Performance of individual audit filters in predicting opportunities for improvement in adult trauma patients

A registry based cohort study

Josef Al-Khalili

# Abbreviations

OFI – Opportunities For Improvement AF – Audit filter CI – confidence interval GCS – Glascow Coma Scale ISS – Injury Severity Score ED – Emergency Department AUC – Area Under Curve ROC – Reciever Operating Characteristic CPR – Cardiopulmonary Resuscitation SBP – Systolic Blood Pressure WHO – World Health Organisation YLL – Years Life Lost DALY – Disability Adjusted Life Years PTSD – Post Traumatic Stress Disorder

# Introduction

Trauma is defined as a physical injury of external origin together with the associated reaction of the body. This phenomenon accounts for 9% of global deaths annually [1]. Trauma affects low- and middle-income countries at a higher rate. In addition, young people are at higher risk of trauma compared to the general population. It is the leading cause of death in people between the ages of 10 and 49 [2];[3]. The most common type of trauma for people of all ages is road traffic injuries [2];[3]. In Sweden, road traffic injuries account for about 40% of injuries and falls for 40% [4].

Trauma is broadly divided into two groups according to the underlying causal mechanism: penetrating and blunt trauma. Common examples of penetrating trauma are gunshot wounds and knife cuts. Blunt trauma, on the other hand, is caused by injuries such as road traffic accidents and falls. In general, the two types of trauma can also be characterized by the size of the force causing the injury and the area of impact. Blunt trauma is caused by a high force impact over a larger area. In contrast, penetrating trauma is caused by a force applied to a smaller area, causing greater pressure so that it is penetrating and often results in deeper lacerations to tissues and organs. However, blunt trauma with sufficient force can be penetrating in nature [5]. Trauma varies widely and has both long term and short term consequences on an individual, a societal level and economical level.

## Impact

The effects of a trauma depend greatly on the type of trauma, where it happened and whom it affected.

Trauma is responsible for 11.9% of years of life lost (YLL) worldwide [3]. In addition, trauma is associated with a higher propensity for depression, post-traumatic stress disorder (PTSD) and negative effects on cognitive function, etc. [6];[7].

It is estimated that up to 11% of trauma patients have PTSD 3 years after the traumatic event [8]. In addition, people who witness traumatic injuries are also at a higher risk of developing PTSD. Traumatic injuries are associated with 36% not returning to work within 1 year [9].

However, injuries are not only a burden on the person affected, but also on society as a whole [10]. One aspect of such societal impact is the economic cost. Attempts have been made to estimate the global cost of injuries, which is a complicated task due to their variability. However, it is estimated that the cost of road traffic injuries alone accounts for 2% of gross domestic product (GDP) in high-income countries [1].

## Trauma Care Systems

Trauma care is a multidisciplinary, complex and time-critical healthcare service provided by specialised trauma centres. A variety of different specialties are involved in trauma care, including surgeons, orthopedists, anesthesiologists, emergency physicians and nurses. Trauma care is divided into three components: pre-hospital, in-hospital and post-hospital. The prehospital component constitutes first responders, basic life support and advanced life support.[11]. The in hospital component is defined as the instance a trauma patient is admitted to a health care facility, often a trauma center. The post-hospital component is about the rehabilitation and recovery of treated trauma patients.

trauma centres have a significantly lower mortality rate compared to non-trauma centres. And the maturity of a trauma centre also correlates with lower mortality, demonstrating the importance of high-quality, specialised trauma care [12];[13]. A similar study in Sweden [14] showed that 30-day mortality is 41% lower in a mature trauma centre compared to a non-trauma centre. However, even in established trauma care systems, it is prone to error due to its complexity and susceptibility to delays [15];[16], which in turn can lead to complications and death. Studies between 1990 and 2014 have shown a pooled preventable death rate of 20%, with more recent studies showing less [17]. A recent study in a Swedish Level I trauma centre found a preventable death rate of 4% [18].

## Quality Improvement

To minimize errors in trauma care, quality improvement (QI) programs have been established by the World Health Organization (WHO) programs by the World Health Organization (WHO) and the International International Association for Trauma Surgery and Intensive Care (IATSIC) [19]. These programs form the core of current trauma care systems and their development around the world.

QI programs consist of a series of recommended techniques aimed at facilitating discussion and analysis of the trauma process in order to take corrective action for future success. The following techniques are used: A multidisciplinary mortality and morbidity conference (MMC), a preventable death review panel, and the use of audit filters[19].

### Morbidity and Mortality Conferences and Preventable Death Review Panels

The MMC is a central QI technique. It is a proven framework with the critical components of anonymity, focusing on specific adverse events, recognising flawed approaches, critical analysis, seeking change and implementing that change [20].

MMCs are regular meetings at which specific patient cases are presented for discussion. The conference participants are healthcare professionals involved in trauma care and its processes, but not necessarily the specific patient case. The selection of patient cases varies, but common themes for discussion are unexpected mortality, unexpected morbidity and errors [21].

It is recommended that they last about 40 minutes, but this varies from hospital to hospital [19].

Five themes have been proposed that broadly define QI-centred MMC: (1) clear definition of the role of the MMC (2), involvement of stakeholders, (3) recognising and selecting appropriate patient cases for presentation, (4) structuring focused discussions, and (5) formulating recommendations and assigning follow-up actions[22];[23].

