Opportunities for improvement in the care of adult trauma patients arriving in shock

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Carl Skog

# Introduction

## Epidemiology

Trauma is a major global public health concern. It causes over four million deaths, among those younger populations are the most affected(1). Globally low and middle income countries are disproportionately affected, while high income countries like Sweden have lower overall numbers but the younger and economically active demographic are also affected. In Sweden between 2018 and 2021, the most common age demographic for trauma is the working aged population, between 18 and 64 years old(2). This not only leads to premature loss of life but also imposes a substantial socio-economic burden, due to long-term disabilities and rehabilitation needs(1).

## Trauma

Trauma is generally divided into two groups, blunt and penetrating injury. The most common type in Sweden is blunt injury, constituting around 90% of all trauma. The most common causes for blunt trauma are traffic related and falls, which account for roughly ½ and ⅓ of all blunt trauma(2).

Blunt and penetrating trauma have their own distinct clinical implications. Blunt trauma often results from impacts of different energy factors, and depending on the energy can result in anything from abbrations to fractures and internal organ damage. The most anatomically common type of blunt trauma is blunt abdominal trauma (BAT), which is often caused by traffic accidents. When counting motor vehicle collision and pedestrian versus auto accidents together, they account for 75% of all blunt trauma(3) #sweden or worldwide? .

Penetrating trauma, often caused by gunshots or stab wounds, commonly affects the small intestine, colon, liver, and intra-abdominal blood vessels. These injuries are life-threatening due to significant bleeding from large vessels and the liver’s extensive blood supply. There is also a risk of other complications, such as pancreatic damage leading to autodigestion, and intestinal perforation resulting in contamination from fecal matter. Consequently, penetrating trauma frequently leads to hypovolemic shock and peritonitis(4).

A consequence of both types of trauma is the possibility of significant bleeding, which in turn can result in hemorrhagic shock.

## Shock

The definition for shock is circulatory failure leading to insufficient perfusion and oxygenation of tissue and organ(5). Some of the common symptoms are tachycardia, hypotenstion and altered mental status. Shock are usually classified into four different types based on physiological mechanism. The types are: hypovolemic, obstructive, cardiogenic and distributive, and they all have their own special characteristics(6). These causes can occur alone or in combination, as there can be multiple disruptions on the circulatory system. Examples of diagnoses for each type are, hypovolemic - bleeding, obstructive - tension pneumothorax, cardiogenic - myocardial pump failure and distributive - sepsis(6).

The most common type of shock during trauma is the hypovolemic type due to a major hemorrhage(7). Hemorrhage leads to low blood volume, which beside the common central symptoms noted before, also results in peripheral vasoconstriction, which corresponds with cold, wet and pale extremities(8).

## Shock classifications

To assess the severity of trauma shock, patients can be categorized by stratifying symptoms and physiological parameters into degrees. Although no single international standard exists for such classifications, there is Advanced Trauma Life Support (ATLS) system for major hemorrhage, which is part of the internationally recognised ATLS trauma management course curriculum(9). This system stratifies patients into four shock classes based on estimated blood loss, heart rate (HR), blood pressure (BP), pulse pressure, respiratory rate (RR), mental status, and urine output(9). However, studies have indicated that the ATLS classification has limited prognostic accuracy(10) and is often impractical for clinical use(11), which may explain the low uptake in practice(12).

**ATLS 10th edition**

| **Parameter** | **Class I** | **Class II** (Mild) | **Class III** (Moderate) | **Class IV** (Severe) |
| --- | --- | --- | --- | --- |
| Approximate blood loss | <15% | 15–30% | 31–40% | >40% |
| Heart rate | ↔ | ↔/↑ | ↑ | ↑/↑↑ |
| Blood pressure | ↔ | ↔ | ↔/↓ | ↓ |
| Pulse pressure | ↔ | ↓ | ↓ | ↓ |
| Respiratory rate | ↔ | ↔ | ↔/↑ | ↑ |
| Urine output | ↔ | ↔ | ↓ | ↓↓ |
| Glasgow Coma Scale score | ↔ | ↔ | ↓ | ↓ |
| Base deficit | 0 to –2 mEq/L | –2 to –6 mEq/L | –6 to –10 mEq/L | –10 mEq/L or less |
| Need for blood products | Monitor | Possible | Yes | Massive Transfusion Protocol |

Alternative scoring systems have been developed to address specific clinical needs, such as the Trauma Associated Severe Hemorrhage (TASH) and Assessment of Blood Consumption (ABC) scores for predicting massive transfusion(13), and the National Early Warning Score 2 (NEWS2) for monitoring general patient deterioration [källa?]. While none of these systems is explicitly designed to classify trauma shock across all shock types, each can, to some extent, aid in categorizing shock severity based on core physiological parameters.

Ultimately, the shared foundation of these classifications lies in their reliance on vital signs and additional clinical indicators, underscoring the importance of physiological metrics in assessing shock severity across different clinical settings.

## Trauma quality improvement and oppertunities for improvement

The initial management of trauma patients once they reach hospital is very time sensitive and error prone(7,14,15). To address this and other challenges within trauma care and reduce preventable errors, different types of Quality Improvement (QI) initiatives were initiated. QI focuses on systematically evaluating healthcare processes and patient outcomes, aiming to reduce morbidity and mortality(16). By implementing formal quality measures and conducting collaborative case reviews, QI programs have strengthened trauma systems and improved patient outcomes in various settings globally(17,18).

