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Increased Incidence and Mortality of Civilian Penetrating Traumatic Brain Injury in Sweden: A Single-Center Registry-Based Study

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■ BACKGROUND: **Penetrating trauma to the head and neck has increased during the past decade in Sweden. The aim of this study was to characterize these injuries and evaluate the outcomes for patients treated at a tertiary trauma center.**

■ METHODS: **Swedish trauma registry data were extracted on patients with head and neck injuries admitted to Karolinska University Hospital (Stockholm, Sweden) between 2011 and 2019. Outcome information was extracted from hospital records, with the primary endpoints focusing on the physiological outcome measures and the secondary endpoints on the surgical and radiological outcomes.**

■ RESULTS: **Of 1436 patients with penetrating trauma, 329 with penetrating head and neck injuries were identified. Of the 329 patients, 66 (20%) had suffered a gunshot wound (GSW), 240 (73%) a stab wound (SW), and 23 (7%) an injury from other trauma mechanisms (OTMs). The median age for the corresponding 3 groups of patients was 25, 33, and 21 years, respectively. Assault was the primary intent, with 54 patients experiencing GSWs (81.8%) and 158 SWs (65.8%). Patients with GSWs had more severe injuries, worse admission Glasgow coma scale, motor, scores, and a higher intubation rate at the injury site. Most GSW patients underwent major surgery (59.1%) as the initial procedure and were more likely to have intracranial hemorrhage (21.2%). The 30-day mortality was 45.5% ($n = 30$) for GSWs, 5.4% ($n = 13$) for SWs, and 0% ($n = 0$) for OTMs. There was an annual increase in the incidence and mortality for GSWs and SWs.**

■ CONCLUSIONS: **Between 2011 and 2019, an increasing annual trend was found in the incidence and mortality from penetrating head and neck trauma in Stockholm, Sweden. GSW patients experienced more severe injuries and intracranial hemorrhage and underwent more surgical interventions compared with patients with SWs and OTMs.**

INTRODUCTION

Trauma is a major public health concern worldwide and the single largest factor in death and severe disability for those aged <45 years. Furthermore, it results in a significant

Key words
- Civilian penetrating traumatic brain injury
- GSW
- Head and neck trauma
- Incidence
- Penetrating trauma
- SW
- Sweden

Abbreviations and Acronyms
CT: Computed tomography
GCS: Glasgow coma scale
GCS-M: Glasgow coma scale, motor
GOS: Glasgow outcome scale
GSW: Gunshot wound
ICH: Intracranial hematoma
ICP: Intracranial pressure
ICU: Intensive care unit
IQR: Interquartile range
ISS: Injury severity score
NISS: New injury severity score
OTM: Other trauma mechanism
SW: Stab wound
SweTrau: Svenska Trauma Registret (Swedish Trauma Registry)
TBI: Traumatic brain injury

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Citation: World Neurosurg. (2024) 182:e493-e505.
https://doi.org/10.1016/j.wneu.2023.11.129

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

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burden of death and disability in all other age groups.[1,2] In the United States, 30,000 patients are hospitalized annually for gunshot wounds (GSWs), of whom 2500 die.[3,4] South Africa, although seeing an annual decrease in firearm homicides, still carries a significant financial and public health burden related to the complex nature of penetrating violence.[4,5] Knife and stab wounds (SWs) carry a similar burden on both public health and healthcare resources and constitute 12%–13% of all major traumas.[6-8] In Europe, penetrating trauma has previously not been considered a major public health issue; however, the injuries and deaths caused by knives and firearms are increasing.[7,9-12] Nevertheless, very few studies have been conducted on the epidemiology of penetrating trauma in Europe.[9,10] Moreover, the available literature is focused on penetrating trauma in general, with little or no data on penetrating head and neck injuries.[9,10,12]

In Sweden, the increasing number of homicides involving firearms has become a pressing criminal policy concern. Sweden is now among the leading countries in the European Union with higher per capita rates of homicides involving firearms.[13,14] Although the increasing trend of penetrating trauma has been reported, little in known regarding the specifics of these injuries.[15,16] As such, data on penetrating head and neck injuries in Sweden are lacking. Consequently, surgical intervention in the case of head and neck injuries, especially cases of penetrating traumatic brain injury (TBI), remains highly controversial. This issue is even more complex for patients with low Glasgow coma scale (GCS) scores, because these patients are assumed to have a poor prognosis, further limiting the data on interventions and outcomes, because interventions are seldom performed.[17,18] We have recently reported on penetrating injuries in Sweden, demonstrating the highest mortality in the subgroup with GSWs and that most penetrating injuries were located in the head and neck region.[19] Furthermore, an analysis of the geographical distribution revealed that the trauma center situated in Stockholm, Sweden, had admitted and treated most of these patients.[19]

The aim of this study was to investigate the characteristics and outcomes of patients with penetrating trauma to the head and neck region treated at a tertiary trauma center in Stockholm, Sweden, with the highest number of penetrating head and neck injury admissions in Sweden.

METHODS

Study Design and Setting

Patient data were retrieved from the Svenska Trauma Registret (National Swedish Trauma Registry [SweTrau]) and local medical records. We performed a retrospective cohort study using data from the Karolinska University Hospital, the primary level 1 trauma center in the Stockholm region. Data were collected for January 1, 2011 to December 31, 2019. Karolinska University Hospital has an uptake area of ~2.8 million people, accounting for ~27% of the Swedish population.[15,16]

Ethical Approval

The government agency for ethical approval provided an ethics permit for the present study (approval no. Dnr 2019/02842).