When implemented effectively, MMCs serve as an important tool for error proofing without serving solely as a negative for individual care providers, but rather as an incentive for reporting. These conferences promote a more comprehensive, systems-based approach that emphasizes task analysis, teamwork and quality improvement[24]. The introduction of MMC has been shown to increase morbidity and mortality reporting[25].

Following MMC, there is an avoidable death review panel whose role is to determine whether a patient’s death could have been avoided [26].

### Audit filters and Opportunities for improvement

Audit filters also known as quality indicators are specific established criteria involved in trauma processes and care. It is used to detect deviation from standardized care in order to further analyse the cause behind complications in trauma patients. An audit filters can be death and the placement of 2 large bore intravenous lines within 15 minutes from arrival to a healthcare facility [19]. The purpose of audit filters is to improve quality of care.

Earlier studies showed a reduction in trauma related mortality after the implementation of audit filters [27]. However, newer studies seem to differ. In 2009 there was an extensive review made that sought to determine if audit filters could be used in improving processes of trauma care however none of the studies met established inclusion criteria [28]. The use of audit filters have also been associated with high frequencies of false positives, ranging from 24% to 80%.[29]; [30].

OFIs are the endpoint and aim of MMC. Following the review of individual patient cases there is a consensus decision made regarding the existence of an OFI. It has been shown that such review process is associated with high-quality trauma care [31]. OFIs are typically associated with failures in initial care [16], specifically in airway management, fluid resuscitation, haemorrhage control and chest injury management [29]; [30]; [32]. Some audit filters seem to not correlate with OFIs at all [33]

## Aim

The aim of the study is to determine whether audit filters are good indicators for predicting OFIs.

# Methods

We conducted a single center, registry-based, retrospective cohort study which uses data from the trauma registry and trauma care quality database at the Karolinska University Hospital in Solna in order to evaluate the performance of individual audit filters in predicting OFIs.

## Study setting and population

Karolinska University Hospital is classified as a Trauma level I hospital. Every year around 1500 patients receive treatment at the hospital. If a patient case results in team activation it is added to the Karolinska trauma registry. If no team activation occurred but the patient had ISS>9 retrospectively it is also included in the registry. The Karolinska trauma registry reports to the Swedish Trauma registry (SweTrau). The registry includes data on vital signs, times, injuries, and interventions as well as patient demographics according to the European consensus statement, the Utstein template [34]

The Karolinska trauma registry also contains a local care quality database including specific audit filters and OFIs that are determined in MMC conferences through consensus decision.

This process of determining OFIs unfolds in multiple stages, characterized by escalating levels of scrutiny. Notably, instances of mortality are directly referred to the multidisciplinary conference, where, in addition to assessing OFIs, a determination is made regarding whether the death was preventable or potentially preventable, a classification also falling under the purview of OFIs.

From 2013 to 2017 there was an effort put forward in identifying adverse outcomes which where unrelated to mortality, the review process underwent subsequent refinement and formalization during the study period. During the initial period each trauma patient case underwent individual assessments by a specialized trauma nurse in order to identify potential OFIs. It was, however not until 2017 in which this procedure was formalized and it became standardized to incorporate a preliminary individual evaluation by a specialized trauma nurse upon data registration in the trauma registry and the trauma quality database. The trauma quality data underwent screening of audit filters. All cases falling within the criteria delineated by these filters, along with those trauma patients flagged by the nurse during the initial review for possible care failures, were subjected to a secondary review by two specialized nurses. Subsequent identification of a potential OFI during this second review prompted a comprehensive evaluation of the respective trauma patient’s case.

## Participants

In this study, we included all who underwent screening for OFIs. Exclusion criteria were applied to individuals under the age of 15, as their clinical management process has notable distinctions compared to those applicable to the adult population.

## Variables

### Outcome

The outcome variable in this study is an OFI, as established by the MMC conference through unanimous decision and furthermore valued as a dichotomous variable with “Yes - At least one OFI identified” and “No - No OFI identified”.

### Exposures

The exposure variable is the 11 audit filters used at Karolinska University Hospital.

## Data sources/measurement

The data used in this retrospective cohort was retrieved from the trauma registry and the trauma care quality database during the period spanning from 2012 to 2022.

Patient data on vital signs, care processes and interventions, level of care and time aspects etc. was retrieved from the national trauma registry while both exposures (audit filters) and outcome (OFI) was retrieved from the local trauma care quality database.

All data were anonymized to protect patient privacy.

## Bias

There is a possibility that consensus decisions from the MMC conferences are flawed which causes misclassification bias. Furthermore, the process of flagging a patient case with an audit filter is done manually by a specialised nurse as mentioned above. This means that there may be a selection bias.

There is a level of recall bias in these sort of studies. Care proffesionals who attend the MMC and has also been a witness to the specific patient case in question might not remember certain key elements that might affect the decision-making around OFI.

## Study size

The study cohort encompasses all eligible patients treated at the hospital from 2012 to 2022. There were only two patient cases from 2012.

## Statistical methods

The study results are generated by statistical analytics methods with the help of the statistical programming language, R. [35]

The sensitivity and specificity of each individual audit filter in predicting OFI will be calculated.

