Performance of Individual Audit Filters in Predicting Opportunities for Improvement in Adult Trauma Patients

A single-center registry-based retrospective cohort

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# Abstract

## Background

Trauma is responsible for 9% of global deaths annually and has a significant impact on individuals and society. Quality Improvement (QI) programs seek to minimize these adverse outcomes using Audit Filters (AFs) and interdisciplinary Morbidity and Mortality Conferences (MMC). AFs are based on criteria for standard care and can function as a screening tool of eligible patient cases for discussion at MMCs. One of the goals with MMCs is to determine potential Opportunities for Improvement (OFI).This study aimed to evaluate the performance of individual AFs in predicting OFIs and to assess their relevance as a screening tool for Morbidity and Mortality Conferences (MMC).

## Methods

Register data from 8,309 patient cases were collected for analysis. The sensitivity, specificity and Area Under the Receiver Operating Characteristics Curve (AUC) was calculated to assess performance. An empirical bootstrapping test of AUC values was conducted to compare the performance of each AF to coincidence (AUC = 0.5) and minimum AUC for diagnostic tests (AUC = 0.8).

## Results

Four out of the 11 AFs assessed had an AUC of 0.5 (p > 0.05). The remaining AFs demonstrated a correlation with OFI, with AUC ranging from 0.51 to 0.63. The AF “> 60 min until first intervention” exhibited the highest AUC (0.63, 95% CI [0.61-0.65]).

## Conclusion

No individual AF seemed to perform well in predicting OFI, which suggest rethinking the current screening method for MMCs.

# Introduction

Trauma, defined as a physical injury and the body’s associated response, causes 8-9% of global deaths annually (1,2), disproportionately affecting younger individuals in low- and middle-income countries, primarily due to road traffic injuries (2–4). Trauma also ranks highest in disability-adjusted life-years (DALYs) (3) and increases the risk of mental disorders and cognitive decline (5–9), impacting individuals, communities and society at large (8). Road traffic injuries alone cost approximately 2% of gross domestic product (GDP) in high-income countries (1).

To reduce trauma burden, quality improvement (QI) programs have been established by the World Health Organization (WHO) and the International Association for Trauma Surgery and Intensive Care (IATSIC) (10). These programs form the core of current trauma care systems (11) and commonly include multidisciplinary mortality and morbidity conferences (MMC), preventable death review panels, and the use of AFs also known as quality indicators (10). Despite QI programs, trauma care remains prone to errors (12–14). Studies have shown a pooled preventable death rate of 20% from 1990 to 2014, with more recent studies indicating lower rates (15). For instance, a recent study in a Swedish Level I trauma centre found a preventable death rate of 4% (16).

The MMC is a central QI technique focusing on anonymity, critical analysis of specific adverse events, recognizing flawed approaches, and proposing and implementing improvements (17). Attended by healthcare professionals involved in trauma care, MMCs discuss themes like unexpected mortality, morbidity, and errors (18), fostering error reduction and encouraging reporting without negative feedback (19). Effective MMC implementation has been shown to increase morbidity and mortality reporting (20).

AFs are criteria based on standardized care to enhance trauma care quality. Deviation from AFs should raise the attention of health care professionals with the purpose of improving the quality of care (11). AFs can involve outcomes like “death” or adherence to guidelines, such as “placement of two large bore intravenous lines within 15 minutes of arrival.” (10).Studies have shown mixed results on the effectiveness of AFs in reducing trauma-related mortality. While some early studies reported mortality reduction (21,22), a 2009 review by Evans et al. (23) found no substantial evidence supporting AFs’ effectiveness. Stelfox et al. (24) identified over 1,500 AFs but noted a lack of a common, evidence-based set for evaluating trauma care quality, despite the high perceived usefulness of AFs (25).

Opportunities for improvement (OFIs) are decided upon review of individual patient cases (11). They are typically associated with failures in initial care (13) like airway management, fluid resuscitation, haemorrhage control and chest injury management (14,26,27). There is lacking evidence for the use of AFs for improving trauma care (23,24) and the focus has been on mortality as outcome measure (21,22). Furthermore, the use of AFs has been associated with high frequencies of false positives, ranging from 24% to 80% (26,27), and some AFs do not appear to correlate with OFIs at all (28).

