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

A registry based cohort study

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Abbreviations

OFI – Opportunities for Improvement

CI – Confidence Interval

GCS – Glascow Coma Scale

ISS – Injury Severity Score

ED – Emergency Department

AUC – Area Under Curve

ROC – Receiver Operating Characteristics

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

Sammanfattning

Bakgrund: Trauma står för 9% av globala dödsfall årligen och har en betydande påverkan på individer och samhället. Kvalitetsförbättringsprogram (QI) syftar till att minimera dessa ogynnsamma utfall genom användning av audit filter som indikatorer för standardvård och genom att utvärdera patientfall för potentiella förbättringsmöjligheter (OFI). *Syfte:* Denna studie syftade till att utvärdera prestandan hos audit filter för att förutsäga OFI och att bedöma deras relevans som screeningverktyg för Morbiditets- och Mortalitetskonferenser (MMC). *Material och Metoder:* Sensitivitet, specificitet och Area Under the Receiver Operating Characteristics Curve (AUC) beräknades för att utvärdera prestanda. En t-test för AUC genomfördes för att jämföra prestanda med slumpmässighet. *Resultat:* Av de 11 audit filter som utvärderades hade 3 en AUC på 0,5 ($p > 0{,}05$). De återstående audit filterna visade en korrelation med OFI, med AUC-värden som varierade från 0,51 till 0,63. Audit filtret "> 60 min till första ingrepp" uppvisade den högsta AUC på 0,63. *Slutsats:* Ingen enskild revisionsfilter tycktes prestera väl i att förutsäga OFI. Detta antyder behovet av att ompröva den nuvarande screeningmetoden för MMC.

Abstract

Introduction: Trauma is responsible for 9% of global deaths anually and pose a significant impact on individuals and society. Quality Improvement (QI) programs seek to minimize these adverse outcomes through the use of audit filters as indicators of standard care and through assessing patient cases for potential Opportunities for Improvement (OFI). *Aims:* This study aimed to evaluate the performance of audit filters in predicting OFI and to assess their relevance as a screening tool for Morbidity and Mortality Conferences (MMC). *Material and Methods:* The sensitivity, specificity and Area Under the Reciever Operating Characteristics Curve (AUC) was calculate din order to assess performance. A t-test for AUC was conducted to compare the performance to coincidence. *Results:* Of the 11 audit filters assessed, 3 had an AUC of 0.5 ($p > 0.05$). The remaining audit filters demonstrated a correlation with OFI, with AUC ranging from 0.51 to 0.63. The audit filter "> 60 min until first intervention" exhibited the highest AUC of 0.63. *Conclusion:* No individual audit filter seemed to perform well in predicting OFI. Which suggest rethinking the current screening method for MMC.

Keywords: Trauma, Opportunities for Improvement, audit filter, performance

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 approximately 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. Commonly known 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 magnitude 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 and short term consequences on an individual, societal and economical level.

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 [6, 7].

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

However, trauma is 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 trauma, 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 health care service provided by hospitals. A variety of different specialities are involved in trauma care, including surgeons, orthopaedists, anaesthesiologists, 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 centre. 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 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 adjusted risk of death is 41% lower in a mature trauma centre compared to a non-trauma centre. Despite this, even established trauma care systems are 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]. For example, 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) and the 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) a clear definition of the role of the MMC, (2) involvement of stakeholders, (3) recognising and selecting appropriate patient cases for presentation, (4) structured and 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].

Audit Filters and Opportunities for Improvement

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

Earlier studies showed a reduction in trauma related mortality after the implementation of audit filters [26]. Per contra, 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 in trauma care. Yet, none of the studies met established inclusion criteria [27]. The use of audit filters have also been associated with high frequencies of false positives, ranging from 24% to 80%.[28]; [29].