A receiver operating curve (ROC) for binary classification will be made and the area under the curve (AUC) calculated in order to compare the performance of each audit filter [36]

Using a bootstrapping method with 1000 iterations of the selected data, a 95% confidence interval for sensitivity, specificity and AUC will be calculated. Furthermore, comparing AUC of each audit filter with that of coincidence (AUC = 0.5) through a one sample T test will be done to determine significance. This applies soley to any audit filter that might have an AUC confidence interval spanning 0.5.

## Ethical considerations

All patient data is anonymised. However there is data on various factors like date, time of admission, etc. and different patient characteristics such as age, gender, etc. Which in theory could enable one to identify patient cases based on public knowledge through news reporting for example. However this means that such information has to be leaked somehow. The only way that would be possible is through a person with access to the registry or through a data breach. In order to minimize the risk of a potential data breach, access to the registry is only possible while connected to a VPN with a special login in key.

The study was approved by Stockholm Research Ethics Review Board, approval 107 number 2021-02541 and 2021-03531.

# Results

## 1 Participants

### 1.2 Study Participants and Setting

Figure 1 presents a flowchart showcasing the exlusion and inclusion of the patient cases from the trauma registry. After excluding patients under 15 years old and patients not screened for OFI, a total of 8309 individuals where admitted to the hospital and also screened for an OFI. A total of 7797 of the screened individuals had no OFI and 512 had an OFI.

In this retrospective cohort, a total of 8309 trauma care cases were assessed. The study was conducted at Karolinska University Hospital, which is a level I trauma center specializing in trauma care.

### 1.3 Participant Characteristics

Table 1 presents the baseline characteristics of the study participants.

Patient characteristics was implemented to showcase the demography of the included patients comparing those with and those without an assigned OFI. The different variables used in table 1 was directly correlated with the audit filters which where manually created.

69% out of all patients included in the study where men and 31% where women. Among the 512 patients with an OFI compared to the 7797 patients without, the mean age was slightly higher (mean 49 vs 42 years old) and the ISS was higher (mean 17 vs 9). The number of intubations was also higher (16% vs 8.3%). Patients with OFI had longer times to definitive treatment from hospital arrival compared to patients without OFI (median: 144 vs 102 minutes). Furthermore the time to first CT was also longer in the group with OFI compared to the group without OFI (39 min vs 33 min).

The mean systolic blood pressure in the OFI group did not differ from the systolic blood pressure in the no OFI group.

The variables with the highest amount of missing data was “time to definitive treatment” [n=5990] and “time to first CT” [n=1012].

## 2. Individual Audit Filters

### 2.1. Performance of Individual Audit Filters

Performance for each audit filter was determined through a calculation of sensitivty and specificity. Table 3 summarizes the performance of each individual audit filter in identifying opportunities for improvement in trauma care by specificity and sensitivity.

There where varying number of patient cases flagged with each audit filter. The audit filter that was flagged most frequently was “>30 min until CT”. The least flagged audit filter was “GCS<9 and not intubated”.

The audit filter with the highest specificity was “GCS<9 and not intubated” (98.7% CI: 98.5-98.9) was also the audit filter with the lowest sensitivity (1.2% CI: 0.1-2).

The audit filter with the highest sensitivity was “>30min until CT” (59.2% Ci: 55.3-63.3). The same audit filter had the lowest specificity (53.8% CI: 52.7-55.2).

The confidence intervals varied between sensitivity and specificity with sensitivity having greater span.

Table 4 summarizes the performance of each individual audit filter in identifying OFIs in trauma care by AUC. three of the ten audit filters, “Dead at 30 days”, “GCS<9 and not intubated” and “CPR and thoracotomy” showed a performance in predicting an OFI equal to that of coincidence. >60 min until first intervention had the highest AUC.

## Missing Data

Table 2 shows the missing data for each audit filter. “SBP<90”, “GCS < 9 and not intubated”, “>30 min until first CT”, “>60 min until first intervention”, “ISS>15 and not in intensive care unit”, “ISS>15 and no team activation”, “death in 30 days” was manually created from the data supplied by the registry. This was done in order to minimise selection bias during the manual screening for audit filters by the specialized nurse. The rest of the audit filters are not possible to create with the existing data from the registry.

The missing data from the audit filters were instead interpreted as “no audit filter”.

The audit filter that displayed the highest amount of missing data was “>60 min until first intervention” (n = 5990, 72.1%). The least amount of missing data was found in “SBP<90”

Table 1: Patient characteristics of individuals with and without an OFI. Missing values is shown only were there is any.

Demographic and Clinical Characteristics of patients screened for OFI.