The aim of this study is to determine the performance of AFs in predicting OFIs and furthermore assess their relevance as a screening tool for MMCs.

# Methods

## Study design

We conducted a registry-based study using all trauma patients included in both the Karolinska University Hospital trauma registry and trauma care quality database between 2012 and 2022 to compare the performance of AFs in their ability to predict OFI. This study was approved by Stockholm Research Ethics Review Board, approval number 2021-02541 and 2021-03531.

## Setting

Karolinska University Hospital, a Trauma level I hospital, treats around 1,500 trauma patients annually. If a patient case results in team activation or the patient has an Injury Severity Score (ISS) of less than 9 retrospectively, it is recorded in the Karolinska trauma registry, which reports to SweTrau. This registry includes data on vital signs, timings, injuries, interventions, and patient demographics as per the European Consensus Statement (Utstein template) (29)

The Karolinska trauma registry also contains a local care quality database with AFs and OFIs, identified by MMCs through consensus decisions. OFIs are assessed in multiple stages of scrutiny. Notably, mortality is directly referred to the MMCs in order to assess OFIs and deciding whether the death was preventable or potentially preventable, a classification also falling under the purview of OFIs.

From 2013 to 2017, efforts focused on identifying adverse outcomes unrelated to mortality. Initially, trauma cases where individually assessed by a specialized trauma nurse for potential OFIs. In 2017, this procedure became standard practice, incorporating preliminary evaluations by specialized trauma nurses. Cases flagged by an AF or identified by the nurse as potential care failures underwent a second review by two specialized nurses. Potential OFIs identified in this review prompted review in a MMC.

## Participants

The study included 8,309 patients treated at Karolinska University Hospital from 2012 to 2022 who underwent OFI screening. Patients under 15 and those not screened for OFIs were excluded due to differences in clinical management for minors.

## Variables and data sources/measurements

The outcome variable is an OFI, as established by the MMCs and treated as a dichotomous variable with “Yes - At least one OFI identified” and “No - No OFI identified”. The 11 AFs used at Karolinska University Hospital served as the exposure variable, as shown in Table 1. Each AF is labeled “original” or “manually created.” Manually created AFs were calculated using trauma registry data, while original AFs were recorded in the quality database based on criteria beyond the available registry data.

The data spanning 2012 to 2022 was retrieved from the Karolinska University Hospital trauma registry and trauma care quality database. Patient data on vital signs, care processes and interventions, level of care and time aspects was retrieved from SweTrau while both exposures (AFs) and outcome (OFI) were retrieved from the Karolinska University Hospital trauma care quality database. All data was anonymised to protect patient privacy.

## Bias

Consensus decisions at MMC conferences may introduce misclassification bias. Additionally, AF flagging by specialized nurses is a manual process, potentially leading to selection bias. Healthcare professionals attending MMCs may not accurately recall key details impacting OFI decisions, introducing recall bias. Furthermore, professionals not present for specific cases might over- or underestimate OFI significance.

## Statistical methods

The study utilized R (30) for statistical analysis. Patient characteristics between cases with and without OFI were compared using the Wilcoxon signed-rank test for continuous variables and the Chi-squared test for categorical variables.

The predictive performance of AFs was assessed by calculating sensitivity and specificity for each AF in predicting OFI. Receiver operating characteristic (ROC) curves were constructed for binary classification, and the area under the curve (AUC) was computed to compare AF performance. (31).

Bootstrap resampling (1,000 iterations) was applied to estimate 95% confidence intervals for sensitivity, specificity, and AUC. The significance of each AFs’ AUC was evaluated against chance (AUC = 0.5) and the minimum standard for diagnostic tests (AUC = 0.8) (32) using an empirical bootstrap test (1,000 iterations).

Missing values for AFs were treated as negative (i.e., “not flagged”).