Opportunities for improvement (OFIs) are the endpoint of patient care. 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 processes are associated with high-quality trauma care [30]. OFIs are typically associated with failures in initial care [16], specifically in airway management, fluid resuscitation, haemorrhage control and chest injury management [28]; [29, 31].

Audit filters can work as a guidance to determining OFI and OFI can work as basis for developing new audit fitlers. There seems to be lacking evidence for the use of audit filters in predicting OFI [27] and some audit filters seem not to correlate with OFIs at all [32].

Aim

The aim of the study is to determine the performance of audit filters in predicting OFIs and furthermore assess there relevance as a screening tool for MMC.

Methods

We conducted a single centre, registry-based, retrospective cohort study with data from the Swedish trauma registry (SweTrau) and the local trauma care quality database at 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 trauma 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 an Injury Severity Score (ISS) of less than 9 retrospectively it is also included in the registry. The Karolinska trauma registry reports to the 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 [33]

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 decisions.

This process of determining OFIs unfolds in multiple stages, characterised by escalating levels of scrutiny. Notably, instances of mortality are directly referred to the multidisciplinary conference, where, in addition to assessing OFIs, a decision 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 that where unrelated to mortality, whereafter the review process underwent subsequent refinement and formalisation 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. Only in 2017 was this procedure formalised and it became standardised 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 specialised 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 patient cases who underwent screening for OFIs. Exclusion criteria were applied to those not screened for OFI and 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 and furthermore treated as a dichotomous variable with "Yes - At least one OFI identified" and "No - No OFI identified". ### Exposures

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

A list of the audit filters currently in use at Karolinska University Hospital can be seen in Table 1. Each audit filter is labelled as either "original" or "manually created" depending on how they were managed. Manually created audit filters were calculated using trauma registry data instead of relying on the decision by the specialised nurse as recorded in the quality database. The original audit filters were instead used as recorded in the quality database, since their criteria encompassed variables outside of what could be retrieved from the existing data in the registry.

Data sources/measurement

The data used in this retrospective cohort was retrieved from the Karolinska University Hospital trauma registry and 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 was retrieved from SweTrau while both exposures (audit filters) and outcome (OFI) were retrieved from the Karolinska University Hospital trauma care quality database.

All data was anonymised to protect patient privacy.

Bias

It is possible that consensus decisions from the MMC conferences are flawed, leading to 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.

Health care professionals who attend MMCs and have also been a witness to a specific patient case might not remember certain key elements that may affect the decision-making around OFI. Patient-case reviews in this fashion are subject to recall bias. On the other hand, health care professionals who have not witnessed that particular case may be over- or underestimating the significance of an OFI.

Study size

The study cohort encompasses all eligible patients treated at Karolinska University Hospital from 2012 to 2022.

Statistical methods

The study results will be generated by statistical analytics methods with the help of the statistical programming language, R [34].

To evaluate the predictive performance of audit filters, the sensitivity and specificity of each individual audit filter in predicting OFI will be calculated. Additionally, a receiver operating curve (ROC) for binary classification will be constructed and the area under the curve (AUC) calculated in order to compare the performance of each audit filter [35].

Using a bootstrapping method with 1000 iterations of the selected data, 95% confidence intervals for sensitivity, specificity and AUC will be calculated. The significance of the AUC of each audit filter will then be compared with that of coincidence (AUC = 0.5), through a one sample T-test.

Instances of missing values for audit filters will be treated as negative, as in “not flagged”.

Ethical considerations

In Sweden register-based studies do not require informed consent by patients in the registry. Approval by the Swedish Ethical Review Authority is required in order to execute a study in this manner. This authority comprises of medical, judicial and lay members appointed by the government. In order to uphold the principle of autonomy, measures are in place to ensure integrity of each patient.

All patient data is anonymised according to General Data protection Regulation (GDPR) standard [36]. In the registry used, there is data on various factors such as date and time of admission, and patient characteristics e.g. age and gender. Theoretically, these attributes could make patient cases identifiable through external sources like news reports. Nonetheless, this means that such information must be leaked, which would only be possible through direct registry access. In order to minimise the risk of a potential data breach, the registry is password protected and access to the registry server is only possible while connected to a VPN with special credentials requiring two-factor authentication.