|  | **No**, (N = 7797) | **Yes**, (N = 512) | **Overall** (N = 8309) |
| --- | --- | --- | --- |
| **Gender** |  |  |  |
| Female | 2,411 (31%) | 143 (28%) | 2,554 (31%) |
| Male | 5,386 (69%) | 369 (72%) | 5,755 (69%) |
| **Age** | 42 (27, 61) | 49 (30, 67) | 43 (27, 61) |
| **ISS** | 9 (1, 17) | 17 (10, 25) | 9 (2, 17) |
| Unknown | 11 | 0 | 11 |
| **ED Systolic Blood Pressure** | 135 (120, 150) | 135 (120, 151) | 135 (120, 150) |
| Unknown | 155 | 15 | 170 |
| **ED GCS** | 15.00 (14.00, 15.00) | 15.00 (14.00, 15.00) | 15.00 (14.00, 15.00) |
| Unknown | 816 | 50 | 866 |
| **Time to first CT** | 33 (21, 65) | 39 (25, 70) | 33 (21, 66) |
| Unknown | 967 | 45 | 1,012 |
| **Intubated at ED** |  |  |  |
| No | 7,149 (92%) | 430 (84%) | 7,579 (91%) |
| Yes | 646 (8.3%) | 82 (16%) | 728 (8.8%) |
| Unknown | 2 | 0 | 2 |
| **Dead at 30 days** |  |  |  |
| No | 7,102 (91%) | 469 (92%) | 7,571 (91%) |
| Yes | 686 (8.8%) | 41 (8.0%) | 727 (8.8%) |
| Unknown | 9 | 2 | 11 |
| **Time to definitive treatment** | 102 (49, 251) | 144 (90, 289) | 107 (53, 260) |
| Unknown | 5,748 | 242 | 5,990 |
| **Highest level of care** |  |  |  |
| 1 | 1,478 (19%) | 22 (4.3%) | 1,500 (18%) |
| 2 | 2,955 (38%) | 123 (24%) | 3,078 (37%) |
| 3 | 1,449 (19%) | 146 (29%) | 1,595 (19%) |
| 4 | 343 (4.4%) | 50 (9.8%) | 393 (4.7%) |
| 5 | 1,572 (20%) | 171 (33%) | 1,743 (21%) |
| **Trauma** |  |  |  |
| 1 | 5,040 (65%) | 342 (67%) | 5,382 (65%) |
| 2 | 2,115 (27%) | 102 (20%) | 2,217 (27%) |
| 4 | 228 (2.9%) | 17 (3.3%) | 245 (3.0%) |
| 33 | 405 (5.2%) | 50 (9.8%) | 455 (5.5%) |
| Unknown | 9 | 1 | 10 |

Table 2: Comparison of missing values for each audit filter as a number and as a percentage of the total amount of instances.

| Audit filters | Missing values (n (%)) |
| --- | --- |
| SBP < 90 | 13 (0.2) |
| Death at 30 days | 11 (0.1) |
| ISS > 15 and no team activation | 21 (0.3) |
| Massive transfusion | 978 (11.8) |
| ISS > 15 and not in ICU | 866 (10.4) |
| GCS < 9 and not intubated | 11 (0.1) |
| > 60 min until first intervention | 5990 (72.1) |
| > 30 min until first CT | 1012 (12.2) |
| CPR and thoracotomy | 404 (4.9) |
| Liver or spleen injury | 1929 (23.2) |
| No anticoagulantia within 72 hours after TBI | 2986 (35.9) |
| Definition of abbreviations: OFI = Opportunity for Improvement; ED = Emergency Department; GCS = Glascow Coma Scale; ISS = Injury Severity Score; CPR = Cardiopulmonary Resuscitation; TBI = Traumatic Brain Injury | |

Table 3: Comparison of performance for each audit filter in predicting OFI. Performance is defined by sensitivity (%) and specificity (%). A 95% confidence interval is shown together with each performance indicator. The number of cases flagged by each filter is displayed.

| Auditfilter | (N) | Specificity (%) | Sensitivity (%) |
| --- | --- | --- | --- |
| AF\_sap\_less90 | 501 | 94.1 (93.6-94.6) | 8 (5.6-10.1) |
| AF\_death\_30d | 727 | 91.2 (90.5-91.9) | 8 (5.7-9.8) |
| AF\_iss\_15\_ej\_TE | 583 | 93.8 (93.3-94.5) | 20.1 (16.5-23.6) |
| AF\_mass\_transf | 337 | 96.3 (95.8-96.7) | 9.4 (6.8-12) |
| AF\_gcs\_less9\_ej\_intubTE | 107 | 98.7 (98.5-98.9) | 1.2 (0.1-2) |
| AF\_iss\_15\_ej\_iva | 1295 | 85.7 (85-86.6) | 35.4 (31-38.9) |
| AF\_mer\_60\_min\_interv | 1668 | 81.5 (80.6-82.5) | 43.9 (39.4-47.8) |
| AF\_mer\_30min\_DT | 3907 | 53.8 (52.7-55.2) | 59.2 (55.3-63.3) |
| AF\_hlr\_thorak | 149 | 98.2 (97.9-98.6) | 2 (0.7-3.1) |
| AF\_lever\_och\_mjaltskada | 398 | 95.5 (95.1-96.1) | 9.4 (7.2-12.1) |
| AF\_ej\_trombrof\_TBI\_72h | 241 | 97.3 (96.8-97.7) | 5.7 (3.2-7.5) |
| Definition of abbreviations: OFI = Opportunity for Improvement; ED = Emergency Department; GCS = Glascow Coma Scale; ISS = Injury Severity Score; CPR = Cardiopulmonary Resuscitation; AUC = Area under the receiver operating characteristic curve. | | | |

Table 4: Comparison of performance for each audit filter in predicting OFI. Performance is defined by the area under the reciever operating curve. P-value show significance of AUC compared to 0.5 through t-test. A 95% confidence interval is used.

