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ORIGINAL ARTICLE

Early prediction of acute traumatic coagulopathy: a validation of the COAST score using the German Trauma Registry

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Abstract

Background Early identification of trauma patients at risk of developing acute traumatic coagulopathy (ATC) is important for initiating appropriate, coagulopathy-focused treatment. A clinical ATC prediction tool is a quick, simple method to evaluate risk. The COAST score was developed and validated in Australia but is yet to be validated on a European population. We validated the ability of the COAST score to predict coagulopathy and adverse bleeding-related outcomes on a large European trauma population.

Methods The COAST score was modified and applied to a retrospective cohort of trauma patients from the German Trauma Registry (TR-DGU). The primary outcome was coagulopathy defined as INR > 1.5 or aPTT > 60 s. Secondary outcomes were massive transfusion, blood product requirements, urgent surgery and mortality. The cohort included adult trauma patients with Injury Severity Score > 15 treated in Germany/Austria in 2012–2016.

Results 15,370 cases were included, of which 10.9% were coagulopathic. The COAST score performed with sensitivity 21.6% and specificity 94.2% at a threshold of COAST ≥ 3. The AUROC was 0.625 (95% CI 0.61–0.64). The COAST score also identified patients who had more massive transfusions (15.3% v 1.6%), more emergency surgery (49.6% v 28.2%), and higher early (21.7% v 5.4%) and total in-hospital mortality (38.1% v 14.5%).

Conclusion This large retrospective study demonstrated that the modified COAST score predicts coagulopathy with low sensitivity but high specificity. A positive COAST score identified a group of patients with bleeding-related adverse outcomes. This score appears adequate to act as an inclusion criterion for clinical trials targeting ATC.

Keywords Acute traumatic coagulopathy · Trauma · Bleeding · Prediction model · Prediction score · Blood coagulation disorders

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Abbreviations

TBI	Traumatic brain injury
ED	Emergency department
ATC	Acute traumatic coagulopathy
INR	International normalised ratio
aPTT	Activated partial thromboplastin time
COAST	Coagulopathy of severe trauma
PATCH	Prehospital anti-fibrinolytics for traumatic coagulopathy and haemorrhage
TXA	Tranexamic acid
TR-DGU	TraumaRegister of the Deutsche Gesellschaft für Unfallchirurgie
ICU	Intensive care unit
ISS	Injury severity score
PRBC	Packed red blood cells
FFP	Fresh frozen plasma
SBP	Systolic blood pressure

AIS Abbreviated injury scale
ROC Receiver operating characteristic

Introduction

Traumatic injury is a leading cause of death around the world in people aged 1–44 years In Germany in 2016, the overall in-hospital mortality of patients presenting to hospital after injury was 11.2% [1–3]. In Germany in 2016, the overall in-hospital mortality of patients presenting to hospital after injury was 11.2% [4]. Two important causes of early death following trauma are brain injury and haemorrhage [5]. Death due to traumatic brain injury (TBI) is often not preventable; however, haemorrhage may be managed.

One strategy to manage haemorrhage is to prevent or treat coagulation disorders. About 25% of trauma patients have a clinically relevant coagulopathy by the time they arrive at the emergency department (ED), called acute traumatic coagulopathy (ATC) [6]. ATC may lead to worsening haemorrhage and thus is associated with high mortality, reported at around 50% [7]. Timely and effective treatment is vital to prevent irreversible damage or death from ongoing haemorrhage.

Conventionally, diagnosis of coagulopathy relies on standard laboratory tests such as the International Normalised Ratio (INR) and activated partial thromboplastin time (aPTT), which take around 60 min to return [8]. Point-of-care tests for INR have not proved to be accurate in the initial stages of trauma resuscitation [9]. Viscoelastic testing such as TEG and ROTEM are useful for identifying clotting dysfunction but do not yet have enough evidence to support widespread implementation [10]. In the absence of reliable diagnosis of ATC, initial management often involves transfusion of large volumes of blood products, which have their own side effects and risks and may be potentially an inefficient use of resources. In addition, the inability to accurately identify a population of patients with ATC limits the ability to identify populations for inclusion in trials of agents targeted at ATC.