This was a retrospective cohort study and as such, no patients were put through any additional interventions and all patients were given care according to standard. Thus, patients were at no risk of any harm due the study.

This study will possibly give new insights to current quality improvement programs by assessing the advantage of audit filters. These new insights, if implemented, might further lead to a better outcome for trauma patients in terms of reduced mortality and morbidity.

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

Results

Figure 1 presents a flowchart showcasing the exclusion and inclusion of the patient cases from the trauma registry. After excluding patients under 15 years old and patients not screened for OFIs, a total of 8309 individuals were included in the study. 7797 out of 8309 (93.8%) patient cases did not have an OFI and 512 out of 8309 (6.2%) had an OFI.

Missing Data

Table 2 shows the missing data for each audit filter. As mentioned in the method section, these values where interpreted as not flagged with an audit filter. The variables with the highest amount of missing data was “time to definitive treatment” (n = 5990, 72.1%) and “time to first CT” (n = 1012, 12.2%). The least amount of missing data was found in “SBP<90” (n = 13, 0.2%).

Participant Characteristics

Table 3 presents the baseline characteristics of the study participants, comparing those with and without an assigned OFI. The variables presented in Table 3, except gender and age, were used in the calculation of audit filters.

5755 (69%) out of all patients included in the study were men and 2554 (31%) women. Results varied depending on whether patients had an OFI or not. The mean age was slightly higher 49 (30, 67) vs 42 (27, 61) and the ISS was higher 17 (10, 25) vs 9 (1, 17). The number of intubations in the emergency department was higher NA vs NA. Patients with OFI had longer times to definitive treatment from hospital arrival compared to patients without OFI 144 (90, 289) vs 102 (49, 251). Moreover, the time to the first CT was also longer in patients with OFIs `inline_text(tableOne, variable = dt_ed_first_ct, column = stat_2)` vs 33 (21, 65).

The mean systolic blood pressure and GCS at the emergency department did not differ between the OFI and no OFI group.

Individual Audit Filters

Performance of Individual Audit Filters

The performance of each audit filter was determined through a calculation of sensitivity and specificity. This is demonstrated in Table 4.

Varying numbers of patient cases were flagged with each audit filter. The audit filter 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 sensitivity was ">30min until CT" (59.2% CI: 55.3-63.3). The audit filter with the lowest sensitivity was "GCS<9 and not intubated" (1.2% CI: 0.1-2).

The audit filter with the highest specificity was "GCS<9 and not intubated" (98.7% CI: 98.5-98.9). The The audit filter with the lowest specificity was ">30min until CT" (53.8% CI: 52.7-55.2).

Generally, the confidence intervals varied between sensitivity and specificity, with sensitivity having a greater interval span.

Table 5 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 as good as coincidence (AUC = 0.5). >60 min until first intervention had the highest AUC.

Table 2: Comparison of missing values for each audit filter as a number and percentage of the total amount of patient cases (n = 8309).

Audit filters	Missing values n (%)
SBP < 90	13 (0.2)
Dead at 30 days	11 (0.1)
ISS > 15 and no team activation	21 (0.3)
Massive transfusion	978 (11.8)
GCS < 9 and not intubated	866 (10.4)
ISS > 15 and not in ICU	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; SBP = Systolic Blood Pressure; ISS = Injury Severity Score; GCS = Glascow Coma Scale; ICU = Intensive Care Unit; CT = Computer Tomopgraphy; ED = Emergency Department; CPR = Cardiopulmonary Resuscitation; TBI = Traumatic Brain Injury

Table 3: Patient characteristics of individuals with and without an OFI. Missing values are shown only when they exist.