# Results

##Participants After excluding patients under 15 years old and patients not screened for OFIs, a total of 8,309 individuals were included in the study. 7,797 out of 8,309 (93.8%) patient cases did not have an OFI and 512 out of 8,309 (6.2%) had an OFI. Figure 1 presents a flowchart showcasing the exclusion and inclusion of the patient cases from the trauma registry.

Most trauma patients were men (n = 5,755, 69%). Patient characteristics varied depending on whether patients had an OFI or not. Respectively, the mean age was significantly higher  
49 (30, 67) vs 42 (27, 61), p<0.001 and the ISS was significantly higher 17 (10, 25) vs 9 (1, 17), p<0.001. The number of intubations in the emergency department was significantly higher 82 (16%) vs 7,149 (92%), 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), p<0.001. The time to the first CT was also longer in patients with OFIs compared to patients without 39 (25, 70) vs 33 (21, 65), p<0.001.

The number of OFIs were highest in patients admitted to the intensive care unit 171 (33%) and surgical ward 146 (29%).

Gender p=0.2, the mean systolic blood pressure p>0.9, death at 30 days p=0.6 and trauma team activation p=0.3 was not significantly correlated with OFI.

Notably, there was a statistical significant correlation between GCS at ED and OFI (p < 0.001).

Table 2 shows the missing data for each AF. As mentioned in the method section, these values were interpreted as “not flagged” with an AF. The variables with the highest amount of missing data were “time to definitive treatment” (n = 5,990, 72.1%) and “time to first CT” (n = 1,012, 12.2%). The smallest amount of missing data was found in “SBP<90” (n = 13, 0.2%).

## Performance of Individual Audit Filters

The performance of each AF was determined through a calculation of sensitivity and specificity which is demonstrated in Table 4.

The number of patient cases flagged by each individual AF varied between 107 for “GCS<9 and not intubated” and 3907 for “>30 min until CT”. The AF with the highest sensitivity was “>30 min until CT” (59.2%, 95% CI [55.2-63.8]). The lowest sensitivity was seen in “GCS<9 and not intubated” (1.2%, 95% CI [0.2-2]). The AF with the highest specificity was “GCS<9 and not intubated” (98.7%, 95% CI [98.5-98.9]). The lowest specificity was seen in “>30 min until CT” (53.8%, 95% CI [52.7-54.8]). Notably, the confidence intervals varied between sensitivity and specificity, with sensitivity displaying a greater interval.

Table 5 summarises the performance of each individual AF in identifying OFIs in trauma care by AUC. Four of the 11 AFs, “SBP<90”, “dead at 30 days”, “GCS<9 and not intubated” and “CPR and thoracotomy” showed a performance in predicting OFIs equal to that of coincidence (AUC = 0.5). The highest AUC was seen in “>60 min until first intervention” (0.63, 95% CI [0.61-0.65]). All AFs showed significantly lower AUC compared to the minimum standard for diagnostic tests (AUC = 0.8) (p < 0.001).