Data Sources, Collection, and Study Population

The SweTrau is a national registry founded in 2011 that follows the *Utstein Trauma Template for Uniform Reporting of Data Following Major Trauma: Data Dictionary*.[15,16] With a Swedish trauma center catchment rate of 84%, SweTrau records data for all admitted trauma patients of all ages and genders if they activated a trauma alert or admitted patients with a new injury severity score (NISS) of >15 who did not activate a trauma alert.[15,16] SweTrau automatically excludes those who do not fulfill these criteria or whose only traumatic injury is a chronic subdural hematoma.[15,16]

Using SweTrau, all registered admissions for penetrating trauma to Karolinska University Hospital between 2011 and 2019 were extracted. Further selection for relevant anatomical injury locations was determined using the abbreviated injury scale and International Classification of Diseases codes. During the initial inclusion, all patients with penetrating trauma lacking proper abbreviated injury scale registration were also included to ensure inclusion of the total patient cohort. Specific injury locations were then extracted from the hospital records to allow for proper exclusion of nonrelevant patients, without confounding by registry errors. Exclusion criteria were no national identification number and a lack of anatomically or mechanistically relevant injuries. The included patients were then grouped according to the primary mechanism for the penetrating trauma. "Other trauma mechanisms" (OTMs) were defined as a penetrating trauma mechanism that could not be classified as a SW or GSW (e.g., animal bites). For all patients, only 1 injury mechanism was recorded, even if multiple were present; thus, the primary and most relevant mechanism was chosen. No further data regarding the injury mechanism such as weapon caliber data, military equipment classification, or firearm mechanism were available from either the medical records or the trauma registry. Thus, no differentiation regarding this information and its relationship to the observed outcomes was available.

Data on hospital arrival, age, sex, personal identification number, and Glasgow coma scale, motor (GCS-M), score were extracted from SweTrau and checked against the data in the medical records. The following data were extracted only from the patient medical records: fracture occurrence, fracture type, surgical intervention at arrival and admission, number of interventions, type of interventions, penetrating trauma type, minutes from arrival to surgery, other injuries, pupillary reflex at arrival, intracranial penetration engagement of hemispheres and lobes, total hematoma volume, dominant hematoma volume and type, presence of intracranial hemorrhage (ICH), presence of subdural hematoma, presence of bilateral subdural hematomas, presence of epidural hematoma, presence of subarachnoid hemorrhage, midline shift, patency of basal cisterns, presence of intraventricular hemorrhage (IVH), and signs of diffuse axonal injuries to the basal ganglia, splenium, or brainstem. Additionally, the glucose levels, hemoglobin, and systolic blood pressure at admission were recorded from the medical records in accordance with the recommendations from the IMPACT studies.[20] For the neuroradiological assessment, we used the Marshall computed tomography (CT) classification and Stockholm CT score.[21]

Outcome Measures

The primary endpoints were the GCS, GCS-M, and Glasgow outcome scale (GOS) scores at discharge and 30-day mortality. As

part of the GCS-M scoring registration, all cases of prehospital intubation, performed according to international principles per airway patency, were not registered with a GCS-M score in SweTrau but simply registered as intubated before hospital admission when arriving at the trauma center. The secondary endpoints were the number of surgical interventions, types and severity of injuries, and radiological severity. The severity of the injuries was differentiated by the NISS and ISS scores. Surgical interventions were graded as either major or minor surgery, with major surgery defined as all surgical procedures recorded aside from simple wound suturing. Surgical interventions occurring directly after the primary trauma survey were further classified as the initial procedures to allow for visualization of which interventions occurred emergently during admission compared with the total number of interventions performed during the inpatient period.

Statistical Analysis

Due to the descriptive nature of the study, we performed descriptive statistical analyses on the collected data. Data are presented as the mean and median with the interquartile range (IQR) for scale data and counts and percentages for nominal data. Data preparation and analysis were performed with IBM SPSS Statistics, version 28.0 (IBM Armonk, New York, USA) and R, version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria). Data points that could not be recovered from the registry records or medical records were not directly recorded in the descriptive analyses but were labeled as unknown and presented appropriately in the tabular data.

RESULTS

A total of 1436 patients suffered penetrating trauma during the study period, of whom 640 met our inclusion criteria for initial selection. Next, using our exclusion criteria, all patients with nonrelevant injuries were excluded, for a final patient cohort of 329 patients with penetrating head and neck injuries. The results of the patient selection are shown in **Figure 1**.

Demographics

The general patient demographics are presented in **Table 1**. Of the 329 patients, 66 admitted patients suffered a GSW (20%), 240 patients a SW (73%), and 23 patients (7%) had experienced injures with OTMs to at least one relevant anatomical location.

The median age was 25 years (IQR, 21–37 years), 33 (IQR, 24–49 years), and 21 years (IQR, 3–41 years) for the GSW, SW, and OTM groups, respectively. Male patients accounted for 95.5% of the GSWs, 90.0% of the SWs, and 78.3% of the OTMs. Most patients (79.3%) had American Society of Anesthesiologists classification grade 1 before their injuries (**Table 1**). The severity of the GSW injuries was greater than that for injuries with OTMs, reflected in the median GSW ISS and NISS scores of 25 (IQR, 10–38) and 33 (IQR, 12–57), respectively. The median ISS and NISS scores for SWs and OTMs was 5 (IQR, 1–11) and 6 (IQR, 3–14) and 5 (IQR, 2–9) and 9 (IQR, 3–13), respectively. The GSW group had a median ward stay of 2 days, similar to that for the SW and OTM groups and was the only group with a recorded intensive care unit (ICU) stay. The median ICU stay for the GSW group was 0 days (IQR, 0–3 days).

The GCS-M score varied widely among the different trauma mechanisms, showing the heterogeneity of the admitted trauma patient population. Of the admitted GSW patients, only 30 (45.5%) had a GCS-M score of 6. In contrast, those with SWs mainly had unaffected motor status (209 patients; 87.1%) with a GCS-M score of 6. In addition, 26 patients in the GSW group (39.4%) were intubated in the prehospital setting. Also, patients with GSWs more frequently had an abnormal pupil response and hypotension (systolic blood pressure <90 mm Hg) on admission ($n = 19$ [28.8%] and $n = 24$ [36.4%], respectively). GSWs and SWs were primarily associated with an intention of assault, with 54 patients with GSWs (81.8%) and 158 patients with SWs (65.8%) recorded as caused by an assault. Self-inflicted injuries were uncommon for all 3 groups, although relatively more common in SW group than in the other groups. Accidents were also uncommon, with only 3 GSW patients (4.5%) and 22 SW patients (9.2%) injured by accident. OTMs were mostly caused by accidents, accounting for 19 patients (82.6%; **Table 1**).