	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)

	No, (N = 7797)	**Yes**, (N = 512)	**Overall** (N = 8309)
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			
Emergency department	1,478 (19%)	22 (4.3%)	1,500 (18%)
General ward	2,955 (38%)	123 (24%)	3,078 (37%)
Surgical ward	1,449 (19%)	146 (29%)	1,595 (19%)
Specialist ward/Intermediate ward	343 (4.4%)	50 (9.8%)	393 (4.7%)
Intensive care unit	1,572 (20%)	171 (33%)	1,743 (21%)
Trauma team activation			
No	5,040 (65%)	342 (67%)	5,382 (65%)
Yes	2,748 (35%)	169 (33%)	2,917 (35%)
Unknown	9	1	10

Table 4: Comparison of performance for each audit filter in predicting OFIs. 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.

Audit filter	(N)	Specificity (%)	Sensitivity (%)
SBP < 90	501	94.1 (93.6-94.6)	8 (5.6-10.1)
Dead at 30 days	727	91.2 (90.5-91.9)	8 (5.7-9.8)
ISS > 15 and no team activation	1951	77.7 (76.6-78.7)	41.2 (37.4-45.6)
Massive transfusion	337	96.3 (95.8-96.7)	9.4 (6.8-12)
GCS < 9 and not intubated	107	98.7 (98.5-98.9)	1.2 (0.1-2)
ISS > 15 and not in ICU	1295	85.7 (85-86.6)	35.4 (31-38.9)
> 60 min until first intervention	1668	81.5 (80.6-82.5)	43.9 (39.4-47.8)
> 30 min until first CT	3907	53.8 (52.7-55.2)	59.2 (55.3-63.3)
CPR and thoracotomy	149	98.2 (97.9-98.6)	2 (0.7-3.1)
Liver or spleen injury	398	95.5 (95.1-96.1)	9.4 (7.2-12.1)
No anticoagulantia within 72 hours after TBI	241	97.3 (96.8-97.7)	5.7 (3.2-7.5)

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Table 5: Comparison of performance for each audit filter in predicting OFIs. Performance is defined by the

area under the receiver operating characteristics curve. P-values show the significance of AUC compared to coincidence (AUC = 0.5) through a t-test. A 95% confidence interval is used.

Audit filter	AUC	p-value
SBP < 90	0.51 (0.5-0.52)	<0.0001
Dead at 30 days	0.5 (0.49-0.52)	1
ISS > 15 and no team activation	0.59 (0.56-0.6)	<0.0001
Massive transfusion	0.53 (0.52-0.54)	<0.0001
GCS < 9 and not intubated	0.5 (0.49-0.51)	0.5
ISS > 15 and not in ICU	0.61 (0.59-0.64)	<0.0001
> 60 min until first intervention	0.63 (0.61-0.66)	<0.0001
> 30 min until first CT	0.56 (0.54-0.58)	<0.0001
CPR and thoracotomy	0.5 (0.49-0.51)	0.0662
Liver or spleen injury	0.52 (0.5-0.53)	<0.0001
No anticoagulantia within 72 hours after TBI	0.51 (0.49-0.51)	<0.0001

Definition of abbreviations: OFI = Opportunity for Improvement; AUC = Area under the receiver operating characteristic curve; SBP = Systolic Blood Pressure; ISS = Injury Severity Score; GCS = Glascow Coma Scale; ICU = Intensive Care Unit; CT = Computer Tomopgraphy; ED = Emergency Department; CPR = Cardiopulmonary Resuscitation; TBI = Traumatic Brain Injury