One way to improve trauma care quality is through identifying Opportunities for Improvement (OFI). This method has an advantage compared to traditional mortality reviews in that it also includes non-fatal outcomes, which gives a broader perspective and a chance to reduce chronic morbidity. There are different processes to finding OFIs, but one of the primary ways is through structured multidisciplinary morbidity and mortality (M&M) reviews of patient cases(16). In order for the review content to be as comprehensive as possible and taking in a system oriented approach, the Donabedian quality of care framework can be used(16,19). It is based on the three factors of structure, process and outcome. By following this framework, healthcare providers will be able to systematically find OFIs as part of QI. This will in turn improve the effectiveness of trauma care, directly impacting mortality and morbidity(17,18).

## Shock and OFI

Shock is the leading cause of preventable death within the first 24 hours of injury(20), with a median time to death from hemorrhagic shock of just 2 hours(21). Despite this, the relationship between shock, its severity, and Opportunities for Improvement (OFI) remains largely unexamined. Most studies on OFI focus on trauma as a whole and do not explore shock in detail, for example, one study (22) noted that 80% of patients had bleeding or hypotension but did not investigate further. However, studying shock more closely is crucial, as it is common, highly preventable, and one of the most deadly. This knowledge would help clinicians better identify and avoid preventable mistakes in shock patients who need urgent care.

## Aims

This study aims to describe the types of opportunities for improvement for adult trauma patients arriving in shock, and to assess how the degree of shock is associated with opportunities for improvement.

# Methods

## Study design

A registry-based retrospective cohort study was conducted using data from the trauma registry and trauma care quality database at the Karolinska University Hospital in Solna.

## Setting

The trauma registry is compromised of patients treated at Karolinska University Hospital in Solna, which treats all major trauma in the greater metropolitan area of Stockholm. We included patients registered between 2014 and 2023. The trauma care quality database is a subset of the trauma registry and includes patients selected for review.

## Participants

Inclusion in the trauma registry requires either admission through trauma team activation or presenting with an Injury Severity Score (ISS) greater than nine after admission to the Karolinska University Hopsital. Each trauma patient is then included in a morbidity and mortality review process, which involves both individual case evaluations by specialized nurses and audit filters. Patients identified with a high potential for OFIs are discussed at multidisciplinary conferences. The identified OFIs are then categorized into broad and detailed categories. The presence or absence of OFIs is determined by consensus among all participants and is documented in the trauma care quality database.

All patients in the trauma registry and Trauma care quality database were included. Patients younger than 15 and/or were dead on arrival were excluded.

## Variables and data sources/measurements

The outcome was defined as the presence of at least one OFI, determined by the multidisciplinary M&M conference in the trauma care quality registry. An OFI can be various types of preventable events, and can be categorized as: clinical judgment error, inadequate resources, delay in treatment, missed injury, inadequate protocols, preventable death and other errors.

The patients will be classified to different degrees of shock in parallel and separately, once with systolic blood pressure (SBP) and once with base excess (BE), regardless of their cause of shock. Based on these two parameters, the patients will be classified into four classes roughly based on the ATLS trauma shock classifications.

We included five other metrics to be adjusted for, due to potential for confounding. Pre-injury ASA and gender were categorical, meanwhile age, ISS and INR were kept continuous.

## Bias

## Study size

All available data in trauma registry and trauma care quality database were included.

## Quantitative variables

The BE parameter was divided into four classes with these cutoffs: Class I (above -2), Class II (-2 to -6), Class III (-6 to -10), and Class IV (below -10). Similarly, SBP was divided into four classes: Class I (above 110 mmHg), Class II (109-100 mmHg), Class III (99-90 mmHg), and Class IV (below 90 mmHg). This classification follows the tenth edition ATLS hemorrhage classification (9), which does not specify exact values for any parameter other than BE. To solve this, we assigned numerical SBP values to each class based on findings from Eastridge et al. and Oyetunji et al., who redefined hypotension as 110 mmHg respective 90 mmHg dependent on age(23,24). Therefore, we used 110 mmHg as the lower limit for (Class I: no shock) - (ATLS: normal SBP) and below 90 mmHg for (Class IV: clear shock) - (ATLS: clear hypotension), class 2 and 3 divided equally in between. This also aligns with the classification done by Mutschler et al.(11).

**ATLS tenth edition - Systolic blood pressure and Base excess (BD)**

| **Parameter - original ATLS 10th edition** | **Class I** | **Class II** (Mild) | **Class III** (Moderate) | **Class IV** (Severe) |
| --- | --- | --- | --- | --- |
| Base deficit | 0 to –2 mEq/L | –2 to –6 mEq/L | –6 to –10 mEq/L | –10 mEq/L or less |
| Systolic Blood pressure | ↔ | ↔ | ↔/↓ | ↓ |
| **Parameter - numerical approximated SBP** |  |  |  |  |
| Systolic Blood pressure | >110 mmhg | 109-100 mmhg | 99-90 mmhg | <90 mmhg |

Please note that ATLS classification defines class I for the BE parameter as (0 to -2) however, the original source(25) defines class I as base deficit (Inverted BE) ≤ 2, with no lower limit (i.e. an upper limit for BE). The original source classification was chosen for this study.

## Statistical methods

The statistical analysis was performed using R, a programming language and environment for statistical computing. OFI subcategories was presented as percentage distributions and visualized in a bar chart. Unadjusted logistic regression was used to determine the association between the OFI, and degree of shock defined by BE and SBP classifications. Adjusted logistic regression incorporated other patient factors such as age, sex, preinjury ASA, INR, and ISS. It was presented as odds ratios (OR) between the presence of OFI, and shock classes. The OR was determined with 95% confidence intervals, and a significance level of 5% was used. All statistical analysis was first done on synthetic data and then later implemented on the data collected from the trauma registry and the trauma care quality database to ensure objectivity. Missing data was addressed by listwise deletion.