Surgical Interventions

The initial and total number of surgical interventions for the admitted patients are presented in **Table 2**. In the GSW group, 44 patients (66.7%) underwent an initial emergency procedure; 39 patients (59.1%) had major surgery as an initial procedure, of whom 20 (30.3%) underwent craniotomy, spine surgery, and intracranial pressure (ICP) monitoring. Thus, the GSW group was the patient subgroup with the most neurosurgical interventions.

Of the SW and OTM groups, 223 patients (92.9%) and 20 patients (87%), respectively, underwent an initial emergency procedure. These were all wound revisions, except for 1 craniotomy and 2 ear, nose, and throat/plastic surgery procedures (**Table 2**). The total patient population underwent a large breadth of surgical interventions, representing a large surgical subspeciality need, with suturing, wound revisions, and ear, nose, and throat/plastic surgery the dominant procedures in all 3 subgroups (**Table 2**).

Neuroradiological Investigations

A CT scan of the head was performed in most cases, with 50 GSW patients (75.6%), 144 SW patients (60.0%), and 14 OTM patients (60.9%) undergoing a CT scan of the brain (**Table 3**). Hematomas of all types were more common in the GSW group than in the SW or OTM group, with ICH having the largest volume of the hematoma subgroups in the GSW group. The GSW group (22.7%) was also the only group with intraventricular hemorrhage (IVH). However, 51.5% of the GSW, 58.8% of the SW, and 52.2% of the OTM groups who underwent CT scan of the head and brain did not have any visible hematoma. Additionally, few cases of hematoma occurred in the SW and OTM groups, and most hematomas had a volume of <0.005 cm^3. Radiological features suggesting an increased ICP such as basal cistern compression and obliteration were only seen in 7 GSW patients (10.6%) and 1 SW patient (0.4%). The occurrence of brain penetration was greater in the GSW patients, with single hemispheric and bilateral hemispheric trajectories in 22 patients compared with 2 patients in the SW group and no patient in the OTM group.

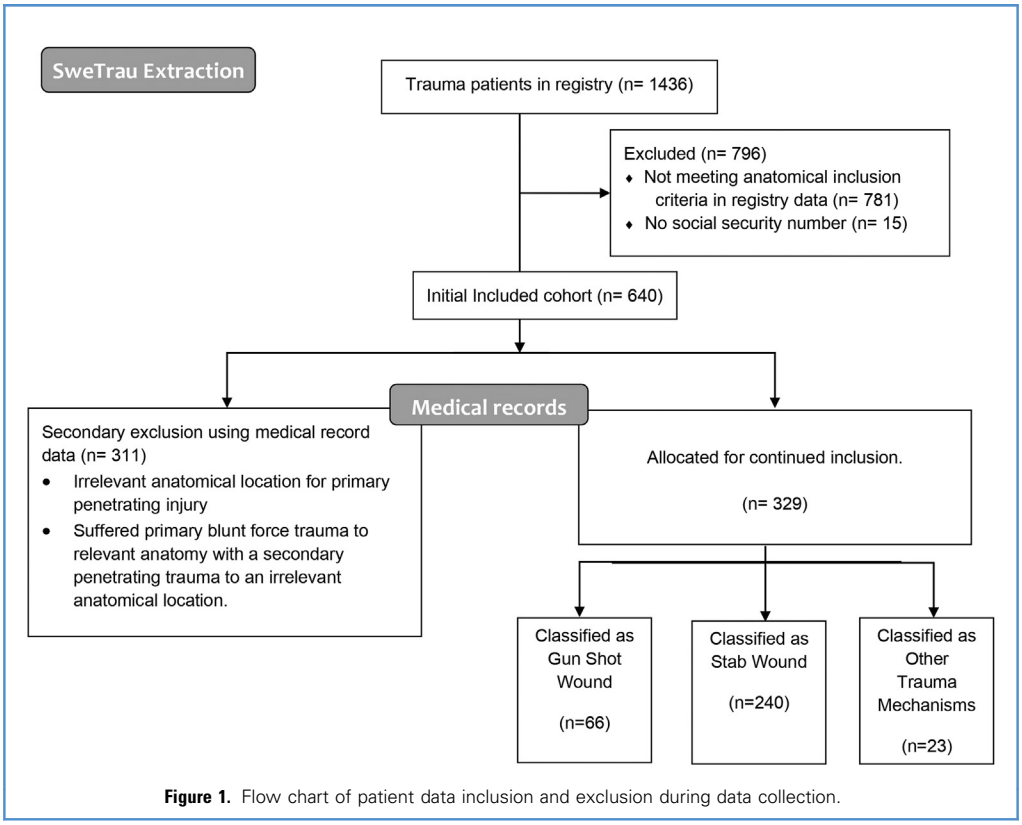

Figure 1. Flow chart of patient data inclusion and exclusion during data collection.

Incidence of Trauma and Mortality

The overall 30-day mortality from admission was 45.5% (30 patients) for the GSW group, 5.4% (13 patients) for the SW group and 0% (0 patients) for the OTM group. This distribution of mortality is further reflected in the GOS scores for the different patient groups, with the GSW group associated with more severe disability at discharge compared with the SW and OTM groups. An increase in the annual incidence of penetrating head and neck trauma was seen between 2011 and 2019, for both GWSs and SWs but not OTMs (**Figure 2A**). A similar annual increasing trend could be also seen for 30-day mortality for patients with penetrating head and neck trauma (**Figure 2B**). A large increase in trauma volumes occurs after 2012, lowering the relative mortality but increasing the total mortality. Patients with GSWs had higher mortality (GOS score at discharge), and most patients with SWs had moderate disability and good recovery at discharge (**Figure 3**).