| Auditfilter | AUC | p-value |
| --- | --- | --- |
| AF\_sap\_less90 | 0.51 (0.5-0.52) | <0.0001 |
| AF\_death\_30d | 0.5 (0.49-0.52) | 1 |
| AF\_iss\_15\_ej\_TE | 0.57 (0.56-0.59) | <0.0001 |
| AF\_mass\_transf | 0.53 (0.52-0.54) | <0.0001 |
| AF\_gcs\_less9\_ej\_intubTE | 0.5 (0.49-0.51) | 0.5 |
| AF\_iss\_15\_ej\_iva | 0.61 (0.59-0.64) | <0.0001 |
| AF\_mer\_60\_min\_interv | 0.63 (0.61-0.66) | <0.0001 |
| AF\_mer\_30min\_DT | 0.56 (0.54-0.58) | <0.0001 |
| AF\_hlr\_thorak | 0.5 (0.49-0.51) | 0.0662 |
| AF\_lever\_och\_mjaltskada | 0.52 (0.5-0.53) | <0.0001 |
| AF\_ej\_trombrof\_TBI\_72h | 0.51 (0.49-0.51) | <0.0001 |
| Definition of abbreviations: OFI = Opportunity for Improvement; ED = Emergency Department; GCS = Glascow Coma Scale; ISS = Injury Severity Score; CPR = Cardiopulmonary Resuscitation; AUC = Area under the receiver operating characteristic curve. | | |

![](data:application/pdf;base64,) Figure 1: Flowchart of the patient selection process. Shows the patients excluded and included in this study. # Discussion

## Interpretation of Results

The aim of the study was to determine the performance of individual audit filters in predicting OFI to assess whether they are a sufficient screening method for morbidity and mortality conferences.

The number of male trauma cases was almost double that of females, which is consistent with what has been shown in previous studies both nationally [4] and globally [3]. It is thought that the reason for this lies in the higher risk pursuement of men compared to women.

The reason for a significantly higher ISS in the OFI group compared to the group without OFI could be that trauma cases with higher severity are more complex to treat than those with lower ISS, leading to a higher risk of OFI. These findinga are similar to a previous study also conducted at Karolinska University Hospital by Albaaj et. al [37], which attempted to compare patient factors associated with OFI. They found that a higher ISS was significantly correlated with OFI. A Similar explanation, regarding injury severity and patient case complexity could be made with patients intubated at ED.

The possible reason behind the audit filters generally having a high specificity relative to their sensitivity may be due to the outcome being rather uncommon whilst every individual audit filter miss the majority of OFI. Theoretically, adding all audit filters together as one audit filter would result in the sensitivity increasing.

The explanation behind the relatively high specificity is due to the amount of true negative values being high. A patient case with no audit filter will often also have no OFI to them.

An extensive review article by Evans et. al [28] sought to review the evidence for audit filters as a tool to improve care. They screened for a total of 741 studies by title. Of these studies, 42 abstracts were appraised and five complete articles were examined in detail. None of the five studies met the inclusion criteria established. two of the studies which where examined in detail by Chadbunchachai et. al [27];[38] where also two of the studies mentioned in WHO:s guidelines for quality improvement programmes [19]. The reason for their exclusion was due to no clear pre‐ or post‐intervention data points or clearly defined a point in time when the respective interventions were implemented.

in a 2008 study by Willis [39] they looked at the individual risk for poor outcome in 14 audit filters. Out of these 14 audit filters only three audit filters showed an increased risk for poor outcome while the rest showed no significant ability to predict poor outcome. One audit filter, “GCS<9 and not intubated”, which was used by Willis is also used at the trauma center at Karolinska University Hospital. Similarly the audit filter showed no significant ability to predict poor outcome as in an OFI.

The audit filters that did not prove to be better than randomness suggest that their use as a screening method for determining OFI is not valuable and should not be used for that purpose.

Some of the audit filters, however, showed promising results in predicting OFI. ### Delay Both audit filters measuring delay (“>60 until first intervention” and “>30min until first CT”) showed promising results in predicting opportunities for improvement. This is could be a result from the fact that delay seem to strongly correlate with adverse outcomes such as preventable death [40]. A recent study in Japan showed a significant reduction in mortality if patients recieved a whole body CT within 10 minutes from arrival to the ED [41]. This could suggest that a lower threshold for our local audit filter regarding delay to CT could be made in the future.

[18] found that the most common error in trauma care was due to delay in treatment, delay to CT and clinical judgement errors as in inappropriate treatment or procedural errors. This stands well with our findings where delay to first intervention and to CT was associated with OFI.

A german study [42] evaluated quality indicators through interdisciplinary peer review and found that, similarly, various audit filters regarding time to different care processes had consensus on its relevance in trauma care.