## Ethics

The handling of registry data and the extraction of information from medical records pose a potential risk to patient privacy. To mitigate this, patients were anonymized after data collection, with personal identity numbers replaced by unique study identifiers.

From a self-determination standpoint, the Swedish trauma registry does not require patient consent for data registration. However, it is mandatory for the caregiver to inform patients of their inclusion in the registry. Patients have the right to view, correct, opt out of, and request the deletion of their data, without any impact on the care they receive.

In this study, data will be presented at the group level, ensuring that no individual patient details can be identified. Ethical approvals have been obtained for this study, with the record numbers: 2021-02541, 2021-03531, and 2023-02975-02.

The benefits of this study, in relation to its risks, are substantial due to its potential to improve care for future critically ill patients. This research is a step toward reducing mortality and morbidity in a significant portion of the younger and economically active population worldwide.

# Results

You can include code in this document like this:

## Participants

There were a total of 14022 patients in the trauma registry. After excluding the patients younger than 15 and/or were dead on arrival, there were 12153 patients left. Out of those, 7152 patients had been reviewed for the presence of OFI. A total of 2233 patients were excluded due to missing data, resulting in 4919 patients for the final analysis.

The variable with most missing data is BE which lack the data for 1721 patients.

Table 3 - Sample characteristics showing missing data.

| **Characteristic** | **Overall** N = 7,152*1* | **No** N = 6,716*1* | **Yes** N = 436*1* | **p-value***2* |
| --- | --- | --- | --- | --- |
| Age (Years) | 40 (26, 56) | 40 (26, 56) | 45 (28, 61) | <0.001 |
| Gender (M/F) |  |  |  | 0.14 |
| Female | 2,159 (30%) | 2,041 (30%) | 118 (27%) |  |
| Male | 4,993 (70%) | 4,675 (70%) | 318 (73%) |  |
| Pre-injury ASA |  |  |  | 0.031 |
| 1 | 4,362 (61%) | 4,121 (61%) | 241 (55%) |  |
| 2 | 1,803 (25%) | 1,684 (25%) | 119 (27%) |  |
| 3 | 949 (13%) | 874 (13%) | 75 (17%) |  |
| 4 | 29 (0.4%) | 28 (0.4%) | 1 (0.2%) |  |
| Unknown | 9 | 9 | 0 |  |
| Systolic blood pressure (mmhg) | 135 (121, 150) | 135 (121, 150) | 135 (120, 150) | 0.6 |
| Unknown | 123 | 114 | 9 |  |
| Injury Severity Score | 9 (1, 16) | 8 (1, 14) | 17 (10, 24) | <0.001 |
| Unknown | 2 | 2 | 0 |  |
| OFI categories broad |  |  |  | >0.9 |
| Clinical judgement error | 157 (36%) | 0 (NA%) | 157 (36%) |  |
| Delay in treatment | 67 (15%) | 0 (NA%) | 67 (15%) |  |
| Documentation Issues | 14 (3.2%) | 0 (NA%) | 14 (3.2%) |  |
| Inadequate protocols | 21 (4.8%) | 0 (NA%) | 21 (4.8%) |  |
| Inadequate resources | 104 (24%) | 0 (NA%) | 104 (24%) |  |
| Missed diagnosis | 67 (15%) | 0 (NA%) | 67 (15%) |  |
| Other errors | 5 (1.1%) | 0 (NA%) | 5 (1.1%) |  |
| Unknown | 6,717 | 6,716 | 1 |  |
| Base Excess (BE) | 0.8 (-1.3, 2.1) | 0.9 (-1.2, 2.2) | 0.0 (-2.4, 1.5) | <0.001 |
| Unknown | 1,721 | 1,597 | 124 |  |
| INR | 1.00 (1.00, 1.10) | 1.00 (1.00, 1.10) | 1.00 (1.00, 1.10) | <0.001 |
| Unknown | 1,620 | 1,517 | 103 |  |
| Shock classification - BE |  |  |  | 0.003 |
| Class 1 | 4,391 (81%) | 4,162 (81%) | 229 (73%) |  |
| Class 2 | 719 (13%) | 664 (13%) | 55 (18%) |  |
| Class 3 | 191 (3.5%) | 172 (3.4%) | 19 (6.1%) |  |
| Class 4 | 130 (2.4%) | 121 (2.4%) | 9 (2.9%) |  |
| Unknown | 1,721 | 1,597 | 124 |  |
| Shock classification - SBP |  |  |  | 0.006 |
| Class 1 | 6,356 (90%) | 5,983 (91%) | 373 (87%) |  |
| Class 2 | 355 (5.1%) | 331 (5.0%) | 24 (5.6%) |  |
| Class 3 | 147 (2.1%) | 138 (2.1%) | 9 (2.1%) |  |
| Class 4 | 171 (2.4%) | 150 (2.3%) | 21 (4.9%) |  |
| Unknown | 123 | 114 | 9 |  |
| *1*Median (Q1, Q3); n (%) | | | | |
| *2*Wilcoxon rank sum test; Pearson's Chi-squared test; Fisher's exact test | | | | |

## Descriptive data

The study demographics median age is 39 (25, 56) and the most common gender is male, 3,506 (71%). Clinically, the median ISS is 5 which is considered minor injuries, median INR is 1,00, and the most common Preinjury ASA class is 1, at 62%.

