report, medical records
Defensive injuries	Present / Absent	Autopsy or clinical report, photographs
Hesitation injuries	Present / Absent	Autopsy or clinical report, photographs
Severity		
Organ and vessel injuries	Heart / Vessel(s) / Lung(s) / Liver / Spleen / Pancreas / Stomach and intestines / Urogenital	Autopsy or clinical report, medical records
NISS	Continuous, Potential survivable / Unsurvivable, Minor / Moderate / Severe / Critical	Autopsy or clinical report, medical records
Time until death	Found ≥ 24h after stabbing / Found < 24h	Police report
Medical care		
Type of care	Hospital care / Ambulance care / None	Medical and ambulance records
Complexity of medical interventions	No or minimal / Moderate / Life-saving interventions	Medical and ambulance records

The table summarises all variables included in Papers I–V, their subcategories, and the sources from which each variable was extracted.
NISS, New Injury Severity Score;

Table S2. Multivariable logistic regression analyses of variables associated with homicides, survivors of corroborated assaults and all survived assaults

Variabels	Homicides (Ref suicides), OR (95% CI)	Survived corroborated assaults (Ref survived non-corroborated), OR (95% CI)	All survived assaults (Ref homicides), OR (95% CI)
Other indoor location than home	18.7 (4.5–77.5)	1.3 (0.7–2.5)	0.5 (0.3–1.1)
Outdoor location	17.4 (5.2–57.9)	0.7 (0.4–1.3)	0.5 (0.3–1.0)
At home	Ref	Ref	Ref
Weapon found in situ	0.01 (0.002–0.08)	0.6 (0.1–2.9)	0.9 (0.2–3.7)
Weapon found elsewhere	0.03 (0.005–0.1)	2.6 (1.7–4.1)	1.5 (0.9–2.5)
No weapon found	Ref	Ref	Ref
Defect in clothing	15.7 (1.2–200.4)	33.5 (0.8–1438.1)	0.4 (0.03–5.6)
No clothing	3.4 (0.3–45.7)	error	error
No defect in clothing	Ref	Ref	Ref
Suicide note	error		
No suicide note	Ref		
Alcohol	6.9 (2.7–17.9)	1.8 (1.1–2.9)	0.3 (0.2–0.4)
No alcohol	Ref	Ref	Ref
Illicit narcotics	2.9 (1.0–8.5)	0.9 (0.4–2.2)	0.1 (0.06–0.2)
No illicit narcotics	Ref	Ref	Ref
Abdomen	1.2 (0.5–3.1)	1.3 (0.8–2.0)	1.8 (1.1–3.1)
Thorax	Ref	Ref	Ref
The back	error	1.2 (0.7–1.9)	3.8 (1.9–7.5)
Right axillary region	error	1.1 (0.4–2.6)	2.2 (0.7–6.8)
Left axillary region	error	2.1 (1.1–3.8)	3.8 (1.5–9.1)
Frontal trunk	Ref	Ref	Ref
Area other than the midline and left thorax at the frontal trunk	3.6 (1.0–13.5)	0.9 (0.5–1.4)	1.5 (1.0–2.6)
Midline and left thorax at the frontal trunk	Ref	Ref	Ref
Penetrating		2.2 (1.3–3.5)	
Non-penetrating		Ref	
Bones/cartilage of the ribcage	2.8 (1.3–6.2)	1.2 (0.6–2.5)	0.1 (0.1–0.2)
Intercostal space	Ref	Ref	Ref
Vertical oriented entrance wound	7.1 (1.8–28.7)	1.7 (0.8–3.7)	0.8 (0.4–1.5)
Down–right-oriented entrance wound	2.9 (1.0–8.8)	0.9 (0.4–2.1)	0.5 (0.2–0.9)
Down–left-oriented entrance wound	1.3 (0.5–3.7)	1.3 (0.6–2.9)	1.2 (0.5–2.6)
Horizontal oriented entrance wound	Ref	Ref	Ref
Length of the injury channel*, median (range) (cm)	1.1 (0.9–1.3)	1.1 (0.9–1.2)	0.7 (0.6–0.8)

Variabels	Homicides (Ref suicides), OR (95% CI)	Survived corroborated assaults (Ref survived non-corroborated), OR (95% CI)	All survived assaults (Ref homicides), OR (95% CI)
Cranial injury channel	0.2 (0.08–0.7)	1.5 (0.5–4.3)	1.1 (0.5–2.3)
Straight horizontal injury channel	0.2 (0.03–1.7)	error	0.2 (0.03–2.1)
Caudal injury channel	Ref	Ref	Ref
Lateral injury channel	0.3 (0.09–1.07)	0.8 (0.2–3.1)	0.7 (0.3–1.8)
Straight sagittal injury channel	0.2 (0.03–1.7)	error	0.3 (0.03–2.8)
Medial injury channel	Ref	Ref	Ref
Defensive wounds	9.7 (0.9–93.7)	0.5 (0.2–1.1)	0.7 (0.3–1.5)
No defensive wounds	Ref	Ref	Ref
Hesitation wounds	error		
No hesitation wounds	Ref		

Multivariable logistic regression models, adjusting for gender and age, presenting associations between variables, and the classifications of homicides using suicides as a reference and also survived assaults using homicides as a reference. Also, a multivariable logistic regression model adjusting for gender, age, psychiatric history and alcohol and/or narcotic abuse, presenting associations between variables, and survivors of corroborated assaults using survivors of non-corroborated assaults as a reference.

Ref, Reference; OR, Odds Ratio; CI, Confidence Interval

MARIA BERG VON LINDE began her career in forensic medicine as a resident physician at the unit of Forensic Medicine in Lund in 2019 and enrolled as a PhD student two years later, combining clinical work with research. Since 2024 she has been working as a board-certified forensic pathologist. This thesis brings together her doctoral work, driven by an interest in strengthening the scientific foundations of forensic assessments and contributing to a more evidence-based practice.

Picture taken by Therese Bondesson in 2024 at a forensic conference maintained by Deutsche Gesellschaft für Rechtsmedizin (DGRM) in Potsdam, Germany.

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