Table 2: Comparison of missing values for each AF. Missing values is shown as a number and percentage of the total number of patient cases included in the study (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 anticoagulants 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 Tomography; 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) | **p-value** |
| --- | --- | --- | --- | --- |
| **Gender** |  |  |  | 0.2 |
| 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) | **<0.001** |
| **ISS** | 9 (1, 17) | 17 (10, 25) | 9 (2, 17) | **<0.001** |
| Unknown | 11 | 0 | 11 |  |
| **ED Systolic Blood Pressure** | 135 (120, 150) | 135 (120, 151) | 135 (120, 150) | >0.9 |
| Unknown | 155 | 15 | 170 |  |
| **ED GCS** | 15.00 (14.00, 15.00) | 15.00 (14.00, 15.00) | 15.00 (14.00, 15.00) | **<0.001** |
| Unknown | 816 | 50 | 866 |  |
| **Time to first CT** | 33 (21, 65) | 39 (25, 70) | 33 (21, 66) | **<0.001** |
| Unknown | 967 | 45 | 1,012 |  |
| **Intubated at ED** |  |  |  | **<0.001** |
| 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** |  |  |  | 0.6 |
| 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) | **<0.001** |
| Unknown | 5,748 | 242 | 5,990 |  |
| **Highest level of care** |  |  |  | **<0.001** |
| 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** |  |  |  | 0.3 |
| 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 AF 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 (5.5-10.3) |
| Dead at 30 days | 727 | 91.2 (90.6-91.8) | 8 (5.7-10.4) |
| ISS > 15 and no team activation | 1951 | 77.7 (76.7-78.5) | 41.2 (36.8-45.5) |
| Massive transfusion | 337 | 96.3 (95.9-96.7) | 9.4 (6.6-11.8) |
| GCS < 9 and not intubated | 107 | 98.7 (98.5-98.9) | 1.2 (0.2-2) |
| ISS > 15 and not in ICU | 1295 | 85.7 (84.9-86.5) | 35.4 (31.2-39.5) |
| > 60 min until first intervention | 1668 | 81.5 (80.6-82.4) | 43.9 (39.4-48.3) |
| > 30 min until first CT | 3907 | 53.8 (52.7-54.8) | 59.2 (55.4-63.8) |
| CPR and thoracotomy | 149 | 98.2 (97.9-98.5) | 2 (0.8-3.1) |
| Liver or spleen injury | 398 | 95.5 (95.1-96) | 9.4 (7-12) |
| No anticoagulants within 72 hours after TBI | 241 | 97.3 (96.9-97.6) | 5.7 (3.7-7.6) |
| 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 AF 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) and to the minimum standard for diagnostic tests (AUC = 0.8) (32). The p-values were calculated using an empirical bootstrap test. Furthermore, a 95% confidence interval was used. {=openxml} <w:tbl xmlns:w="http://schemas.openxmlformats.org/wordprocessingml/2006/main" xmlns:wp="http://schemas.openxmlformats.org/drawingml/2006/wordprocessingDrawing" xmlns:r="http://schemas.openxmlformats.org/officeDocument/2006/relationships" xmlns:w14="http://schemas.microsoft.com/office/word/2010/wordml"><w:tblPr><w:tblCellMar><w:top w:w="0" w:type="dxa"></w:top><w:bottom w:w="0" w:type="dxa"></w:bottom><w:start w:w="60" w:type="dxa"></w:start><w:end w:w="60" w:type="dxa"></w:end></w:tblCellMar><w:tblW w:type="auto" w:w="0"></w:tblW><w:tblLook w:firstRow="0" w:lastRow="0" w:firstColumn="0" w:lastColumn="0" w:noHBand="0" w:noVBand="0"></w:tblLook><w:jc w:val="center"></w:jc></w:tblPr><w:tr><w:trPr><w:cantSplit></w:cantSplit><w:tblHeader></w:tblHeader></w:trPr><w:tc><w:tcPr><w:tcBorders><w:top w:val="single" w:sz="16" w:space="0" w:color="D3D3D3"></w:top><w:bottom w:val="single" w:sz="16" w:space="0" 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![](data:application/pdf;base64,)

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

You can include code in this document like this:

## The datasets swetrau, swetrau.20210602.20230228, atgarder, atgarder.20210602.20230228, problem, fmp, fmp.20210602.20230228, kvalgranskning2014.2017 have been imported.

You can also embed plots:



You can also mix text and code, so called inline code, like this: 7.

# Discussion

The aim of this study was to evaluate the performance of individual AFs in predicting OFIs and to assess their suitability as a screening tool for MMCs. This study showed that no AFs was significantly successful in predicting OFIs. Four AFs (“SBP<90,” “dead at 30 days,” “GCS<9 and not intubated,” and “CPR and thoracotomy”) were equivalent to random chance in their predictive ability. The highest AUC was for “>60 minutes until first intervention,”. Notably, all AFs performed significantly below the accepted standard for diagnostic tests (>0.8).

## Limitations

OFI, while dichotomously defined, includes a diverse set of outcomes. This convolutes the process of creating AFs that perform well in predicting OFIs. AFs would favour the identification of some, but not all, errors.