A similar german study [43] looked at the correlation between audit filters and mortality on top of a interdiciplinary expert review according to the QUALIFY process. They looked at two methods in assessing the performance of auditfilters: The indicator approach and the clinical approach. The indicator approach in assessing performance of audit filters was to assess wether the desired indicator level was associated with a lower mortality compared to without the desired level. The clinical aproach compared different hospitals and ranked them as “good hospitals or”bad hospitals”. Good hospitals had a lower 5-year mortality rate among a selected patient group with quality indicator parameters of interest compared to the RISK II predicted mortality. Evaluation of each approach ranked the usefullnes of each audit filter between “strong association with mortality”, “unclear association with mortality” and “no association with mortality”. The expert review was carried out in the same fashion as Bieler et. al. Only 3 audit filters was similar to the audit filters used in Karolinska university hospital: “prehospital intubation in patients with GCS < 9”, “Time to whole body CT”, “time to first emergency procedure”. prehospital intubation showed an unclear correlation to mortality in the clinical approach, a strong association in the indicator approach and scored high by the review panel. In this study “GCS < 9 and not intubated” showed no association with OFI. “Time to whole body CT” showed unclear association with mortality in both approaches but scored high in expert review. “more than 30 min until first CT” was in our case associated with OFI. “time to first emergency procedure” had no correlation with mortality but expert review agreed that it was still useful. “>60 min until first intervention” was in our case associated with OFI. It is important to note that OFI in our case was not only a reflection of mortality but a much broader concept encompassing different aspects of care quality. It is therefore not a comparison that holds much weight. If anything it highlights the difference between hospitals in what audit filters are in use and how they are being assessed.

The reason behind the fact that the audit filter “Dead at 30 days” showed no difference from randomness could be because severe traumatic injuries might inevitably die within 30 days of admission to the hospital resulting in no consensus on the existence of an OFI in such particular case.

A similar explanation can be done with the audit filter “CPR and thoracotomy” which also showed a performance in predicting OFI equal to coincidence. A patient who undergo CPR and thoracotomy generally have a very low survival rate and might only be done to those who are severely injured. Theoretically a lower time in the hospital also calls for less time to perform potential mistakes resulting in lower OFI rate.

We can compare this with the audit filters that performed well in predicting OFI which generally have a low mortality. For example, “>60 min until first intervention”. Also involves a large patient pool.

[37] looked at patient factor associated with OFI and found that delay of between 30-60 minutes until first CT was associated with OFI. Higher levels of care was associated with OFI. Similarly they found no clear association between 30 day survival and OFI. The found that higher ISS was associated with higher OFI occurences, mosy likely due to the increased complexity of patient cases with higher ISS, therefore prone to OFI. This could partly explain the association between “ISS > 15 and no team activation” and OFI predicition and similarly regarding “ISS > 15 and not in intensive care unit”.

[29] OFIs predominantly exist in the ED and relate to airway management, fluid resuscitation, and chest injury management The only audit filter directly associated with air way management was “GCS under 9 and not intubated” which performed poorly. This suggests that an alternative audit filter related to the airway management should be considered in the future. ## Generalizability

Since the screening method for identifying an OFI may vary at different trauma centres there will be a difference in results.

The audit filters being used differ between trauma centrer which adds to the difficulty of creating a standard screening system.

The use of audit filters and quality improvement programs are wildly used and the findings in this study suggest that some audit filters perform better than others. The audit filters sucessful in this cohort might be a beneficial addon to already existing quality improvement programs or work as a guidance in fine-tuning audit filters already in use.

Due to the study being conducted on a single, trauma level I center in Stockholm it is unfair to assume replicability of these findings on other hospitals in other countries. It is already suggested that the efficacy of audit filters vary depending on country. Low and middle income countries seem to benefit from certain audit filters that high income countries do not benefit from and vice versa [44].

## Strengths

As stated in the method section, some audit filters whose criteria were possible to be retrieved from the registry was manually created instead of relying on the selection process by the specialized nurse. This was done in order to minimize misclassification bias.

## Limitations

Opportunity for improvement, while defined as a binary variable, includes a diverse set of outcomes ranging from preventable deaths to bad documentation. This makes it difficult to create audit filters that do well in predicting an OFI.

The current screening system for OFI might also introduce bias since the filters would favour the identification of some, but not all, errors

Future research should focus on identifying potential subgroups of OFI that proves to be relatively hard to predict and adjust accordingly.

The way the audit filters performance were individually calculated, as stated in the method section, was to look at every patientcase with or without an OFI and silmuntaniously flagged or not flagged with the audit filter. THis means that even tho an audit filter presented a true positive correlation with an OFI, there is still a chance, if the same patient case had more than one audit filter flagged, that it was not the tested audit filter that predicted truthfully rather it was the other audit filter.

the number of missing values varied greatly among the audit filters. As stated above, missing values from each audit filter was instead flagged as not having that audit filter. This means that some of the patient cases not flagged, might actually meet the audit filter criteria, but for some reason not documented. This reduces the validity of some audit filters who displayed high amounts of missing data.

## Future Studies

With the ever expanding field of artificial intelligence and machine learning, newer studies should focus on using these tools in order to screen for patient cases who risk having an OFI. This will result in misclassification reduction and ensure constant and continued good performance due to its ability to learn from the current context of trauma care. This approach is new but not unexplored. A preprint is currently available by Attergrim et. al [45] at Karolinska University Hospital exploring the idea of machine learning models as screening tool for potential OFIs. They found that machine learning models outperformed the currently used audit filters in predicting OFI.

further look at OFI subgroups. What kind of OFIs are overrepresented in different audit filters. ## Health Equity It could be of interest to study the occurrence of OFI among marginalzed groups of people and women in order to assess whether some groups of people tend to fall out from the screening method or at a higher rate falsely labelled without OFI.