In 2011, the Coagulopathy of Severe Trauma (COAST) score was published by Mitra et al. [11] with the aim of enabling early identification of the coagulopathic patient for enrolment in clinical trials and to expedite initiation of treatment. The COAST score utilised five variables available before or on arrival at the hospital to give a score with which one could predict whether a certain patient would develop a coagulopathy. The COAST score was developed and internally validated in Melbourne, Australia and has since been in use in the Prehospital Antifibrinolytics for Traumatic Coagulopathy & Haemorrhage (PATCH)-Trauma trial [12], a randomised controlled trial investigating the utility of pre-hospital tranexamic acid (TXA) in patients with suspected ATC.

The aim of this study was to externally validate the COAST score on a large trauma patient population by evaluating its ability to predict ATC and related poor outcomes, including mortality, blood product requirements and urgent surgery, on the TraumaRegister DGU®. The overarching aim was to assess the utility of this score to enrol patients from Germany into the PATCH-Trauma trial.

Materials and methods

Setting

The TraumaRegister DGU® of the German Trauma Society (Deutsche Gesellschaft für Unfallchirurgie, DGU®) collects data on trauma patients treated in Germany and several other countries [4]. Founded in 1993, the registry has been gradually growing and now receives information on about 40,000 cases from over 600 hospitals per year. Data are collected from several time periods: the prehospital phase, the ED and initial surgery, intensive care unit (ICU) and hospital discharge. All data are de-identified and standardised in the initial documentation. Cases are included on the registry if they meet the following inclusion criteria: trauma patients admitted to the ED alive who required care in the ICU (or high dependency unit) or died before admission to the ICU. Participation is voluntary; however, basic data is required from hospitals which are members of the TraumaNetzwerk DGU® and almost all trauma cases in Germany are recorded. 95% of German hospitals participate and approximately half of Austrian hospitals, and participating hospitals supply data on all trauma patients meeting the criteria. Data collectors complete either a standard or a reduced dataset form. The reduced dataset includes fewer variables. This study is registered as TR-DGU project ID 2017–049.

Case selection

We extracted data on patients treated in Germany or Austria between January 1st, 2012 and December 31st, 2016. This was a retrospective validation of the COAST score and no intervention or exposure was being investigated. The data were accessed and analysed in June 2018. Our inclusion criteria were age ≥ 16 years and Injury Severity Score (ISS) ≥ 16 and exclusion criteria were secondary admission to hospital (i.e. transfer from another centre), reduced dataset, missing outcome data and missing predictor variables. Case selection is illustrated in Fig. 1.

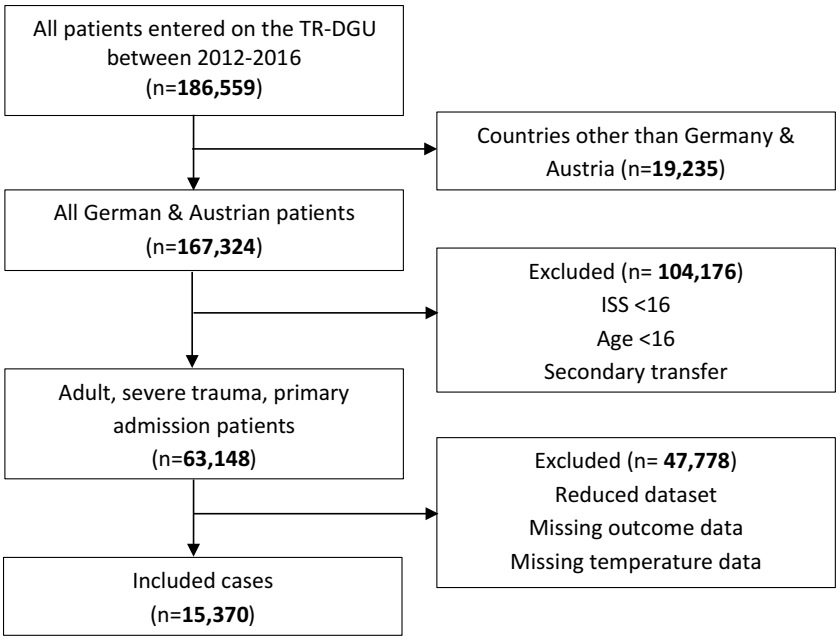

Fig. 1 Flow chart displaying process of inclusion and exclusion of cases from the TraumaRegister DGU for the study. *N* number of cases

