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

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Contents

1 Abstract

Background: Hemorrhagic shock is the leading cause of preventable trauma deaths. Opportunities for improvement (OFI) are common in deaths from massive bleeding. Aims: This study aimed to describe the types of OFI for adult trauma patients arriving in shock and assess the association between shock severity and OFI. Methods: A retrospective cohort study was conducted on adult trauma patients treated at Karolinska University Hospital (2014-2023). Shock severity was categorized into four classes using base excess (BE) and systolic blood pressure (SBP). OFI identified during morbidity and mortality conference were analyzed using bi- and multivariable logistic regression, with adjustments for age, sex, American Society of Anesthesiologists Classification (ASA), international normalized ratio (INR), and injury severity score (ISS) Results: 4919 patients were included, of which 281 had OFI. Clinical judgment error was the most common OFI type for patients in shock. Unadjusted analyses showed positive associations between shock severities and OFI. However, after adjusting for ISS, patients with severe shock (BE $<$ -10) showed 63% reduced odds of OFI compared to those without shock ($p = 0.026$). ISS was a significant confounder ($p < 0.001$). No significant association was observed between SBP classes and OFI in adjusted analysis. Conclusion: Association between shock and OFI seems to be nonlinear, with moderate shock (BE (-2) – (-10)) having highest odds of OFI. The lack of significance in SBP classification highlights potential framework limitations compared to BE. These findings emphasize the importance of accounting for ISS and using validated shock classifications in future research.

1.1 Background

1.2 Methods

1.3 Results

1.4 Conclusion

2 Introduction

3 Introduction

Trauma is a major global public health concern. It causes over four million deaths, among those younger populations are the most affected(1). Beyond the high mortality rate, trauma also imposes a substantial socio-economic burden, due to long-term disabilities and rehabilitation needs(1).

The initial management of trauma patients is highly time-sensitive and prone to error (2–4). Quality Improvement (QI) initiatives address these challenges by systematically evaluating care processes and outcomes, aiming to reduce morbidity and mortality (5).

Hemorrhagic shock is, the second most common cause of death following trauma and it, is the leading preventable cause of death within the first 24 hours post-injury (3,6,7), and opportunities for improvement are common in patients who die because of massive traumatic bleeding (8).

This may indicate that these preventable events potentially leading to suboptimal outcomes are common also in patients who survive massive bleeding. 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. This knowledge would help clinicians avoid such events in bleeding trauma patients.

4 Methods

4.1 Study design

We conducted a registry based retrospective cohort study, using data from the trauma registry and trauma care quality database at the Karolinska University Hospital in Solna.

4.2 Setting

The trauma registry includes 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.

4.3 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.

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

4.4 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 (See Table 1 (9)).

Table 1: ATLS classification for haemorrhagic shock, adapted from (9).

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

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.

4.5 Bias

4.6 Study size

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

4.7 Quantitative variables

Table 2 shows how we defined shock according to BE and SBP. 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(10,11). 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.(12).

Table 2: 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, we choose to follow its original source(13), which defines class I as base deficit (Inverted BE) 2, with no lower limit (i.e. an upper limit for BE).

4.8 Statistical methods

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

5 Results

5.1 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.

5.2 Descriptive data

Table 3 describes the characteristics of the study population. 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

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

Table 3: 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

minor injuries, median INR is 1.00, and the most common Preinjury ASA class is 1, at 62%.

5.3 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

Characteristic	**Class 1** N = 206[1]	**Class 2** N = 52[1]	**Class 3** N = 16[1]	**Class 4** N = 7
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 (%)

Characteristic	**Class 1** N = 247[1]	**Class 2** N = 14[1]	**Class 3** N = 5[1]	**Class 4** N = 15
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 (%)

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

Table 6 - Sub-OFI, classified according to SBP

	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

5.4 Main results

The adjusted analyses showed only statistical significance when comparing BE class 4 to class 1, which had 63% lower 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 (OR 1,61; 95% CI 1,17-2,20; p-value 0.003) and 3 (OR 1,91; 95% CI 1,08-3,16; p-value 0.018) were significant in increased risk for OFI. For the SBP group, comparison between class 1 and class 4 showed significant increased risk (OR 2,28; 95% CI 1,26-3,85; p-value 0.004).