# Conclusion

Audit filters as a tool in quality improvement programs are wildly used. Strong evidence supporting their efficacy in quality improvement is scarse but seem to depend on were they are used, in what context and for what purpose. In this study, 8 out of 11 audit filters currently in use at Karolinska University Hospital was deemed effective in predicting OFI. 3 of the audit filters did not show promising results. These results highlight the importance of continually evaluating the relevancy of certain audit filters and to fine tune audit filter criteria to better reflect the current gap in trauma care quality.

# Acknowledgements

I want to thank my supervisor Martin Gerdin Wärnberg and my co-supervisors Jonatan Attergrim and Kelvin Szolnoky. I also want to show appreciation to my good friend and colleague Anton Wasielewski for all the support.

# Tables

# References

1. Organization WH et al. Injuries and violence: The facts 2014. 2014.

2. Vos T, Lim SS, Abbafati C, Abbas KM, Abbasi M, Abbasifard M, et al. [Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: A systematic analysis for the global burden of disease study 2019](https://www.thelancet.com/action/showPdf?pii=S0140-6736%2820%2930925-9). The Lancet. 2020;396:1204–22.

3. Roth GA, Abate D, Abate KH, Abay SM, Abbafati C, Abbasi N, et al. [Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: A systematic analysis for the global burden of disease study 2017](https://www.thelancet.com/action/showPdf?pii=S0140-6736%2818%2932203-7). The Lancet. 2018;392:1736–88.

4. SweTrau ST. Arsrapport - 2022. 2022.

5. Hexdall A, Miglietta MA. Mechanism of injury. In: Legome E, Shockley LWE, editors. Trauma: A comprehensive emergency medicine approach. Cambridge University Press; 2011. p. 24–34.

6. North N. The psychological effects of spinal cord injury: A review. Spinal cord. 1999;37:671–9.

7. Muscatelli S, Spurr H, O’Hara NN, O’Hara LM, Sprague SA, Slobogean GP. Prevalence of depression and posttraumatic stress disorder after acute orthopaedic trauma: A systematic review and meta-analysis. Journal of orthopaedic trauma. 2017;31:47–55.

8. Visser E, Gosens T, Den Oudsten BL, De Vries J. The course, prediction, and treatment of acute and posttraumatic stress in trauma patients: A systematic review. Journal of Trauma and Acute Care Surgery. 2017;82:1158–83.

9. David SD, Aroke A, Roy N, Solomon H, Lundborg CS, Wärnberg MG. [Measuring socioeconomic outcomes in trauma patients up to one year post-discharge: A systematic review and meta-analysis](https://www.injuryjournal.com/article/S0020-1383(21)00880-9/pdf). Injury. 2022;53:272–85.

10. Newnam S, Collie A, Vogel A, Keleher H. The impacts of injury at the individual, community and societal levels: A systematic meta-review. Public health. 2014;128:587–618.

11. Organization WH et al. Prehospital trauma care systems. World Health Organization; 2005.

12. Alharbi RJ, Shrestha S, Lewis V, Miller C. The effectiveness of trauma care systems at different stages of development in reducing mortality: A systematic review and meta-analysis. World Journal of Emergency Surgery. 2021;16:1–12.

13. Mann NC, Mullins RJ, MacKenzie EJ, Jurkovich GJ, Mock CN. Systematic review of published evidence regarding trauma system effectiveness. Journal of Trauma and Acute Care Surgery. 1999;47:S25–33.

14. Candefjord S, Asker L, Caragounis E-C. Mortality of trauma patients treated at trauma centers compared to non-trauma centers in sweden: A retrospective study. European journal of trauma and emergency surgery. 2020;1–12.

15. Nikouline A, Quirion A, Jung JJ, Nolan B. Errors in adult trauma resuscitation: A systematic review. Canadian Journal of Emergency Medicine. 2021;23:537–46.

16. Vioque SM, Kim PK, McMaster J, Gallagher J, Allen SR, Holena DN, et al. Classifying errors in preventable and potentially preventable trauma deaths: A 9-year review using the joint commission’s standardized methodology. The American Journal of Surgery. 2014;208:187–94.

17. Kwon A, Garbett N, Kloecker G. Pooled preventable death rates in trauma patients: Meta analysis and systematic review since 1990. European Journal of Trauma and Emergency Surgery. 2014;40:279–85.

18. Ghorbani P, Strömmer L. Analysis of preventable deaths and errors in trauma care in a scandinavian trauma level-i centre. Acta Anaesthesiologica Scandinavica. 2018;62:1146–53.

19. Organization WH et al. Guidelines for trauma quality improvement programmes. World Health Organization; 2009.

20. Gregor A, Taylor D. Morbidity and mortality conference: Its purpose reclaimed and grounded in theory. Teaching and learning in medicine. 2016;28:439–47.

21. Orlander JD, Fincke BG. Morbidity and mortality conference: A survey of academic internal medicine departments. Journal of general internal medicine. 2003;18:656–8.

22. Giesbrecht V, Au S. Morbidity and mortality conferences: A narrative review of strategies to prioritize quality improvement. The Joint Commission Journal on Quality and Patient Safety. 2016;42:516–27.

23. Churchill KP, Murphy J, Smith N. Quality improvement focused morbidity and mortality rounds: An integrative review. Cureus. 2020;12.