Outcome selection

The outcome we investigated was presence or absence of ATC based on laboratory results. ATC was defined as INR > 1.5 or aPTT > 60 s, as described in the original COAST development in 2011 [11]. Blood tests used to define the outcome were obtained in the ED from the first sample. In the setting of resuscitation after major trauma, this occurs immediately after the first intravenous access and usually within 15 min of arrival to the ED. Secondary outcomes were measures of injury and bleeding severity and indicators that directed treatment for coagulopathy was required. Outcomes examined were conventional coagulation test results, platelet and haemoglobin levels, packed red blood cell (PRBC) and fresh frozen plasma (FFP) requirements, incidence of emergency surgery, hospital length of stay and 24-h and in-hospital mortality.

Predictor selection

The COAST score required some modification to be applied to the TR-DGU® patient cohort. Prehospital systolic blood pressure (SBP) and prehospital chest decompression were available on the database. Surrogates were used for the other variables: initial ED temperature replaced prehospital temperature; "long-on-scene", defined as > 45 min ambulance on-scene time or > 90 min total time from injury to ED arrival, replaced entrapment; and abdominal Abbreviated Injury Scale (AIS) > 3 replaced paramedic diagnosis of abdominal or pelvic content injury. We chose this surrogate as it represents a serious injury that would likely be identifiable by prehospital staff, validated by previous literature demonstrating that paramedics correctly identified patients with abdominal AIS > 3 with 93.3% specificity [13]. The modified COAST score is shown in Table 1. All variables were collected prospectively and analysed retrospectively from the database. Scores for each variable were added together to give a COAST score. A patient with COAST score of ≥ 3 had a positive score and was, therefore, predicted to develop ATC.

Missing outcome or COAST variable data was dealt with by listwise deletion of cases. Imputation of missing variables was outside of the scope and the aim of this study.

Statistical analysis

Descriptive data was reported using number and percentage of patients for nominal/binary variables, median (interquartile range) for ordinal variables and mean (standard

Table 1 Modified COAST Score [11]

Variable	Value	Score
Long-on-scene (> 45 min on-scene time or total pre-hospital time > 90 min)	Yes	1
Prehospital SBP	< 100 mmHg	1
	< 90 mmHg	2
Temperature on ED arrival	< 35 °C	1
	< 32 °C	2
Prehospital thorax drain	Yes	1
Abdominal AIS > 3	Yes	1
Highest total possible		7

SBP systolic blood pressure, *ED* emergency department, *AIS* abbreviated injury scale

deviation) for numeric variables. Calibration was assessed by comparing specificity at different cut-points between the internal and external COAST validations. Discriminatory power was reported using sensitivity, specificity and positive and negative predictive values. An overall measure of predictive ability was demonstrated by the area under the Receiver Operating Characteristic (ROC) curve with 95% confidence intervals. The ROC curve was derived using multiple sensitivity and specificity cut-off values. Performance on the external validation cohort was compared with performance on development and internal validation studies. Significance testing was not done due to the large sample size and thus inevitable statistical significance. All statistical analysis was performed using SPSS® statistical software (IBM Inc, Armonk, NY).

To calculate the required sample size we aimed to demonstrate 90% specificity, compared with the internal validation specificity of 96%, 90% power and alpha of 0.05. The required sample size was 756 coagulopathic patients to prove efficacy, and as only approximately 10% of the registry population were estimated to have laboratory-diagnosed coagulopathy on arrival, our sample size was estimated to require at least 7560 cases.

The study protocol was reviewed and approved by the Ethics Committee of the University of Witten/Herdecke (application no. 64-2018).

We drafted this manuscript in accordance with the Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD) [14] [Supplementary File 1].