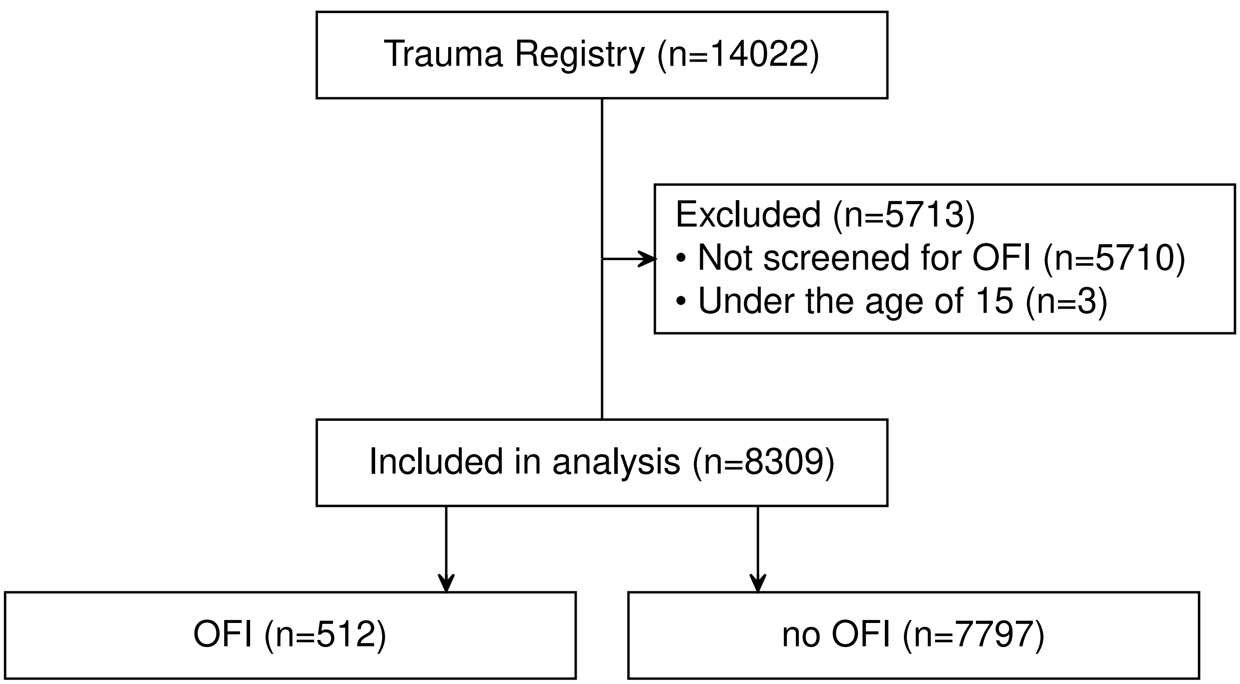

Figure 1: Flowchart of the patient selection process. Shows the patients excluded and included in this study.

Discussion

Interpretation of Results

The aim of this study was to evaluate the performance of individual audit filters in predicting OFIs, to assess their suitability as a screening tool for morbidity and mortality conferences.

The observed twofold prevalence of male trauma patients compared to females is consistent with previous findings both nationally [4] and globally [3]. This is believed to lie in the tendecy to high-risk behaviours in males.

The higher ISS in the patients with OFIs as opposed to patients without OFIs could be explained by the greater complexity of trauma cases with increasing ISS. Greater complexity allows for more mistakes. These findings stay true with a previous study conducted at Karolinska University Hospital by Albaaj et. al [37]. Albaaj et. al sought to identify patient factors associated with OFIs and found that a higher ISS was significantly correlated with OFIs.

Audit filters generally exhibited a high specificity relative to their sensitivity which may be attributed to the outcome being rather uncommon, whilst every individual audit filter miss the majority of OFIs. Theoretically, adding all audit filters together as one audit filter would result in the sensitivity increasing, and simultaneously the specificity decreasing.

An extensive review by Evans et. al [27] sought to review the evidence for audit filters as a tool to improve care. A total of 741 studies were screened 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 by Chadbunchachai et. al [26];[38], which were examined in detail by Evans et. al were mentioned in WHO:s guidelines for quality improvement programmes [19]. They were excluded from Evans et. al review due to no clear pre- or post-intervention data points or a clearly defined point in time when the respective interventions were implemented.