Table 4 - Sample characteristics used in regression.

| **Characteristic** | **Overall** N = 4,919*1* | **No** N = 4,638*1* | **Yes** N = 281*1* | **p-value***2* |
| --- | --- | --- | --- | --- |
| Age (Years) | 39 (25, 56) | 39 (25, 55) | 44 (26, 60) | 0.016 |
| Gender (M/F) |  |  |  | 0.2 |
| Female | 1,413 (29%) | 1,341 (29%) | 72 (26%) |  |
| Male | 3,506 (71%) | 3,297 (71%) | 209 (74%) |  |
| Pre-injury ASA |  |  |  | 0.12 |
| 1 | 3,032 (62%) | 2,874 (62%) | 158 (56%) |  |
| 2 | 1,240 (25%) | 1,163 (25%) | 77 (27%) |  |
| 3 | 626 (13%) | 580 (13%) | 46 (16%) |  |
| 4 | 21 (0.4%) | 21 (0.5%) | 0 (0%) |  |
| Systolic blood pressure (mmhg) | 136 (122, 150) | 136 (122, 150) | 136 (120, 150) | 0.8 |
| Injury Severity Score | 5 (1, 14) | 5 (1, 13) | 17 (9, 22) | <0.001 |
| OFI categories broad |  |  |  | >0.9 |
| Clinical judgement error | 103 (37%) | 0 (NA%) | 103 (37%) |  |
| Delay in treatment | 49 (17%) | 0 (NA%) | 49 (17%) |  |
| Documentation Issues | 9 (3.2%) | 0 (NA%) | 9 (3.2%) |  |
| Inadequate protocols | 6 (2.1%) | 0 (NA%) | 6 (2.1%) |  |
| Inadequate resources | 61 (22%) | 0 (NA%) | 61 (22%) |  |
| Missed diagnosis | 48 (17%) | 0 (NA%) | 48 (17%) |  |
| Other errors | 5 (1.8%) | 0 (NA%) | 5 (1.8%) |  |
| Unknown | 4,638 | 4,638 | 0 |  |
| Base Excess (BE) | 0.9 (-1.2, 2.2) | 0.9 (-1.1, 2.3) | 0.0 (-2.4, 1.4) | <0.001 |
| INR | 1.00 (1.00, 1.10) | 1.00 (1.00, 1.10) | 1.00 (1.00, 1.10) | <0.001 |
| Shock classification - BE |  |  |  | 0.004 |
| Class 1 | 3,989 (81%) | 3,783 (82%) | 206 (73%) |  |
| Class 2 | 644 (13%) | 592 (13%) | 52 (19%) |  |
| Class 3 | 170 (3.5%) | 154 (3.3%) | 16 (5.7%) |  |
| Class 4 | 116 (2.4%) | 109 (2.4%) | 7 (2.5%) |  |
| Shock classification - SBP |  |  |  | 0.028 |
| Class 1 | 4,455 (91%) | 4,208 (91%) | 247 (88%) |  |
| Class 2 | 239 (4.9%) | 225 (4.9%) | 14 (5.0%) |  |
| Class 3 | 98 (2.0%) | 93 (2.0%) | 5 (1.8%) |  |
| Class 4 | 127 (2.6%) | 112 (2.4%) | 15 (5.3%) |  |
| *1*Median (Q1, Q3); n (%) | | | | |
| *2*Wilcoxon rank sum test; Pearson's Chi-squared test; Fisher's exact test | | | | |

## Outcome data

Out of the 4919 patients reviewed without missing data, 281 (5.7%) patients had at least one positive OFI.

The most common broad sub-ofi category was clinical judgement error, at 103 (37%). The other three major broad sub-ofis are: inadequate resources 61 (22%), delay in treatment 49 (17%) and missed diagnosis 48 (17%). The smallest one, is other errors, at 5 (1,8%).

When classified, the most common broad sub-ofi in class 1 (no shock) is clinical judgement error both in the BE and SBP groups, while the other sub-ofi also follow a similar distribution between the groups. The largest sub-ofi continuous to be clinical judgment error for BE group in class 2, 3 and 4, at 34,6%; 31,2%; and 42,9% in this order. On other hand, the largest sub-ofi in SBP class 2 is delay in treatment at 50%. The SBP class 3 is evenly distributed between clinical judgement error and missed diagnosis at 40% each. Lastly, class 4 SBP’s most common sub-ofi is clinical judgment error 46,7%.

Overall 3989 (81%) of the patients were classified as having no shock (class 1) according to the BE classification, the sum of the remaining classes accounted for 930 (19%) patients. The distribution of the classes were decreasing in numbers with increased severity, with class 2: 644 (13%), class 3: 170 (3,5%), and class 4: 116 (2,4%).

The SBP classification system sorted 4455 (91%) patients as having no shock (class 1), while the remaining classes with patients in shock accounted for 464 (9%) of all the patients. Among the classes defined with shock, class 2 was the biggest at 239 (4,9%), followed by class 4 at 127 (2,6%), and lastly class 3 with 99 (2,0%).

Table 5 - Sub-OFI, classified according to BE

| **Characteristic** | **Class 1** N = 206*1* | **Class 2** N = 52*1* | **Class 3** N = 16*1* | **Class 4** N = 7*1* |
| --- | --- | --- | --- | --- |
| OFI categories broad |  |  |  |  |
| Clinical judgement error | 77 (37%) | 18 (35%) | 5 (31%) | 3 (43%) |
| Delay in treatment | 32 (16%) | 12 (23%) | 4 (25%) | 1 (14%) |
| Documentation Issues | 6 (2.9%) | 2 (3.8%) | 1 (6.3%) | 0 (0%) |
| Inadequate protocols | 5 (2.4%) | 1 (1.9%) | 0 (0%) | 0 (0%) |
| Inadequate resources | 46 (22%) | 9 (17%) | 4 (25%) | 2 (29%) |
| Missed diagnosis | 39 (19%) | 8 (15%) | 1 (6.3%) | 0 (0%) |
| Other errors | 1 (0.5%) | 2 (3.8%) | 1 (6.3%) | 1 (14%) |
| *1*n (%) | | | | |