Each AF was individually related to OFI. Consequently, if an AF demonstrated a true positive correlation with an OFI, instances where the same patient case had multiple AFs introduce uncertainty regarding which specific AF truthfully predicted the OFI.

The number of missing values varied greatly among the AFs. As stated above, missing values from each AF were coded as “not flagged” by an AF. This means that some instances where patient cases were not flagged, might actually meet the AF criteria, but for some reason not documented. This reduces the validity of some AFs that featured high amounts of missing data.

##Interpretation Higher ISS, longer times to CT, longer times to first intervention, and higher levels of care correlated with OFIs, consistent with a recent study by Albaaj et al. (33). Notably, GCS at the ED also showed a correlation with OFIs despite identical median GCS values, likely due to distribution differences outside the IQR.

The AF “GCS<9 and not intubated” showed no significant ability to predict OFIs, similarly shown by Willis et al. (34). Possibly because the AF might be more reflective of clinical decision rather than quality of care (34). For instance, An abnormal GCS resulting from intoxication is managed differently than one caused by a head injury.

Both delay-related AFs: “>60 until first intervention” and “>30min until first CT”, showed a correlation with OFI. Comparably, Teixeira et al. (35) linked delays to preventable death and Ghorbani et al. (16) identified treatment and CT delays as common errors in trauma care. A recent study in Japan by Yamamoto et. al (36) found reduced mortality with whole-body CT scans within 10 minutes of ED arrival.

“Dead at 30 days” and “CPR and thoracotomy” showed no correlation with OFI. This could be explained by inevitable mortality, thus presenting with a smaller time frame for mistakes to be made.

AFs generally exhibited a high specificity relative to their sensitivity which may be attributed to the outcome being rather uncommon, whilst every individual AF misses the majority of OFIs. This could suggest that the AFs are too rigid in their criteria. On the contrary, a too inclusive criteria might flag several patients, without an OFI (34).

## Generalizability

AFs are widely used, but lack consensus on which to use, purpose, and application (24,25,37). They have static criteria and may not adapt to evolving healthcare challenges, or upon resolution of the quality gaps they were designed for, reducing their utility over time. This underscores the need for regular evidence-based reviews of AF performance (38). However, these reviews might be cost-prohibitive

While AFs can help identify an OFI, they might overshadow other contributing factors, leading to over-reliance and potentially failing to recognize cases outside their scope. (34). For example, AFs often focus on aspects relevant to doctors, despite the interdisciplinary nature of trauma care. Lastly, Confounding variables, such as different treatment times based on injury severity, add to the uncertainty of AFs’ effectiveness. (34).

Due to the study being conducted in a single, trauma level I centre in Stockholm it is unrealistic to assume applicability of these findings at other hospitals facing unique challenges (10). For instance AFs that benefit low and middle income may not benefit high income countries and vice versa (25).

## Future Studies

Given the expanding field of artificial intelligence and machine learning, new studies should focus on using these tools to screen for patient cases at risk of an OFI. This will reduce misclassification and maintain high performance, attributable to an algorithm’s capability to adapt. A recent preprint by Attergrim et al. (39) found that machine learning models outperformed the AFs currently used at Karolinska University Hospital in predicting OFIs. Should the use of AFs remain, they must be routinely updated to reflect current quality gaps.

# Conclusion

AFs are widely used as a tool in QI programmes and should reflect the current gap in trauma care quality. Strong evidence supporting their efficacy in quality improvement is scarce. In this study, no audit filter seemed to show promising performance in predicting OFIs with AUC ranging from 0.5 to 0.63. These results highlight the importance of continually evaluating the relevance of AFs. However, this process takes time and resources and using an alternative to AFs is recommended.

# References

Keep? However, according to Sanddal et al. (26) airway management was associated with OFI, suggesting that an alternative AF related to airway management might perform differently.

Notably, OFI in this study was not soley a reflection of mortality but also morbidity. Rather, it could highlight differences in quality gaps between hospitals. Trauma care is a multidisciplinary, complex and time-critical health care service provided by hospitals, often trauma centres. (11). 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 (40–42). It has been shown that such review processes are associated with high-quality trauma care (38).

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