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

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]

To evaluate performance, the sensitivity and specificity of each individual audit filter in predicting OFI will be calculated. Furthermore, 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. 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. Table 1 shows a list of the audit filters currently in use at Karolinska university hospital. Each audit filter is also labelled with either original or manually created. following audit filters: “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” were manually generated from registry data to minimize selection bias during the specialized nurse’s manual flagging of audit filters. It is noteworthy that the remaining audit filters cannot be derived from the existing data in the registry.

Instances of missing data for audit filters were treated as indicative of the absence of the respective audit filter.

Ethical considerations

All patient data is anonymized. However there is data on various factors like date, time of admission, etc. and different patient characteristics such as age, gender, etc. Theoretically, these attributes could make patient cases identifiable through external sources like news reports. However this means that such information has to be leaked which would only be possible through direct registry access. 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 credentials.

The study was approved by Stockholm Research Ethics Review Board, approval 107 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 OFI, a total of 8309 individuals were included in the study. 7797 out of 8309 patient cases did not have an OFI and 512 out of 8309 patient cases had an OFI.

Participant Characteristics

Table 2 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 variables presented in Table 2 exhibited a direct correlation with the manually created audit filters.

69% out of all patients included in the study where men and 31% where women. Among the patients with an OFI compared to the patients without, 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 at the emergency department was also 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). Furthermore the time to first CT was also longer in the group with OFI compared to the group without: `inline_text(tableOne, variable = dt_ed_first_ct, column = stat_2)` vs 33 (21, 65).

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

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] 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 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 equal to that of coincidence. >60 min until first intervention had the highest AUC .

Missing Data

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

	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			
Emergency department	1,478 (19%)	22 (4.3%)	1,500 (18%)

	No, (N = 7797)	**Yes**, (N = 512)	**Overall** (N = 8309)
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 3: 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)
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 4: 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.

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)

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 5: Comparison of performance for each audit filter in predicting OFI. Performance is defined by the area under the receiver operating curve. P-value show significance of AUC compared to 0.5 through 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

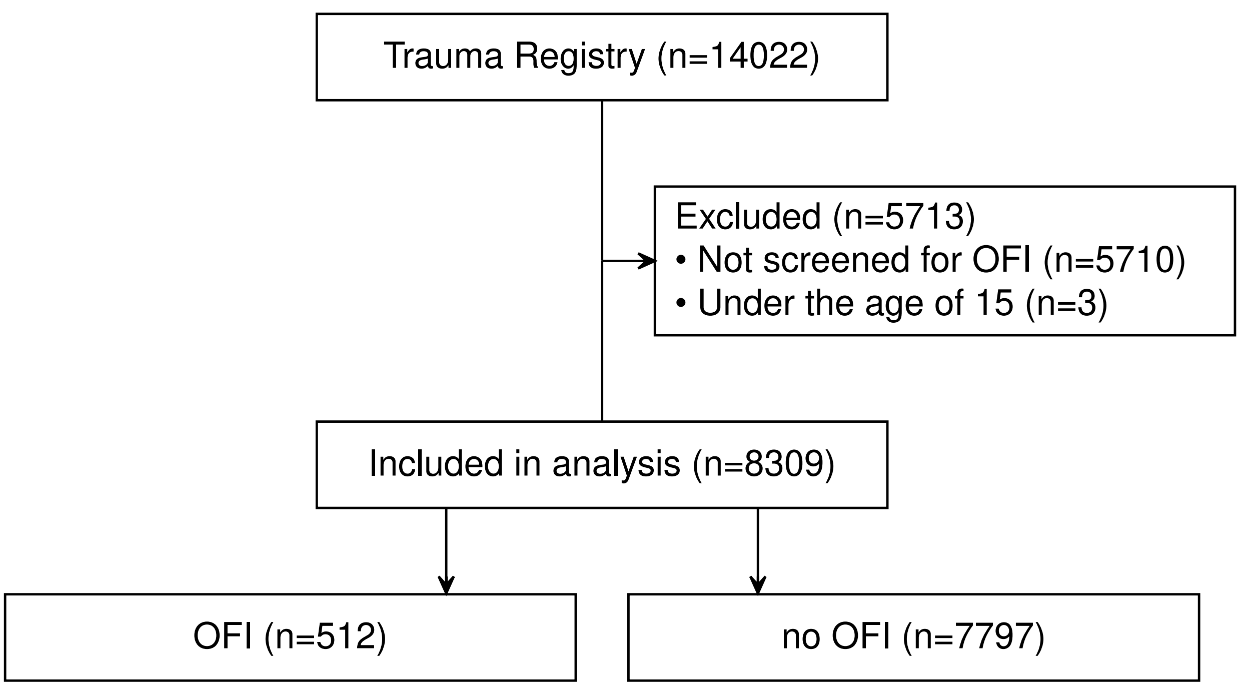

Figure 1: Flowchart of the patient selection process. Shows the patients excluded and included in this study.

Discussion

Interpretation of Results

The aim of the study was to evaluate the performance of individual audit filters in predicting OFI to assess 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]. It is thought that the reason for this lies in the higher-risk behaviours by males.

The higher ISS in the OFI group as opposed to the group without OFI 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 OFI and found that a higher ISS was significantly correlated with OFI.

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 OFI. Theoretically, adding all audit filters together as one audit filter would result in the sensitivity increasing.

An extensive review 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]. They were excluded 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, 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.

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

Delay

Both audit filters measuring delay: “>60 until first intervention” and “>30min until first CT”, showed relatively good performance in predicting OFI. This is comparable to what Teixeira et. al [41] demonstrated, with delay being correlated with preventable death. Furthermore Ghorbani et al. [18] identified delay in treatment, delay to CT, and clinical judgment errors as common errors in trauma care. This 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. A german study by Bieler et. al [43] evaluated quality indicators through a survey partaken by different medical professionals and agreed on the usefulness of delay as an audit filter in trauma care.

A similar german study [44] 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 audit filters "Dead at 30 days" and "CPR and thoracotomy" showed no difference from randomness 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] looked at patient factor associated with OFI, identifying delays of 30-60 minutes until the first CT, higher levels of care and higher ISS as linked to OFI. Similarly they found no clear association between 30 day survival and OFI. his 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".

Sanddal et. al [29] 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 air way 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 should be considered in the future.

The sole purpose of audit filters is to elevate the quality of care. Audit filters should therefore reflect the current quality gap. However when quality have been improved, these audit filters loose their purpose which can result in their performance dropping. This could suggest that rather than the audit filters simply being bad, they have actually fulfilled their purpose. It is therefore cruicial to continuasley update the 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 center the results will vary too. Furthermore, audit filters are used to fill quality gaps and due to individual trauma centers suffering from unique problems, there wont be a golden standard set of audit filters that work everywhere.

Audit filters and quality improvement programs are however wildly used and the findings in this study suggest that some audit filters perform better than others. The audit filters performing better than coincidence might be a beneficial addon to already existing quality improvement program or work as a guidance in fine-tuning audit filters already in use to suit the hospitals quality gap. However, due to the study being conducted on a single, trauma level I centre in Stockholm it is unfair to assume applicability of these findings at 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 [45].

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.

Further more there has been very limited high quality evidence supporting audit filter efficacy [28]. This study adds to the evidence suggesting that some audit filters perform better than others.

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

From 2017 all trauma patients was included in the registry.

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 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.

The way the audit filters performance 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 flagged 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 instead flagged as not having that 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 [46] 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 marginalized groups of people and women in order to assess whether some groups 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 and when 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.

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Tables

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#Appendices