In 2008, Willis et. al [39] assessed 14 audit filters, finding only three to be associated with an increased risk of poor outcomes. One audit filter, "GCS<9 and not intubated", also used in this study showed no significant ability to predict poor outcome.

Audit filters demonstrating a performance equal to coincidence are deemed unsuitable as screening tools for OFIs. On the contrary, audit filters demonstrating a performance superior to that of coincidence could still be used as audit filters. However, it is important to note that despite these audit filters proving meaningful, it does not mean they are acceptable as a screening tool. That would not have been the case with a diagnostics test where the AUC should be at least 0.8 for it to be considered acceptable [40].

A noteworthy challenge with audit filters is the risk of overrelying on them. While they may help in deciding the existence of OFI, they could overshadow other factors that may contribute to that decision.

Audit filters are static in their criteria, oppositely to healthcare in general. This means that audit filters may loose their purpose if new guidelines are introduced. For example, liver and spleen injuries did not perform at all in predicting OFIs. It could very well be that new and improved guidelines and gold standards reduced the number of OFIs.

A further problem with audit filters being static is that they themselves can fulfill their purpose and subsequently loose their relevance through a negative feedback loop. For example, a problem in health care occurs and in response an audit filter is made in order to tackle this problem. At first this will theoretically result in a good predictability for OFI. However, when such OFIs are taken into consideration the audit filter will gradually loose its performance.

Some audit filter criteria are more rigid than others. A criterion too rigid will fail to recognise the majority of OFIs while too inclusive criteria might flag several patients, who do not necessarily have an OFI. This in turn leads to the next problem regarding the resources and time needed for making an OFI decision. A very inclusive criterion will cause many patient cases being flagged and will lead to many patient cases being discussed at MMCs.

Suggest we were to replace audit filters used by Karolinska University Hospital with other audit filters. We would have to review them over time and simultaneously risk the fact that they might not perform.

Another general challenge with audit filters is the unintended bias that comes with postulating audit filters. They might disproportionally affect certain groups of people. Moreover, the risk of confounders are present when establishing such criteria.

Audit filters currently in use at Karolinska University Hospital focus primarily on aspects of trauma care mostly relevant to medical doctors. It might be beneficial to consider the interdisciplinary nature of trauma care by using criteria related to morbidity for example.

Delay

Both audit filters measuring delay: ">60 until first intervention" and ">30min until first CT", showed a correlation with OFI. This is comparable to what Teixeira et. al [41] demonstrated, with delay correlating to preventable death. Furthermore, Ghorbani et al. [18] identified delay in treatment, delay to CT, and clinical judgment errors as common errors in trauma care, which aligns with our findings. A more recent study in Japan by Yamamoto et. al [42] showed a significant reduction in mortality when patients received a whole body CT within 10 minutes of arrival to the ED. It is important to note that OFI in our case was not only a reflection of mortality but a broader concept encompassing different aspects of care quality. If anything, it highlights the difference between hospitals, which audit filters are in use and how they are being assessed.

The audit filters "Dead at 30 days" and "CPR and thoracotomy" showed no difference from coincidence (AUC = 0.5) in predicting OFI, potentially due to severe traumatic injuries inevitably result in death within 30 days of admission to the hospital resulting in a smaller time frame for mistakes to be made.

Albaaj et. al [37] examined patient factors associated with OFIs, identifying delays of 30-60 minutes until the first CT, higher levels of care and higher ISS as linked to OFIs. Similarly, they found no clear association between 30 day survival and OFIs. This could partly explain the correlation between "ISS > 15 and no team activation" and OFI and similarly regarding "ISS > 15 and not in intensive care unit".