Table 7 and 8 adjusted log

6 Discussion

The purpose of this study was to assess the association between OFI and adult trauma patients arriving in shock, focusing on the types of OFI and severity of shock.

##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 63% reduced odds of OFI when compared against those with no shock. The unadjusted analyses demonstrated a general positive association between shock and OFI. However, this association inverted in the adjusted models, with BE < -10 showing reduced odds for OFI. ##Interpretation Patients with BE < -10, indicating severe shock, were found to have lower odds of OFI compared to other groups, and two hypotheses 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 “reversed” survival bias. Patients with BE < -10 have high mortality rates (25), and for these patients who die, the care process is interrupted prematurely. This may induce generally fewer

Characteristic	Adjusted Model				Unadjusted Model		
	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

procedures or shorter care time for patients with deadly outcomes, which means less chance for errors, and therefore OFIs. This would result in reduced amount of OFIs in groups with higher mortality, which in this case would be class 4.

Interpretation of adjusted model after inclusion of ISS When looking at the distribution of the significant and insignificant results of the BE group (table 6), it can be observed that the significance reverses for the classes when adding ISS. One explanation is that the unadjusted positive correlation may be driven by a shared variability with ISS, as we can see significant positive association between ISS and OFI in our results. This positive association between OFI and ISS have also been shown 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 criteria. Another hypothetical explanation is multicollinearity, as both BE and ISS assess injury severity. Theoretically anatomical injury, bleeding and physiological response should be closely interconnected. A correlation between ISS and BD (inversed BE) or SBP was also shown in the two studies by Mutscher et al. (11,25). Therefore, adjusting for each other may explain the inversion of OR. However, it may also result in results that's difficult to interpret or lack any meaning in a clinical context. This may also explain why class 2 and 3 are not significant but class 4 are in the adjusted analysis, as seen in study by Hussein et al (26), ISS does not correlate linearly to OFI, but we included ISS linearly in the model.

However, when adding ISS to the SBP group, the significance of class 4 disappears, but the significance of classes 2 and 3 does not change, like in the case for BE group. The same can be said about the OR, it does change but not nearly as major 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 OR changes 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 results of the study that BE classification was originating from (25), shows that BE class 1 had a mean SBP of 132.6 mmHg and class IV had 94.8 mmHg. As an SBP of 132.6 mmHg 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 90 mmHg for class 4. The SBP classification is therefore only somewhat connected to the BE classification at the lower limit e.g. class 4. Also worth noting is that the divider between our SBP class 2 and 3, are arbitrary and made to connect with the ATLS system to make up a four-class system, as the 90 mmHg and 110 mmHg are from Eastridge et al (23) and Oyetunji et al (24) which only defined 110 mmHg and 90 mmHg and nothing in between. This means that this divider may have made the classes too small and no longer scientific. ###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. No studies were found to address this hypothesis of survivorship bias for OFI types. For patients defined as in shock (Class 2-4), the most common OFI 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 negative care outcomes and assessed severity by other factors but only found one that investigated predicting factors and preventable death. This study (29) showed that there was a OR correlation of 14.1 between preventable death and SBP 80mmHg, when comparing to SBP $<$ 80 mmHg. This differs from our SBP findings, as our adjusted results are not statistically significant, and the significant unadjusted results don't have that extreme of OR and are positively correlated with severe and not mild shock. These differences are not strange, but rather understandable, as the studies are conducted at different hospitals, populations, outcomes (surviving vs death) and different classifications (the lowest of our 4 SBP classes is 90mmHg, while they only got 2 classes that separate at 80mmHg). However, if reasoned from a shock standpoint where both SBP and BE are part of, and compare this result with our BE results, they show a similar trend. Our BE results showed reduced odds of OFI when comparing the most severe and the no shock class. This implies that if changing the reference point to the most severe shock class, the result would be increased odds of OFI when compared to the no shock class. Therefore, our results show similar trend to their study (29) result, that showed lesser shock (higher SBP) had increased odds ratio of preventable death. One surprising result is that there is no significance for the SBP group in our adjusted analysis. When comparing to the results from Hussein et al. (26), the SBP results conform, as it also showed significance for the unadjusted results below 90 mmHg and no significance when adjusted with other factors including ISS. Due to a lack of research regarding shock/injury severity and OFI/preventable death, 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. ##Strengths and limitations Strength of this study includes the relatively large cohort of 4919 patients spread over 9 continuous years. From a methodical standpoint, even though an established shock/hemorrhage classification system was not used, two clinical parameters were used in parallel. This includes two perspectives, one physiological and one chemical, to best describe shock and at the same time still using the original parameters the clinicians meet on a day-to-day basis.