DISCUSSION

This registry-based retrospective study investigated the characteristics and outcomes of patients with penetrating trauma to the head and neck treated at our level 1 trauma center in Stockholm, Sweden. To the best of our knowledge, this is the largest European cohort focusing exclusively on civilian head and neck penetrating trauma. The main findings of our study were as follows. First, we found an increasing annual trend of incidence and mortality from penetrating head and neck trauma between 2011 and 2019 in Stockholm, Sweden. Second, patients with GSWs had more severe injuries compared with the patients with SWs and OTMs, as reflected by the worse GCS-M scores at admission and a higher rate of intubation before admission at the site of injury. Patients with GSWs more often had an ICH, and most GSW patients underwent major surgical procedures. Third, although an increase occurred in the incidence of both GSWs and SWs, the outcomes were different for these 2 groups of patients. The 30-day mortality was highest for the GSW group, and these patients also had more severe disability at discharge. Patients with SWs were more likely to have moderate disability outcomes at discharge and good recovery. Moreover, we observed that both GSWs and SWs were primarily associated with assaults.

Compared with earlier studies, our GSW cohort had higher mean and median NISS and ISS scores. In Sweden, between 2005 and 2016, the GSW group had a mean ISS score of 14.3.[9] A German study reported by Bieler et al.[22] reported a mean ISS score of 22.9 for those with GSWs. In England, the median NISS score for all GSWs between 1998 and 2007 was 18.[23] In another study, German patients with penetrating trauma had a mean ISS score of 12.3.[24] In the U.S. Trauma Quality Improvement Program database, patients with GSWs to the head between 2010 and 2014 had a median ISS score of 21.[25] Although a direct comparison with the other studies might not be feasible due to methodological differences, the findings indicate that GSW patients who suffer a primary head and neck injury experienced more severe trauma than the general GSW population. For patients with SWs, we

Table 1. General Epidemiology of Penetrating Trauma Patients (2011—2019)

	Trauma Mechanism		
Variable	**Gunshot Wound**	**Stab Wound**	**Other**
Age (years)			
Mean	31	37	28
Median (IQR)	25 (21—37)	33 (24—49)	21 (3—41)
ISS			
Mean	29	9	7
Median (IQR)	25 (10—38)	5 (1—11)	5 (2—9)
NISS			
Mean	36	12	9
Median (IQR)	33 (12—57)	6 (3—14)	9 (3—13)
ICU stay (days)			
Mean	4	1	0
Median (IQR)	0 (0—3)	0 (0—0)	0 (0—0)
Hospital stay (days)			
Mean	9	3	4
Median (IQR)	2 (1—8)	2 (1—4)	2 (2—5)
Gender			
Male	63 (95.5)	216 (90.0)	18 (78.3)
Female	3 (4.5)	24 (10.0)	5 (21.7)
Mortality			
≤24 hours	25 (37.9)	10 (4.2)	0 (0.0)
≤30 days	30 (45.5)	13 (5.4)	0 (0.0)
≤360 days	30 (45.5)	20 (8.3)	0 (0.0)
Anatomical location			
Head	38 (57.6)	64 (26.7)	4 (17.4)
Face	20 (30.3)	63 (26.3)	14 (60.9)
Neck	8 (12.1)	113 (47.1)	5 (21.7)
Injury intention			
Accident	3 (4.5)	22 (9.2)	19 (82.6)
Self-inflicted	8 (12.1)	57 (23.8)	1 (4.3)
Assault	54 (81.8)	158 (65.8)	3 (13.0)
Unknown	1 (1.5)	3 (1.3)	0 (0.0)
GCS-M score at admission			
1	7 (10.6)	6 (2.5)	0 (0.0)
4	0 (0.0)	1 (0.4)	0 (0.0)
5	3 (4.5)	4 (1.7)	2 (8.7)

Data presented as n (%), unless noted otherwise.

IQR, interquartile range; ISS, injury severity score; NISS, new injury severity score; ICU, intensive care unit; GCS-M, glasgow coma scale, motor; GOS, glasgow outcome scale; SBP, systolic blood pressure; ASA, american society of anesthesiologists

*Relevant fractures include only head, face and neck fractures occurring from the trauma incident; thus, patients who might have experienced other fractures were considered to not have relevant fractures.

Continues

Table 1. Continued

Variable	Trauma Mechanism		
	Gunshot Wound	Stab Wound	Other
6	30 (45.5)	209 (87.1)	19 (82.6)
Intubated before arrival	26 (39.4)	17 (7.1)	2 (8.7)
Unknown	0 (0.0)	3 (1.3)	0 (0.0)
GOS at discharge			
Death	29 (43.9)	13 (5.4)	0 (0.0)
Persistent vegetative state	0 (0.0)	0 (0.0)	0 (0.0)
Severe disability	11 (16.7)	12 (5.0)	1 (4.3)
Moderate disability	16 (24.2)	132 (55.0)	17 (73.9)
Good recovery	9 (13.6)	83 (34.6)	5 (21.7)
Pupil response at admission			
Normal	15 (22.7)	96 (40.0)	11 (47.8)
Right eye altered	0 (0.0)	0 (0.0)	0 (0.0)
Left eye altered	0 (0.0)	0 (0.0)	0 (0.0)
Bilaterally altered	1 (1.5)	1 (0.4)	1 (4.3)
Right eye, no response	2 (3.0)	0 (0.0)	0 (0.0)
Left eye, no response	2 (3.0)	0 (0.0)	0 (0.0)
Bilaterally, no response	19 (28.8)	10 (4.2)	0 (0.0)
Unknown	27 (40.9)	133 (55.4)	11 (47.8)
SBP at admission (mm Hg)			
>90	47 (71.2)	217 (90.4)	21 (91.3)
<90	19 (28.8)	23 (9.6)	0 (0.0)
Unknown	0 (0.0)	0 (0.0)	2 (8.7)
Fracture*			
None relevant	10 (15.2)	117 (48.8)	4 (17.4)
Relevant fracture	43 (65.2)	36 (15.0)	8 (34.8)
Unknown	13 (19.7)	87 (36.3)	11 (47.8)
ASA class before trauma			
1	54 (81.8)	190 (79.2)	18 (78.3)
2	10 (15.2)	37 (15.4)	3 (13.0)
3	2 (3.0)	11 (4.6)	2 (8.7)
Unknown	0 (0.0)	2 (0.8)	0 (0.0)