24. Lazzara EH, Salisbury M, Hughes AM, Rogers JE, King HB, Salas E. The morbidity and mortality conference: Opportunities for enhancing patient safety. Journal of Patient Safety. 2022;18:e275–81.

25. Kong VY, Clarke DL. Analysis of 5 years of morbidity and mortality conferences in a metropolitan south african trauma service. South African Medical Journal. 2016;106:695–8.

26. Ghorbani P, Falkén M, Riddez L, Sundelöf M, Oldner A, Strömmer L. Clinical review is essential to evaluate 30-day mortality after trauma. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine. 2014;22:1–7.

27. Chadbunchachai W, Sriwiwat S, Kulleab S, Saranrittichai S, Chumsri J, Jaikwang P. [The comparative study for quality of trauma treatment before and after the revision of trauma audit filter, khon kaen hospital 1998.](https://frontpage.eurekamag.com/011484126.pdf) Journal of the Medical Association of Thailand= Chotmaihet Thangphaet. 2001;84:782–90.

28. Evans C, Howes D, Pickett W, Dagnone L. [Audit filters for improving processes of care and clinical outcomes in trauma systems](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7197044/). Cochrane database of systematic reviews. 2009.

29. Sanddal TL, Esposito TJ, Whitney JR, Hartford D, Taillac PP, Mann NC, et al. Analysis of preventable trauma deaths and opportunities for trauma care improvement in utah. Journal of Trauma and Acute Care Surgery. 2011;70:970–7.

30. Roy N, Kizhakke Veetil D, Khajanchi MU, Kumar V, Solomon H, Kamble J, et al. Learning from 2523 trauma deaths in india-opportunities to prevent in-hospital deaths. BMC health services research. 2017;17:1–8.

31. Santana MJ, Stelfox HT, et al. Development and evaluation of evidence-informed quality indicators for adult injury care. Annals of surgery. 2014;259:186–92.

32. O’reilly D, Mahendran K, West A, Shirley P, Walsh M, Tai N. Opportunities for improvement in the management of patients who die from haemorrhage after trauma. Journal of British Surgery. 2013;100:749–55.

33. Lewis PR, Badiee J, Sise MJ, Calvo RY, Brill JB, Wallace JD, et al. “Delay to operating room” fails to identify adverse outcomes at a level i trauma center. Journal of Trauma and Acute Care Surgery. 2017;82:334–7.

34. Ringdal KG, Coats TJ, Lefering R, Di Bartolomeo S, Steen PA, Røise O, et al. The utstein template for uniform reporting of data following major trauma: A joint revision by SCANTEM, TARN, DGU-TR and RITG. Scandinavian journal of trauma, resuscitation and emergency medicine. 2008;16:1–19.

35. R Core Team. [R: A language and environment for statistical computing](https://www.R-project.org/). Vienna, Austria: R Foundation for Statistical Computing; 2022.

36. Robin X, Turck N, Hainard A, Tiberti N, Lisacek F, Sanchez J-C, et al. pROC: An open-source package for r and s+ to analyze and compare ROC curves. BMC bioinformatics. 2011;12:1–8.

37. Albaaj H, Attergrim J, Strömmer L, Brattström O, Jacobsson M, Wihlke G, et al. Patient and process factors associated with opportunities for improvement in trauma care: A registry-based study. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine. 2023;31:87.

38. Chadbunchachai W, Saranrittichai S, Sriwiwat S, Chumsri J, Kulleab S, Jaikwang P. Study on performance following key performance indicators for trauma care: Khon kaen hospital 2000. Journal of the Medical Association of Thailand= Chotmaihet Thangphaet. 2003;86:1–7.

39. Willis CD, Stoelwinder JU, Cameron PA. Interpreting process indicators in trauma care: Construct validity versus confounding by indication. International Journal for Quality in Health Care. 2008;20:331–8.

40. Teixeira PG, Inaba K, Hadjizacharia P, Brown C, Salim A, Rhee P, et al. Preventable or potentially preventable mortality at a mature trauma center. Journal of Trauma and Acute Care Surgery. 2007;63:1338–47.

41. Yamamoto R, Suzuki M, Funabiki T, Sasaki J. [Immediate CT after hospital arrival and decreased in-hospital mortality in severely injured trauma patients](https://academic.oup.com/bjsopen/article/7/1/zrac133/6995386?login=false). BJS open. 2023;7:zrac133.

42. Bieler D, Hörster A, Lefering R, Franke A, Waydhas C, Huber-Wagner S, et al. Evaluation of new quality indicators for the TraumaRegister DGU using the systematic QUALIFY methodology. European journal of trauma and emergency surgery. 2020;46:449–60.

43. Hörster A, Kulla M, Bieler D, Lefering R. Empirical evaluation of quality indicators for severely injured patients in the TraumaRegister DGU. Der Unfallchirurg. 2020;123:206–15.

44. Berg J, Alvesson HM, Roy N, Ekelund U, Bains L, Chatterjee S, et al. Perceived usefulness of trauma audit filters in urban india: A mixed-methods multicentre delphi study comparing filters from the WHO and low and middle-income countries. BMJ open. 2022;12:e059948.

45. Attergrim J, Szolnoky K, Strömmer L, Brattström O, Whilke G, Jacobsson M, et al. Predicting opportunities for improvement in trauma using machine learning: A registry based study. medRxiv. 2023;2023–01.

#Appendices