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 (30–32). The ATLS shock classification framework would, in turn, would also be better studied and evidence-based, than the proprietary classification we simplified and built our classification from. The choice to not include the ATLS hemorrhage classification 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 (33). 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 was not routinely measured and result in inconsistency for certain patient groups, which risks selection bias. Also worth noting is that the sample size for most

of the shock classes (class 2 to 4) are roughly around 100 to 200 patients, whereof those with positive OFI are as low as 5 patients. This may result in over/underestimation of the OR, as there is higher chance of randomness in smaller sample sizes, which results in broader confidence intervals which may result in more "extreme" average OR.
##Clinical/Practical applications - Generalisability? Clinically the unadjusted are more insightful, as the variables are never separated and instead combined into complex cases. Therefore, from a BE standpoint when a patient's BE is between -2 to -10 the odds of OFI are between 61% to 91% higher than those with BE above -2. Suggesting patients with a BE between these levels may need extra attention. From a SBP perspective, when SBP dips below 90 mmHg odds for OFI increases a massive 128%, compared with those with SBP above 110 mmHg. This supports the idea (24) of using 90 mmHg as a clinical limit for defining hypotension. ###Equity It can be observed that the male gender is more prevalent in our results than females (71% vs 29%), which is like other studies (22,27,28). However, when comparing the event rate of OFI among the patients reviewed for OFI, the difference between the genders becomes minimal at 5.1% for female, respective 6% for male. At the same time, when fully adjusted, gender is not significant ($p = 0.4$), this implies that even though gender may not be proportionate in trauma cases, there seems to be no major difference between the genders for trauma care quality. This may reflect that the standardized protocols for trauma care minimize gender-based differences. When comparing to other studies (27,28), it seems like the percentage potentially preventable death and OPI have a higher amount for males, however, to be noted their percentage is based on ratio between genders and not event risk for each gender. Socioeconomical factors were not incorporated into this study, nonetheless an important factor in emergency medicine, when resources are scarcer. Especially when "inadequate resources" is the third most common OFI type, even for a major hospital in the capital of Sweden. This implies the results of this study cannot be generalized globally, especially not places where standardized trauma care protocols are not incorporated and/or lack adequate resources.
###Future studies The next step for future studies is to validate the findings and improve the methods from this study. As previously discussed, the association between anatomical classification ISS and physiological parameters BE and SBP, and how they correlate to OFI are complex and not necessarily clinically relevant. One way to avoid this problem is using a validated classification for hemorrhagic shock with both anatomical and physiological components, like ABC, TASH, and so on. One other problem when interpreting the results is the "reversed survivorship bias". Due to the design of trauma care quality database, when and where (level of care) the OFI occurred during the length of stay is not recorded. A prospective study can clarify whether shock severity directly affects OFI or if length of stay is a confounding factor. By observing when and where OFIs most commonly occur, it can determine whether the hypothesis of length of stay is correct. This also aids in understanding the reasons behind the nonlinear relationship between ISS, BE or SBP and OFI, as there are currently only theories but no studies.

7 Conclusion

The most common type of OFI for shock patients is clinical judgement error. Association between shock and OFI doesn't seem to be linear, but rather the moderate shock has higher odds of OFI compared to the mild and severe shocks. The lack of significance in SBP classification highlights potential framework limitations compared to BE. These findings emphasize the importance of accounting for ISS and using validated shock classifications in future research.

#Contributions Data collection from the trauma registry, ethics application and study designed by Martin Gerdin Wärnberg. Carl sorted, programmed and analyzed the data, and then wrote the thesis with support from Martin Gerdin Wärnberg, Johanna Berg, Jonatan Attergrim and Kelvin Szolnoky. Technical tools used include Chat-GPT and Google translate. Both were used in the same way, as means to translate more adequate vocabulary for scientific writing between Swedish and English. The overall formulations, structure and content were written by me (Carl), and which of the translations done by the two tools, that were to be used to ensure the content, were also done by me (Carl).

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