Data presented as n (%), unless noted otherwise.
IQR, interquartile range; ISS, injury severity score; NISS, new injury severity score; ICU, intensive care unit; GCS-M, glasgow coma scale, motor; GOS, glasgow outcome scale; SBP, systolic blood pressure; ASA, american society of anesthesiologists
*Relevant fractures include only head, face and neck fractures occurring from the trauma incident; thus, patients who might have experienced other fractures were considered to not have relevant fractures.

observed lower ISS and NISS scores compared with patients with GSWs; however, compared with the existing penetrating trauma literature, those severity scores were lower for the SW patients included in our analysis. A German study conducted between 2009 and 2018 showed that patients with SWs had a mean ISS score of 13.9 and a median score of 10, an ISS score higher than that of our SW patients.[24] The German data for SWs included mostly older patients, had a greater proportion of self-inflicted injuries (30.8%) compared with our study (23.8%), and covered more anatomical localities.[24] This could explain the differences in ISS

Table 2. Surgical Epidemiology of Penetrating Trauma Patients (2011–2019)

	Trauma Mechanism		
Variable	**Gunshot Wound**	**Stab Wound**	**Other**
Initial emergency procedure			
Thoracotomy	5 (7.6)	5 (2.1)	0 (0.0)
Laparotomy	2 (3.0)	14 (5.8)	0 (0.0)
Vascular	0 (0.0)	1 (0.4)	0 (0.0)
ENT/MaxFac/plastic surgery	1 (1.5)	0 (0.0)	2 (8.7)
Craniotomy	8 (12.1)	4 (1.7)	1 (4.3)
Intercranial pressure monitoring	4 (6.1)	0 (0.0)	0 (0.0)
Laminectomy/spinal surgery	1 (1.5)	0 (0.0)	0 (0.0)
Chest tube	3 (4.5)	20 (8.3)	0 (0.0)
Explorative wound revision	14 (21.2)	77 (32.1)	8 (34.8)
Wound revision, only suturing	4 (6.1)	101 (42.1)	9 (39.1)
Fracture surgery	2 (3.0)	0 (0.0)	0 (0.0)
Procedures performed			
Thoracotomy	5	7	0
Laparotomy	4	17	0
Pelvis packing	0	0	0
Revascularization	3	19	0
Radiological intervention	1	0	0
Craniotomy	9	5	1
Intracranial pressure monitoring	10	0	1
Laminectomy/spine surgery	2	0	0
Flap	3	2	2
Chest tube	4	26	0
External fracture fixation	2	2	0
Major fracture surgery	8	5	1
Wound revision, only suturing	8	128	10
Explorative wound revision	23	92	10
Hematoma evacuated*	3	4	0
Diathermia†	1	24	2
Eye surgery	2	1	4
ENT/MaxFac/plastic surgery	20	48	9

Data presented as n (%) or n, including those who did not undergo any surgical intervention.
ENT, ear, nose, and throat; MaxFac, maxillofacial.
*All hematomas surgically evacuated during the admission period, not just neurosurgically relevant hematomas.
†Patients for whom diathermia was expressly used according to the operating room and preoperative registration records.

scores for SW patients, because we focused on a limited anatomical locality, and the ISS is known to provide a more inadequate depiction of penetrating injuries for single anatomical regions. This is because victims of penetrating trauma often have multiple injuries in the same region, which is not adequately reflected by the ISS.[26]

GSWs more often resulted in intracranial penetration, multiple hemisphere injuries, a higher incidence of ICHs, and signs of an increased ICP. Consequently, these patients had longer inpatient ward and ICU stays compared with those with SWs and OTMs. GSW patients were also more likely to have primary head trauma,

Table 3. Neurosurgical CT Epidemiology of Penetrating Trauma Patients (2011–2019)*

	Trauma Mechanism		
Variable	**Gunshot Wound**	**Stab Wound**	**Other**
Total hematoma volume (cm^3)			
Mean	4.00	0.00	0.33
Median (IQR)	0.00 (0.00–5.08)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Total SDH volume (cm^3)			
Mean	1.40	0.00	0.00
Median (IQR)	0.00 (0.00–0.69)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Total EDH volume (cm^3)			
Mean	0.09	0.00	0.00
Median (IQR)	0.00 (0.00–0.00)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Total ICH volume (cm^3)			
Mean	2.52	0.00	0.33
Median (IQR)	0.00 (0.00–2.50)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Dominant hematoma volume (cm^3)			
Mean	3.36	0.00	0.33
Median (IQR)	0.00 (0.00–3.40)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
Midline shift (mm)			
Mean	2.05	1.15	0.92
Median (IQR)	1.29 (0.80–2.00)	1.10 (0.30–1.70)	0.80 (0.30–1.40)
Stockholm CT score			
Mean	2.06	0.42	1.16
Median (IQR)	1.19 (1.11–3.10)	1.11 (1.03–1.17)	1.08 (1.03–1.14)
Hemispherical trajectory			
No intracranial pathology	28 (56.0)	142 (98.6)	0 (0.0)
Single hemisphere	11 (22.0)	2 (1.4)	0 (0.0)
Both hemispheres	11 (22.0)	0 (0.0)	0 (0.0)
Lobe trajectory			
No intracranial pathology	28 (56.0)	141 (95.9)	0 (0.0)
Unilobular	3 (6.0)	3 (2.1)	0 (0.0)
Multilobular	13 (26.0)	0 (0.0)	0 (0.0)
Transventricular	2 (4.0)	0 (0.0)	0 (0.0)
Skull base	4 (8.0)	0 (0.0)	0 (0.0)
Dominant hematoma type			
SDH	9 (18.0)	2 (1.4)	0 (0.0)
EDH	1 (2.0)	0 (0.0)	0 (0.0)
ICH	12 (24.0)	2 (1.4)	2 (14.3)
ICH			
No	36 (72.0)	142 (98.6)	12 (85.7)
Yes	14 (28.0)	2 (1.4)	2 (14.3)