Table 6 - Sub-OFI, classified according to SBP

| **Characteristic** | **Class 1** N = 247*1* | **Class 2** N = 14*1* | **Class 3** N = 5*1* | **Class 4** N = 15*1* |
| --- | --- | --- | --- | --- |
| OFI categories broad |  |  |  |  |
| Clinical judgement error | 91 (37%) | 3 (21%) | 2 (40%) | 7 (47%) |
| Delay in treatment | 39 (16%) | 7 (50%) | 1 (20%) | 2 (13%) |
| Documentation Issues | 8 (3.2%) | 1 (7.1%) | 0 (0%) | 0 (0%) |
| Inadequate protocols | 4 (1.6%) | 1 (7.1%) | 0 (0%) | 1 (6.7%) |
| Inadequate resources | 57 (23%) | 1 (7.1%) | 0 (0%) | 3 (20%) |
| Missed diagnosis | 44 (18%) | 1 (7.1%) | 2 (40%) | 1 (6.7%) |
| Other errors | 4 (1.6%) | 0 (0%) | 0 (0%) | 1 (6.7%) |
| *1*n (%) | | | | |

## Main results

The adjusted analyses showed only statistical significance when comparing BE class 4 to class 1, which had 63% reduced odds for OFI (OR 0,37; 95% CI 0,14-0,83; p-value 0.026).

The un-adjusted analysis showed when comparing to class 1 in BE group, class 2 and 3 increased odds for OFI by 61% (OR 1,61; 95% CI 1,17-2,20; p-value 0.003) respective 91% (OR 1,91; 95% CI 1,08-3,16; p-value 0.018). The SBP group showed, when comparing class 4 to class 1, there were increased odds of 128% (OR 2,28; 95% CI 1,26-3,85; p-value 0.004).

Table 7 and 8 adjusted log

|  | **Adjusted Model** | | | | **Unadjusted Model** | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Characteristic** | **Event Risk** | **OR***1* | **95% CI***1* | **p-value** | **OR***1* | **95% CI***1* | **p-value** |
| Shock classification - BE |  |  |  |  |  |  |  |
| Class 1 | 206 / 3,989 (5.2%) | — | — |  | — | — |  |
| Class 2 | 52 / 644 (8.1%) | 1.12 | 0.79, 1.55 | 0.5 | 1.61 | 1.17, 2.20 | **0.003** |
| Class 3 | 16 / 170 (9.4%) | 0.93 | 0.50, 1.62 | 0.8 | 1.91 | 1.08, 3.16 | **0.018** |
| Class 4 | 7 / 116 (6.0%) | 0.37 | 0.14, 0.83 | **0.026** | 1.18 | 0.49, 2.39 | 0.7 |
| Age (Years) | 281 / 4,919 (5.7%) | 1.01 | 1.00, 1.01 | 0.10 |  |  |  |
| Gender (M/F) |  |  |  |  |  |  |  |
| Female | 72 / 1,413 (5.1%) | — | — |  |  |  |  |
| Male | 209 / 3,506 (6.0%) | 1.10 | 0.84, 1.48 | 0.5 |  |  |  |
| Pre-injury ASA |  |  |  |  |  |  |  |
| 1 | 158 / 3,032 (5.2%) | — | — |  |  |  |  |
| 2 | 77 / 1,240 (6.2%) | 1.05 | 0.77, 1.41 | 0.8 |  |  |  |
| 3 | 46 / 626 (7.3%) | 1.19 | 0.79, 1.76 | 0.4 |  |  |  |
| 4 | 0 / 21 (0.00%) | 0.00 |  | >0.9 |  |  |  |
| INR | 281 / 4,919 (5.7%) | 1.15 | 0.78, 1.52 | 0.4 |  |  |  |
| Injury Severity Score | 281 / 4,919 (5.7%) | 1.06 | 1.05, 1.07 | **<0.001** |  |  |  |
| *1*OR = Odds Ratio, CI = Confidence Interval | | | | | | | |

|  | **Adjusted Model** | | | | **Unadjusted Model** | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Characteristic** | **Event Risk** | **OR***1* | **95% CI***1* | **p-value** | **OR***1* | **95% CI***1* | **p-value** |
| Shock classification - SBP |  |  |  |  |  |  |  |
| Class 1 | 247 / 4,455 (5.5%) | — | — |  | — | — |  |
| Class 2 | 14 / 239 (5.9%) | 0.96 | 0.52, 1.64 | 0.9 | 1.06 | 0.58, 1.78 | 0.8 |
| Class 3 | 5 / 98 (5.1%) | 0.47 | 0.16, 1.13 | 0.13 | 0.92 | 0.32, 2.05 | 0.8 |
| Class 4 | 15 / 127 (12%) | 0.73 | 0.37, 1.35 | 0.3 | 2.28 | 1.26, 3.85 | **0.004** |
| Age (Years) | 281 / 4,919 (5.7%) | 1.01 | 1.00, 1.01 | 0.076 |  |  |  |
| Gender (M/F) |  |  |  |  |  |  |  |
| Female | 72 / 1,413 (5.1%) | — | — |  |  |  |  |
| Male | 209 / 3,506 (6.0%) | 1.13 | 0.85, 1.51 | 0.4 |  |  |  |
| Pre-injury ASA |  |  |  |  |  |  |  |
| 1 | 158 / 3,032 (5.2%) | — | — |  |  |  |  |
| 2 | 77 / 1,240 (6.2%) | 1.03 | 0.76, 1.39 | 0.9 |  |  |  |
| 3 | 46 / 626 (7.3%) | 1.17 | 0.77, 1.73 | 0.5 |  |  |  |
| 4 | 0 / 21 (0.00%) | 0.00 |  | >0.9 |  |  |  |
| INR | 281 / 4,919 (5.7%) | 1.14 | 0.76, 1.52 | 0.4 |  |  |  |
| Injury Severity Score | 281 / 4,919 (5.7%) | 1.06 | 1.05, 1.07 | **<0.001** |  |  |  |
| *1*OR = Odds Ratio, CI = Confidence Interval | | | | | | | |