Sanddal et. al [28] highlighted that OFIs predominantly exist in the ED and relate to airway management, fluid resuscitation, and chest injury management. The only audit filter directly associated with airway management was "GCS under 9 and not intubated" which performed poorly in our case. This could suggest that an alternative audit filter related to airway management could potentially perform differently.

The sole purpose of audit filters is to elevate the quality of care. Audit filters should therefore reflect the current quality gap. However, once quality is improved, these audit filters loose their purpose which can result in their performance dropping. This could suggest that rather than the audit filters performing poorly, they have actually fulfilled their purpose. It is therefore crucial to continuously update the audit filters. ## Generalizability

Given the variability in screening for OFI, what an OFI consists of and what specific audit filters are used at a given trauma centre the results will vary too. Likewise, audit filters are used to fill quality gaps and due to individual trauma centre suffering from unique quality gaps, there will not be a golden standard set of audit filters that work everywhere.

Audit filters and quality improvement programs are widely used and the findings in this study suggest that some audit filters perform better than others. The audit filters with performance exceeding coincidence (AUC = 0.5) might be a beneficial add-on to an already existing quality improvement programme or work as a guidance in fine-tuning audit filters already in use to suit the hospitals' quality gaps. Due to the study being conducted on a single, trauma level I centre in Stockholm it is unjust to assume applicability of these findings at other hospitals in other countries facing different challenges in trauma care. 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 and vice versa [43].

Strengths

As stated in the method section, some audit filters were manually created from registry data instead of relying on the selection process by the specialised nurse. This, in order to minimise misclassification bias.

Furthermore, there has been very limited high quality evidence supporting the efficacy of audit filters [27]. This study adds to the evidence suggesting that some audit filters perform better than others.

Previous studies focus primarily on audit filters' ability to reduce mortality. In this study the morbidity of patient cases is also taken into account using OFIs as an umbrella term consisting of everything from bad documentation to preventable death.

From 2017 all trauma patients admitted to Karolinska University Hospital were included in the registry reducing the risk of bias in inclusion of patient cases.

Limitations

Opportunity for improvement, while dichotomously defined, includes a diverse set of outcomes. This makes it difficult to create audit filters that do well in predicting OFIs.

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

The way the performance of audit filters were individually calculated, as stated in the method section, was to look at every patient case with or without an OFI and simultaneously flagged or not flagged with the audit filter. Consequently, even if an audit filter demonstrated a true positive correlation with an OFI, instances where the same patient case had multiple audit filters introduce a degree of uncertainty regarding which specific audit filter accurately predicted the outcome.

The number of missing values varied greatly among the audit filters. As stated above, missing values from each audit filter was coded as "not flagged" by an audit filter. This means that in some instances where 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

Given the expanding field of artificial intelligence and machine learning, newer studies should focus on using these tools to screen for patient cases at risk of an OFI. This will reduce misclassification 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 [44] 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 OFIs.

If the use of audit filter is still considered, it is important to ensure its performance. Future studies could look at subgroups of OFIs, and which audit filter responds to that subgroup. Some audit filters might perform well in predicting a subgroup of OFIs but fail to predict others.

Health Equity

It could be of interest to study the occurrence of OFIs among marginalised groups of people and women in order to assess whether some groups tend to fall out from the screening method or are at a higher rate falsely labelled with or without OFIs.

Since there is a gender disparity between the number of trauma patients, looking further into whether gender disparities in OFIs could reveal gender discrimination in the screening and labelling of OFIs.

Conclusion

Audit filters as a tool in quality improvement programmes are widely used. Strong evidence supporting their efficacy in quality improvement is scarse, but seem to depend on where and when they are used, in what context and for what purpose. In this study, no audit filter seemed to show good performance in predicting OFIs with AUC ranging from 0.5 to 0.63. These results highlight the importance of either continually evaluating the relevancy of certain audit filters. Audit filters should reflect the current gap in trauma care quality. This process takes time and resources and using an alternative to audit filters is recommended.

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Tables

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#Appendices