Continues

Table 3. Continued

Variable	Trauma Mechanism		
	Gunshot Wound	Stab Wound	Other
SDH			
No	34 (68.0)	143 (99.3)	14 (100.0)
Yes	16 (32.0)	1 (0.7)	0 (0.0)
Bilateral SDH			
No	48 (96.0)	144 (100.0)	14 (100.0)
Yes	2 (4.0)	0 (0.0)	0 (0.0)
EDH			
No	48 (96.0)	144 (100.0)	14 (100.0)
Yes	2 (4.0)	0 (0.0)	0 (0.0)
SAH in basal cisterns			
No	38 (76.0)	144 (100.0)	14 (100.0)
<5 mm	1 (2.0)	0 (0.0)	0 (0.0)
>5 mm	11 (22.0)	0 (0.0)	0 (0.0)
SAH in convexities			
No	34 (68.0)	141 (95.9)	13 (92.9)
<5 mm	5 (10.0)	3 (2.1)	0 (0.0)
>5 mm	11 (22.0)	0 (0.0)	1 (7.1)
Basal cisterns			
Open	43 (86.0)	143 (99.3)	14 (100.0)
Lightly compressed	1 (2.0)	1 (0.7)	0 (0.0)
Fully compressed/obliterated	6 (12.0)	0 (0.0)	0 (0.0)
IVH			
No	35 (70.0)	144 (100.0)	14 (100.0)
Yes	15 (30.0)	0 (0.0)	0 (0.0)
DAI			
No	50 (100.0)	144 (100.0)	14 (100.0)
Yes	0 (0.0)	0 (0.0)	0 (0.0)
Marshall CT classification			
I	3 (6.0)	21 (14.6)	3 (21.4)
II	36 (72.0)	123 (85.4)	11 (78.6)
III	4 (8.0)	0 (0.0)	0 (0.0)
IV	6 (12.0)	0 (0.0)	0 (0.0)
V	0 (0.0)	0 (0.0)	0 (0.0)
VI	1 (2.0)	0 (0.0)	0 (0.0)

Data presented as n (%), unless noted otherwise; the data do not include those who did not undergo CT of the brain but only those who had undergone such an examination at admission; reflective of the admitting clinician's judgment of the indication, 16 gunshot wound, 96 stab wound, and 9 other trauma mechanism patients did not undergo CT of the brain at admission and were not included in the tabular data.

CT, computed tomography; IQR, interquartile range; SDH, subdural hematoma; EDH, epidural hematoma; ICH, intracranial hemorrhage; SAH, subarachnoid hemorrhage; IVH, intraventricular hemorrhage; DAI, diffuse axonal injury.

*Because all patients who underwent CT of the brain were included and most did not have a hematoma, the median essentially became 0.

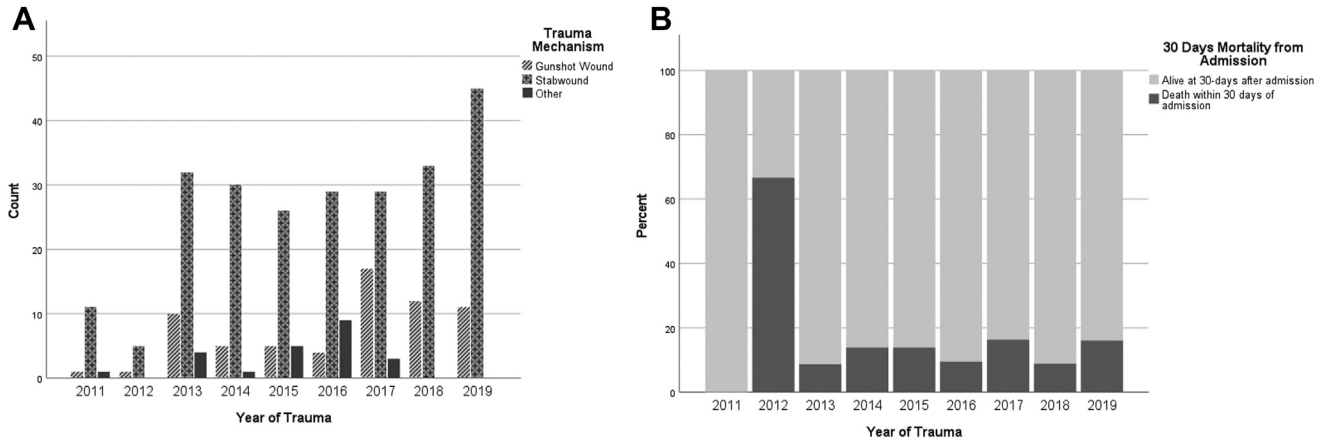

Figure 2. The annual (2011–2019) case incidence of penetrating trauma to the head and neck stratified by (**A**) trauma mechanism and (**B**) 30-day mortality (%).

have an abnormal pupillary response, and undergo initial emergency craniotomy and/or ICP monitoring, indicating that the severity of GSW injuries is higher than that of SWs and OTMs. This data pattern, especially regarding neurosurgical interventions, is similarly reported in some studies, although other studies reported longer ward stays and lower systolic blood pressure for those with SWs.[6,7,19,22-24,27] However, because previous studies mainly focused on either generalized penetrating trauma or solely on GSWs and SWs (in the context of head and neck trauma), we could not determine whether the differences were population specific, anatomically specific, or generalizable to OTMs. Relevant literature for further