When doing the regression in steps, it can be observed that the biggest changes of OR occurs when adding the ISS parameter into the regression model both for the BE and SBP groups.

|  | **Unadjusted** | | | **without ISS** | | | **with ISS** | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Characteristic** | **OR***1* | **95% CI***1* | **p-value** | **OR***1* | **95% CI***1* | **p-value** | **OR***1* | **95% CI***1* | **p-value** |
| Shock classification - BE |  |  |  |  |  |  |  |  |  |
| Class 1 | — | — |  | — | — |  | — | — |  |
| Class 2 | 1.61 | 1.17, 2.20 | **0.003** | 1.60 | 1.15, 2.18 | **0.004** | 1.12 | 0.79, 1.55 | 0.5 |
| Class 3 | 1.91 | 1.08, 3.16 | **0.018** | 1.93 | 1.09, 3.19 | **0.016** | 0.93 | 0.50, 1.62 | 0.8 |
| Class 4 | 1.18 | 0.49, 2.39 | 0.7 | 1.14 | 0.47, 2.32 | 0.7 | 0.37 | 0.14, 0.83 | **0.026** |
| Age (Years) |  |  |  | 1.01 | 1.00, 1.02 | **0.033** | 1.01 | 1.00, 1.01 | 0.10 |
| Gender (M/F) |  |  |  |  |  |  |  |  |  |
| Female |  |  |  | — | — |  | — | — |  |
| Male |  |  |  | 1.22 | 0.93, 1.62 | 0.2 | 1.10 | 0.84, 1.48 | 0.5 |
| pt\_asa\_preinjury |  |  |  |  |  |  |  |  |  |
| 1 |  |  |  | — | — |  | — | — |  |
| 2 |  |  |  | 1.07 | 0.79, 1.44 | 0.7 | 1.05 | 0.77, 1.41 | 0.8 |
| 3 |  |  |  | 1.11 | 0.74, 1.65 | 0.6 | 1.19 | 0.79, 1.76 | 0.4 |
| 4 |  |  |  | 0.00 |  | >0.9 | 0.00 |  | >0.9 |
| ed\_inr\_numeric |  |  |  | 1.27 | 0.92, 1.63 | 0.088 | 1.15 | 0.78, 1.52 | 0.4 |
| ISS |  |  |  |  |  |  | 1.06 | 1.05, 1.07 | **<0.001** |
| *1*OR = Odds Ratio, CI = Confidence Interval | | | | | | | | | |

|  | **Unadjusted** | | | **without ISS** | | | **with ISS** | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Characteristic** | **OR***1* | **95% CI***1* | **p-value** | **OR***1* | **95% CI***1* | **p-value** | **OR***1* | **95% CI***1* | **p-value** |
| Shock classification - SBP |  |  |  |  |  |  |  |  |  |
| Class 1 | — | — |  | — | — |  | — | — |  |
| Class 2 | 1.06 | 0.58, 1.78 | 0.8 | 1.11 | 0.61, 1.88 | 0.7 | 0.96 | 0.52, 1.64 | 0.9 |
| Class 3 | 0.92 | 0.32, 2.05 | 0.8 | 0.90 | 0.31, 2.02 | 0.8 | 0.47 | 0.16, 1.13 | 0.13 |
| Class 4 | 2.28 | 1.26, 3.85 | **0.004** | 2.21 | 1.21, 3.77 | **0.006** | 0.73 | 0.37, 1.35 | 0.3 |
| Age (Years) |  |  |  | 1.01 | 1.00, 1.01 | **0.048** | 1.01 | 1.00, 1.01 | 0.076 |
| Gender (M/F) |  |  |  |  |  |  |  |  |  |
| Female |  |  |  | — | — |  | — | — |  |
| Male |  |  |  | 1.23 | 0.93, 1.63 | 0.15 | 1.13 | 0.85, 1.51 | 0.4 |
| pt\_asa\_preinjury |  |  |  |  |  |  |  |  |  |
| 1 |  |  |  | — | — |  | — | — |  |
| 2 |  |  |  | 1.11 | 0.82, 1.49 | 0.5 | 1.03 | 0.76, 1.39 | 0.9 |
| 3 |  |  |  | 1.15 | 0.77, 1.70 | 0.5 | 1.17 | 0.77, 1.73 | 0.5 |
| 4 |  |  |  | 0.00 |  | >0.9 | 0.00 |  | >0.9 |
| ed\_inr\_numeric |  |  |  | 1.21 | 0.87, 1.56 | 0.2 | 1.14 | 0.76, 1.52 | 0.4 |
| ISS |  |  |  |  |  |  | 1.06 | 1.05, 1.07 | **<0.001** |
| *1*OR = Odds Ratio, CI = Confidence Interval | | | | | | | | | |