Results

We included 15,370 cases in our analysis. Of these, 1682 (10.9%; 95% CI 10.5–11.4) had ATC based on initial INR or aPTT. The median ISS was 25 (IQR 18–33) points and blunt trauma accounted for 96.4% of injuries. Overall in-hospital mortality was 16.3%. Mortality among coagulopathic patients was 46.1% and 12.6% among non-coagulopathic patients. Demographic variables were similar between patients who were coagulopathic and those who were not coagulopathic. In indicators of injury severity, patients with ATC were quite different from patients without ATC: prehospital SBP was lower in coagulopathic patients (116.3 mmHg) than non-coagulopathic (129.6 mmHg), prehospital IV fluid volume was greater (1106 mL v 853 mL) and prehospital CPR was performed in 12.1% of coagulopathic cases but only 2.6% in non-coagulopathic cases. Demographic information is given in Table 2.

A comparison between the COAST derivation population and the TR-DGU validation is given in Table 3. Except for temperature, mortality rate and hospital length of stay, the validation population was similar to the COAST derivation population from 2006 to 2008. All variables demonstrated statistically significant differences due to the large sample size.

The COAST score was shown to be well-calibrated: specificities correlated well between the internal and external validation results, as shown in Fig. 2, however, there was a greater discrepancy between the figures for sensitivity.

Significant differences existed between patients who were coagulopathic and COAST positive and patients who were coagulopathic and COAST negative, as shown in Table 4. Coagulopathic patients with a positive COAST score were younger, had more severe injuries, were more hypotensive, received more prehospital IV fluids and more frequently received CPR.

In our sample population, with a cut-off of ≥ 3 for a positive COAST score, there was a sensitivity of 21.6% and specificity 94.2%. The positive predictive value (the probability that patients who were predicted to have a coagulopathy actually did have a coagulopathy) was 31.3%, the negative predictive value (the probability that patients who were predicted not to have a coagulopathy actually did not have a coagulopathy) was 90.7% and the AUROC was 0.625 (95% CI 0.610–0.641). The ROC curve is shown in Fig. 3.

The secondary outcomes were compared between COAST positive and COAST negative cases, as shown in Table 5. Patients with a COAST score of ≥ 3 were administered more blood and a higher proportion of COAST positive patients received a massive transfusion (at least ten units of PRBCs in less than 24 h) [15]: 15.3% v 1.6%. Clotting dysfunction was more evident in the COAST positive group, with lower platelet counts ($181.2 \times$ v 217.2×10^3/μL), haemoglobin (10.3 v 12.8 g/dL) and base excess (-7.5 v -2.1 mmol/L). Notably, COAST positive patients had a significantly greater early mortality rate, with 21.7% dying within 24 h compared with 5.4% in the COAST negative group.

Correctly identified COAST positive cases were also compared with false COAST negative cases, i.e. missed cases. Mortality rate, incidence of emergency surgery, blood requirements and massive transfusion frequency were all higher in the true COAST positive group. This is shown in Fig. 4.

Discussion

A key reason for the creation of the COAST score was to use as an inclusion criterion in clinical trials assessing management of ATC, and therefore, it is important that the score is highly specific. This external validation of the COAST score demonstrated a high specificity and furthermore identified a group with a clinically relevant coagulopathy; more

Table 2 Demographic information

	Coagulopathy ($n=1682$)	No coagulopathy ($n=13,688$)
Demographics		
Age (years)	58.5 (23.1)	51.4 (20.4)
Male sex	1145 (68.1%)	9818 (71.7%)
Prehospital vital signs		
Heart rate (b/min)	92.8 (33.1)	90.3 (23.1)
Respiratory rate (b/min)	14.4 (7.9)	15.3 (5.7)
SBP (mmHg)	116.3 (47.1)	129.6 (33.5)
GCS	8 [3–14]	14 [8–15]
Initial emergency department vital signs		
Heart rate (b/min)	92.8 (29.8)	88.5 (20.6)
Respiratory rate (b/min)	13.5 (7.3)	14.7 (5.3)
SBP (mmHg)	112.4 (42.4)	128.6 (30.2)
Temperature (°C)	35.7 (1.8)	36.1 (1.2)
IV fluid volume (mL)	1106 (872)	853 (600)
Prehospital management		
Prehospital time (min)	72.5 (32.0)	68.7 (28.9)
IV fluid volume (mL)	1779 (2113)	1297 (1531)
Chest decompression	159 (9.6%)	557 (4.1%)
Intubation	1040 (63.0%)	5186 (38.6%)
Cardiopulmonary resuscitation	200 (12.1%)	345 (2.6%)
Catecholamines	447 (27.1%)	1280 (9.5%)
Injury characteristics		
Blunt trauma	1529 (94.6%)	12,710 (96.6%)
ISS	29 [24–41]	24.5 [18–29]
Traffic accident	797 (50.8%)	7065 (54.8%)
Unconscious (GCS < 9)	817 (51.4%)	3393 (26.2%)
Long-on-scene	326 (19.4%)	2440 (17.8%)