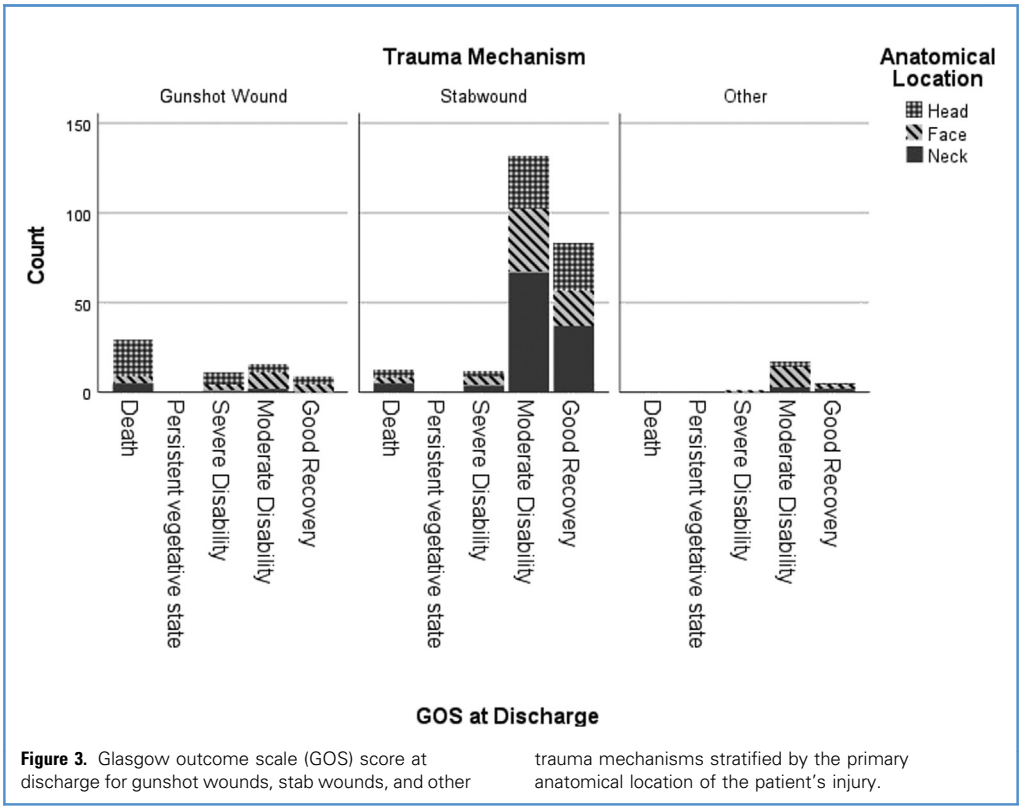

Figure 3. Glasgow outcome scale (GOS) score at discharge for gunshot wounds, stab wounds, and other trauma mechanisms stratified by the primary anatomical location of the patient's injury.

comparisons of the neuroradiological data of TBI due to GSW is also scarce, aside from the known increased mortality incidence that follows greater intracranial pathology, especially multiple hemispheric injuries.[28-30]

The 30-day mortality rate from admission in the studied population was, compared with other penetrating firearm trauma, much higher, with previous Swedish data from between 2011 and 2019 showing a 30-day mortality rate of 16.7%.[10] The in-hospital mortality rate for penetrating trauma in the German data was 10.3%.[9,24] The English data for GSWs reported a mortality rate for men of 7.4% and women of 3.8%.[23] Finnish data showed an overall mortality of 5.4% for penetrating trauma.[12] However, this Finnish cohort had a low rate of GSW and a high proportion of self-inflicted injuries.[12] This large difference and variation in injury intent might explain the difference in mortality between the cohorts. However, the incidence of GSWs in Europe has been low compared with other parts of the world; thus, few comparative studies have investigated this variation.[19,22-24] Therefore, it is difficult to make any greater comparisons between our study and these 3 cited studies, because all 3 investigated either generalized penetrating trauma or anatomically unspecific firearm trauma. Due to the lack of penetrating head and neck trauma literature, the comparison with these general penetrating trauma mortality rates only allows for a cursory overview concerning penetrating head and neck trauma. One German study reported that patients with GSWs to the head had a mortality rate of 38.2%.[22] Nevertheless, the study cohort had a high proportion of self-inflicted injuries (55.8%), which the investigators used to explain the high mortality rate.[22] A similar association can be seen in the American Trauma Quality Improvement Program study, in which self-inflicted injuries dominated the GSWs to the head, with a mortality rate of 43.8%.[25] The mortality rate in our study is higher than in these German and American studies, although we found a high proportion of assaults and few self-inflicted injuries, which contradicts the reasoning behind the high mortality percentage in the cited literature. This variation indicates that head and neck patients are more fragile than patients with general penetrating trauma in terms of mortality and morbidity, especially in cases of direct high-energy injuries, regardless of the intent. This finding also reflects the complexity of the injury panorama and the likelihood of treatment heterogeneity due to the lack of evidence-based guidelines for head and neck injuries, especially those to the brain.[11,17,18,28]

Similar to previous studies, most of the patients in our study were men. The OTM population consisted proportionally of the least number of men, possibly due to the inclusion of patients involved in accidents, with mechanisms more likely to affect a more general population segment. The population was young, with the median age for all subgroups <40 years, similar to previous Swedish data.[19] Compared with previous studies, our cohort's age span was similar, or possibly even younger, than those included in previous studies. Davies et al.[23] found a median age of 30 years for penetrating trauma, Störmann et al.[24] reported a mean age of 38.9 years, and Inkinen et al.[12] reported a mean age of 38 years. Taken together, these findings show that TBI is one of the leading causes of hospitalization, disability, and death in the working age population.[31-33]

Our patient population is similar to those in previous studies in terms of the trauma mechanism, with a clear majority of SW patients (73%) followed by GSW patients (20%). In contrast, data from Finland (1997 and 2011), Germany (2008 and 2013), and England (2000 and 2005) showed a GSW incidence of 12%, 19%, and 19%, respectively, and an SW incidence of 88%, 81%, and 81%, respectively.[12,23,24] Although our GSW incidence is similar to the German and English data, compared with Finnish data, it is higher. This difference in GSW incidence could be explained by the Finnish data covering an earlier period than our study, when gun violence was less widespread, although since 2012, the use of firearms in Sweden has been increasing.[12-14,19,34,35] Our data also include OTMs, not included in previous literature, which could explain why our SW incidence was lower than that in the literature.