| **Characteristic** | **Overall** N = 4,919*1* | **Class 1** N = 3,989*1* | **Class 2** N = 644*1* | **Class 3** N = 170*1* | **Class 4** N = 116*1* | **p-value***2* |
| --- | --- | --- | --- | --- | --- | --- |
| Age (Years) | 39 (25, 56) | 40 (25, 56) | 38 (26, 56) | 38 (27, 51) | 37 (23, 57) | 0.8 |
| Gender (M/F) |  |  |  |  |  | 0.4 |
| Female | 1,413 (29%) | 1,159 (29%) | 185 (29%) | 42 (25%) | 27 (23%) |  |
| Male | 3,506 (71%) | 2,830 (71%) | 459 (71%) | 128 (75%) | 89 (77%) |  |
| Pre-injury ASA |  |  |  |  |  |  |
| 1 | 3,032 (62%) | 2,520 (63%) | 349 (54%) | 97 (57%) | 66 (57%) |  |
| 2 | 1,240 (25%) | 961 (24%) | 203 (32%) | 47 (28%) | 29 (25%) |  |
| 3 | 626 (13%) | 491 (12%) | 91 (14%) | 24 (14%) | 20 (17%) |  |
| 4 | 21 (0.4%) | 17 (0.4%) | 1 (0.2%) | 2 (1.2%) | 1 (0.9%) |  |
| Systolic blood pressure (mmhg) | 136 (122, 150) | 137 (124, 151) | 130 (118, 146) | 125 (107, 143) | 122 (96, 140) | <0.001 |
| Injury Severity Score | 5 (1, 14) | 5 (1, 12) | 10 (4, 19) | 14 (9, 25) | 16 (5, 29) | <0.001 |
| Opportunities for improvement (Y/N) | 281 (5.7%) | 206 (5.2%) | 52 (8.1%) | 16 (9.4%) | 7 (6.0%) | 0.004 |
| OFI categories broad |  |  |  |  |  |  |
| Clinical judgement error | 103 (37%) | 77 (37%) | 18 (35%) | 5 (31%) | 3 (43%) |  |
| Delay in treatment | 49 (17%) | 32 (16%) | 12 (23%) | 4 (25%) | 1 (14%) |  |
| Documentation Issues | 9 (3.2%) | 6 (2.9%) | 2 (3.8%) | 1 (6.3%) | 0 (0%) |  |
| Inadequate protocols | 6 (2.1%) | 5 (2.4%) | 1 (1.9%) | 0 (0%) | 0 (0%) |  |
| Inadequate resources | 61 (22%) | 46 (22%) | 9 (17%) | 4 (25%) | 2 (29%) |  |
| Missed diagnosis | 48 (17%) | 39 (19%) | 8 (15%) | 1 (6.3%) | 0 (0%) |  |
| Other errors | 5 (1.8%) | 1 (0.5%) | 2 (3.8%) | 1 (6.3%) | 1 (14%) |  |
| Unknown | 4,638 | 3,783 | 592 | 154 | 109 |  |
| Base Excess (BE) | 0.9 (-1.2, 2.2) | 1.1 (0.0, 2.8) | -3.5 (-4.4, -2.8) | -7.8 (-8.9, -7.0) | -14.2 (-16.4, -11.6) | <0.001 |
| INR | 1.00 (1.00, 1.10) | 1.00 (1.00, 1.10) | 1.00 (1.00, 1.10) | 1.00 (1.00, 1.20) | 1.10 (1.00, 1.20) | <0.001 |
| Shock classification - SBP |  |  |  |  |  |  |
| Class 1 | 4,455 (91%) | 3,711 (93%) | 543 (84%) | 125 (74%) | 76 (66%) |  |
| Class 2 | 239 (4.9%) | 170 (4.3%) | 48 (7.5%) | 13 (7.6%) | 8 (6.9%) |  |
| Class 3 | 98 (2.0%) | 63 (1.6%) | 21 (3.3%) | 6 (3.5%) | 8 (6.9%) |  |
| Class 4 | 127 (2.6%) | 45 (1.1%) | 32 (5.0%) | 26 (15%) | 24 (21%) |  |
| *1*Median (Q1, Q3); n (%) | | | | | | |
| *2*Kruskal-Wallis rank sum test; Pearson's Chi-squared test | | | | | | |

# Discussion

## Key results

We found that the most common type of OFI is clinical judgment error across almost all shock severities. Out of all shock severities, there is only a statistically significant association between severe shock with a BE of < -10 and OFI, which shows a 63% reduced odds of OFI when compared against those with no shock.

The unadjusted analyses demonstrated a positive correlation between more severe shock and higher odds of OFI. However, this association inverted in the adjusted models, with BE < -10 showing reduced odds for OFI. This shift can be explained by the confounding effect of ISS, which is significantly associated with both shock severity and OFI (p < 0.001). Adjusting for ISS revealed that the initial positive correlation was likely driven by shared variability with ISS.

Association between OFI and ISS can also be observed in a study by Husssein et al (26). It is important to note that Hussein’s study was also conducted at Karolinska Solna, but during a different time frame (2017-2021) and with other inclusion and exclusion factors. Correlation between ISS and BD or SBP was also shown in two studies by Mutscher et al. (11,25).

### Interpretation and generalisability

#### Reduced OR of BE class 4

Patients with BE < -10, indicating severe shock, were found to have lower odds of OFI compared to other groups, and two hypothesis may explain this finding.

First, patients in severe shock should be more easily recognized as critically ill upon arrival, triggering heightened clinical attention and prioritization in triage. This results in more structured management and often receives priority in resource allocation, which may minimize variability in care and reduce the likelihood of errors.

Another explanation is the potential influence of survival bias. Patients with BE < -10 have high mortality rates (25) , and those who survive may represent cases where care was particularly effective, or where errors were less impactful.