Values are shown as mean (standard deviation), median [interquartile range] or number (percentage)

SBP systolic blood pressure, *GCS* Glasgow Coma Scale, *IV* intravenous, *ISS* injury severity score, *Long-on-scene* > 45 min ambulance on-scene time or > 90 min total prehospital time

deranged blood test results, higher blood product requirements, more urgent surgery and higher mortality.

Early prediction of ATC through use of a clinical prediction tool is a convenient and simple step towards initiating goal-oriented treatment sooner. The COAST score was designed to identify a certain group of patients who may benefit from such treatments. In contrast to the many scores which have been developed to predict requirement of massive transfusion following trauma [16, 17], the COAST score aims to predict coagulopathy based on laboratory tests. This is to implement a different management strategy to reduce blood product requirements and increase survival. Therefore, a key feature of this prediction tool was that it identifies not only coagulopathic patients, but rather coagulopathic patients with higher blood product requirements and higher mortality. These features were validated in this study.

The initial COAST score development and validation studies had several limitations. The variable selection was based on multiple logistic regression analysis to identify variables which increase the odds ratio for coagulopathy after trauma. The variables identified were consistent with existing evidence regarding correlation of various factors with ATC; for example, systolic hypotension is a likely cause [18]. However, some variables which did raise the odds ratio, for example cardiopulmonary resuscitation and intubation, were not included in the score. Selection of the variables for the score was not thoroughly discussed. A multivariable logistic regression performed on TR-DGU data could have found predictors of coagulopathy that were more highly predictive and frequently recorded. Creating a predictive score using more or different predictor variables may have resulted in a higher sensitivity to ATC. However, the aim of this study was to validate the COAST score on the German population to ensure applicability to use the score in multi-site trials, so we replicated the score as closely as possible.

Table 3 Demographics of the Mitra 2011 derivation cohort and the TR-DGU validation cohort

	COAST derivation ($n=1680$)	TR-DGU validation ($n=15,370$)
Demographics		
Age (years)	45.6 ± 21.0	52.2 (20.8)
Male gender	1250 (74.4%)	10,963 (71.3%)
Blunt trauma	1623 (96.6%)	14,239 (96.4%)
ISS	21 (17–27)	25 [18–33]
Vital signs		
Glasgow coma scale	13 (4–15)	14 [7–15]
Heart rate (b/min)	90.7 ± 23.7	90.6 (24.4)
Respiratory rate (b/min)	19.1 ± 6.9	15.2 (6.0)
SBP (mmHg)	119.9 ± 37.8	128.2 (35.4)
Temperature (°C)	33.4 ± 9.8	36.1 (1.3)
Outcome		
Mortality	115 (6.8%)	2506 (16.3%)
Hospital LOS (days)	7 (3–13)	16 [8–28]

Mitra 2011 reported values as mean ± standard deviation; number (percentage) and median (interquartile range). We reported values as mean (SD), number (percentage) and median [IQR]

N number of cases, *ISS* injury severity score, *SBP* systolic blood pressure, *LOS* length of stay