In our study, GSW patients were more likely to be victims of assault than of self-inflicted injuries than were SW patients. This predominance is distinctive compared with previous literature on penetrating trauma in general. Previous studies showed accidents and self-inflicted injuries were most common penetrating injuries, with only a few studies identifying assault as the main cause, even when focusing on head and neck injuries.[10,19,22,25,36] Nevertheless, assault as an increasing cause of penetrating injuries in Sweden has been postulated previously, with our data confirming this trend.[9,10,19]

Another aim of our study was to benchmark the surgical interventions required by admitted patients with penetrating head and neck trauma. Compared with centers with large and high penetrating trauma volumes, this is a relatively new phenomenon in Sweden and large parts of Europe.[9-12,14] Thus, no national guidelines exist, and treatment is based on judgment of the trauma at arrival in accordance with Acute Trauma Life Support principles, classic signs for head and neck injuries, and the surgeon's judgment of surgical futility, especially regarding improved survival after neurosurgical interventions. Although we observed a larger heterogeneity in acute surgical indications and complex multispecialty needs, a large majority of the patients who underwent traditional neurosurgical interventions were hemodynamically stable or had decent neurological function after resuscitation. Nonoperative management was used when injuries were judged to have caused a large and unsalvageable deficit, such as penetrating TBIs or massive neck hemorrhage concurrent with an asystole. This relative heterogeneity in both cases and care further highlights the need for the development of modern, international, and evidence-based treatment guidelines for penetrating trauma to the head and neck.

In our study, 87.2% of admitted patients required an initial surgical procedure on admission, of which wound revisions constituted 65% (214 patients). Compared with previous surgical penetrating trauma data, this finding is more in line with smaller centers that tend to favor surgical interventions over a "wait-and-see" approach.[37] Because Sweden historically had low volumes of penetrating trauma, even at the studied primary trauma center, surgeons were possibly more willing to try an operative approach for the observed head and neck trauma cases. A recurring observation, especially for GSW neurosurgical considerations, was the hope that intervention would benefit even patients with a primary survey showing a poor likelihood

of survival. Furthermore, most GSW patients underwent surgical procedures more extensive than simple suturing, indicating that, in addition to the historical aspect, the current burden of head and neck trauma patients due to GSWs on the healthcare system is high.

Although our study focuses on a single trauma center's population, the data do not reflect only a unique trend for our center or country. The observed trend is reflective of a broader trend in many, if not, most European countries regarding penetrating trauma, especially penetrating head and neck trauma with high mortality injuries.[14] A few of these European countries have been recently studied, generally on the subject of penetrating trauma, allowing for limited, but modern, data comparisons, such as in our report. However, it is known that penetrating trauma to the head and neck is increasing across Europe.[9-12,14,37] It is, therefore, of great importance to understand the nature of these injuries and the patient subgroup outcomes, because this will enable proper evidence-based follow-up of recommended practices and creation of modern and population-specific guidelines.

The main strengths of our study are the coverage of a large study period, the use of data from Sweden's primary trauma center, and the largest European cohort acquired from a codified and internationally standardized trauma registry. This study has several limitations that need to be discussed. First, this was a retrospective descriptive study. Thus, the ability to control for outcome confounders such as previous medical conditions and treatment protocols was limited and further affected by the use of registry data. Second, coverage of all relevant cases was not complete. Previous research indicates that registry data can underestimate the total number of trauma cases because not all patients will present to a healthcare institution or law enforcement.[32] Furthermore, although the studied trauma center has been attached to SweTrau since its inception in June 2011, we lack the data to be able to conclude whether all relevant cases were appropriately included in accordance with the correct protocol. Because a large number of early cases were poorly differentiated anatomically in the registry and required manual reclassification and because we saw a dramatic increase in the caseload between 2012 and 2013, we cannot exclude that this was not caused by issues in coverage, even if, according to SweTrau, this should not be an issue regarding our chosen trauma center.[15,16,19] Third, due to the SweTrau inclusion criteria, data on patients who died before hospital admission were not available.[15,16,19] However, we have previously compared data from SweTrau with data from the Swedish National Council for Crime Prevention and the cause of death registry (Dödsorsaksregistret) and found high agreement between the datasets, with similar increasing trends.[19]

CONCLUSIONS

The results from this study suggest that between 2011 and 2019, an increasing annual trend occurred in the incidence and mortality from penetrating head and neck trauma in Stockholm, Sweden. Patients with GSWs to the head and neck suffered more severe injuries compared with those with SWs and OTMs and underwent more neurosurgical interventions. The study highlights the need for further long-term interventions to help combat the primary etiologies of penetrating trauma. More large cohort studies and international collaborative initiatives are needed for a greater understanding of head and neck penetrating trauma and to improve evidence-based management.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Robert D. Lilford: Investigation, Software, Formal analysis, Data curation, Visualization, Writing — original draft. **Iftakher Hossain:** Writing — original draft, Writing — review & editing. **Martin Dahlberg:** Software, Writing — review & editing. **Carl-Magnus Wahlgren:** Conceptualization, Writing — review & editing. **Bo-Michael Bellander:** Conceptualization, Writing — review & editing. **Amir Rostami:** Conceptualization, Writing — review & editing. **Mattias Günther:** Conceptualization, Writing — review & editing. **Jiri Bartek:** Conceptualization, Methodology, Supervision, Resources. **Elham Rostami:** Conceptualization, Methodology, Supervision, Project administration, Funding acquisition.

ACKNOWLEDGMENTS

The authors would like to thank the SweTrau registry and steering board and, in particular, Professor Lars Lundberg and Shahin Mohseni for excellent support.

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Conflict of interest statement: Iftakher Hossain received support from the Integra EANS Research Grant, Finnish Medical Foundation, Päivikki and Sakari Sohlberg Foundation, Paulo Foundation, and Finnish Cultural Foundation. Elham Rostami received support from the Swedish State Support for Clinical Research, SciLifeLab/KAW, Wallenberg Clinical Fellow, and the Kjell and Märta Beijer Foundation.

Received 28 August 2023; accepted 26 November 2023

Citation: World Neurosurg. (2024) 182:e493-e505. https://doi.org/10.1016/j.wneu.2023.11.129

Journal homepage: ***www.journals.elsevier.com/world-neurosurgery***

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