#### Distribution of significance/insignificant results

When looking at the distribution of the significant and insignificant results from the “step reg” table, we can notice for the BE group, that the significance reverses when adding ISS. This may be a sign that the significant unadjusted result is purely because of the ISS which we discussed before. The same can also be said about the OR, as we see bigger changes only happen after the inclusion of ISS.

However the same can not be said about the SBP group. When adding ISS, the significance of class 4 disappears, but the significance of classes 2 and 3 does not invert. The same can be said about the OR, it does change but not nearly as major and clear as in the BE class. Especially for class 2, as the OR merely changes from 1,06 to 1,11 and then to 0,96. Class 3 is more, from 0,92 to 0,90 to 0,47; but the OR difference is still < 0,5, whereof for the BE group and SBP class 4 the difference is always> 0,5. The reason may be due to the cutoffs of the classification system, as the SBP classification does not follow the same range of shock as the BE classification. The result of the BE classification originating study (25), shows that BE class I had a mean SBP of 132,6 mmHg and class IV had 94,8 mmHg. As an SBP of 132,6 is at the higher range of normotensive, we were therefore not able to use it as an upper limit, but the 94,8 mmHg is close to our approximation of 90mmhg for class IV. The SBP classification is therefore only somewhat connected to the BE classification at the lower limit eg class 4. Also worth noting is that the divider between our SBP class 2 and 3, are arbitral and made to connect with the ATLS system to make up a four-class system, as the 90mmgh and 110mmhg are from Eastridge et al (23) and Oyetunji et al (24) which only defined 110mmhg and 90mmhg and nothing in between. This means that this divider may have made the classes too small and no longer scientific.

#### Insignificant results

One surprising result is that there is no significance for the SBP group and classes 2 and 3 of the BE group. When comparing to Hussein et al. [] results, the SBP results conform, as it also showed significance for the unadjusted results below 90mmHg and no significance when adjusted with other factors including ISS.

Due to a lack of research regarding shock/injury severity and OFI/Preventable death as a whole, it is difficult to determine whether the results are reasonable or not. It is therefore also difficult to determine exactly why some of them are significant and others not, leaving us with reasoning and hypothetical explanations.

### Comparison to literature

Previous studies (7,27) which studied cases with a deathly outcome, showed that the most common OFI type was delay in treatment, while the second most common is clinical judgment error (7), or errors in management(27). In comparison, our results showed the most common OFI is clinical judgment error (36%), while inadequate resources were second (22%), and delay in treatment comes third (17%), for the whole study population. These differences may be due to the nature of the studied population, where delay in treatment may be more deadly, therefore it takes up a smaller part of our results, while clinical judgment error takes up a larger part.

For patients defined as in shock (Class 2-4), the most common was still clinical judgment error (BE 34,7%; SBP 35,3%). This result is similar when compared to D O’Reilly’s study (28), in which the most common type of opportunities for performance improvements (OPI) was one involved with decision-making at 63 out of 150 OPIs.

We did not find any publication addressing shock severity and OFI. We have therefore looked at studies addressing preventable death and assessed severity by other factors. In one study (**davoodabadi\_predicting\_2021?**), the odds for the most severe class of the external bleeding severity category can be calculated to 2 and when comparing with the “none” class the odds ratio is then 1,91. This unadjusted result can be compared to our 2,28 when comparing class 4 to class 1 of the SBP classification (class 4 of BE was not significant). While the results are not very close, however, both show a positive association between trauma severity and preventability of negative outcomes. The difference may be explained by different classification/grouping requirements. In the same study (**davoodabadi\_predicting\_2021?**), the odds ratio between patients with SBP ≥ 80 and < 80 for preventable death is calculated to be 0,071. This differs a lot from our findings in the unadjusted and may be due to different study outcomes OFI vs death and different SBP classification intervals.

## Strengths and limitations

One of the limitations is the lack of data to design the study around a modern shock/hemorrhage classification which uses a combination of base parameters. Due to a lack of data on heart rate, FAST, detailed types of injury, and clinical chemistry, we were not able to use categorizations such as TASH, TBSS, and ABC with better sensitivity and specificity than the ATLS framework (29–31). The ATLS shock classification framework would, in turn, would also be better studied and evidence-based, than the propetrially classification we simplified and built our classification from.

The choice to not include the ATLS hemorrhage classification as it is was due to four reasons. The first one is ATLS tenth edition lacks numerical values for vital parameters. The second one is that base deficit alone is superior to vital parameters as a predictive parameter for mortality (32). The third one is due to the nature of having multiple parameters, which makes it difficult to categorize a patient with vital parameters in two or more classes at the same time. The fourth one is difficulties in separating lower GCS due to traumatic brain injury from shock as a cause.

Missing data were handled by listwise deletion, which reduced the sample size by 2233 and may also introduce bias, as the most common missing category was BE which may mean that BE as … (källa)

## Clinical/Practical applications

The results showed only significantly reduced odds for OFI for patients with BE < -10. This could mean that the initial management of trauma patients with severe shock is fairly robust. Leveraging these insights, protocols for such cases should be studied. By simulating these protocols in cases with less severe shock, trauma systems can expand best practices to improve care for patients with less severe shock, minimizing OFI.

## Future studies

The natural next step for future studies is to validate the findings and improve the methods from this study, by using a validated classification for hemorrhagic shock, like ABC, TASH, and so on. There are two reasons, one is the findings are more standardized and therefore easy to validate and compare to other studies. The second reason is that the results are more clinically usable, as it should be more related to reality and therefore practical when making decisions.

As previously mentioned, ISS seems to be correlated to OFI, and we couldn’t find any studies on it. Therefore it would be useful in future studies validating the association between other injury markers from like ISS and OFI. This information can later be used to improve and standardize the audit filters used for QI programs.

# Conclusion

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