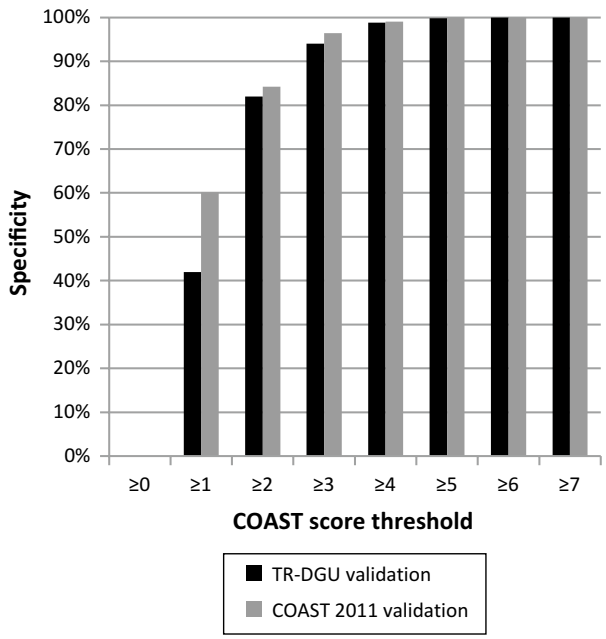

Fig. 2 A calibration curve comparing the TR-DGU validation specificity with the COAST 2011 validation cohort specificity. The columns represent the specificity (that is, the likelihood that a patient who does not develop a coagulopathy is predicted to not develop a coagulopathy by the score) at each potential cut-off for the score. The calibration of the validation study is assessed by comparing the specificities at each cut-point to see if they are similar

Furthermore, the definition of ATC continues to be debated, and the threshold selected in this study does not match the definition used conventionally in Germany. Although this higher threshold for ATC identifies the more severely coagulopathic patient in general, it may miss patients whose coagulation markers are not quite as deranged but still have poor outcomes related to bleeding [19]. However, defining ATC using an INR > 1.5 compared to INR > 1.2 has been suggested to identify a clinically meaningful subset of trauma patients who, adjusting for confounding factors, suffer more adverse outcomes [20]. Limitations of the COAST score that have been addressed in this validation study are the single centre cohort, the subjectivity of the abdominal or pelvic content injury variable and the missing temperature data. Missing temperature erroneously reported as 0 or − 1 °C may have skewed the COAST score development data. This was avoided in this validation by excluding patients with missing temperature data.

Viscoelastic testing is an effective and quick method of diagnosing coagulopathy. It would be interesting to investigate the correlation between diagnosis of coagulopathy based on conventional coagulation tests, prediction of coagulopathy using the COAST score and TEG/ROTEM results. Unfortunately, TEG/ROTEM results are infrequently recorded in the TR-DGU® database and as such we could not perform a reliable analysis using viscoelastic measures to define coagulopathy.

Strengths that were preserved in the validation were the simplicity of the score and pre-hospital application, the unbiased sample and the effectiveness of the score at identifying severely unwell patients. The high specificity was replicated and the difference in outcomes between COAST positive and COAST negative patients was as significant. Simplicity of the score utilising physiological and injury characteristics only enables translation to the pre-hospital setting. This enables enrolment into trials and initiation of targeted management of ATC immediately after assessment by first responders.

Limitations

This COAST validation was limited by requiring modifications to the score to fit variables in the registry. Prehospital temperature was replaced by ED temperature, which is likely to have resulted in fewer low temperatures being recorded as hypothermic patients may have been warmed during prehospital care. “Long-on-scene” was a surrogate for entrapment. This variable was created based on average on-scene and total prehospital times and represents patients who received time-consuming care from prehospital physicians but who were not necessarily entrapped. It can also exclude patients who were entrapped but were transferred

Table 4 Comparison between COAST positive and COAST negative coagulopathic cases

	COAST < 3 ($n = 2844$)	COAST ≥ 3 ($n = 624$)
Age (years)	61.6 (22.4)	46.6 (22.0)
Injury Severity Score	31.5 (14.0)	43 (16.2)
INR	2.5 (1.3)	2.5 (1.7)
Systolic blood pressure (mmHg)	119 (40)	79 (38)
$AIS_{Head} \geq 3$	1934 (68%)	337 (54%)
$AIS_{Abdomen} \geq 3$	427 (15%)	331 (53%)
Prehospital IV fluid volume (mL)	965 (751)	1684 (1023)
Prehospital CPR	284 (10%)	187 (30%)

Values are presented as mean (SD), median [IQR] or number (percentage)

N number of cases, *INR* international normalised ratio, *AIS* abbreviated Injury Scale, *IV* intravenous, *CPR* cardiopulmonary resuscitation

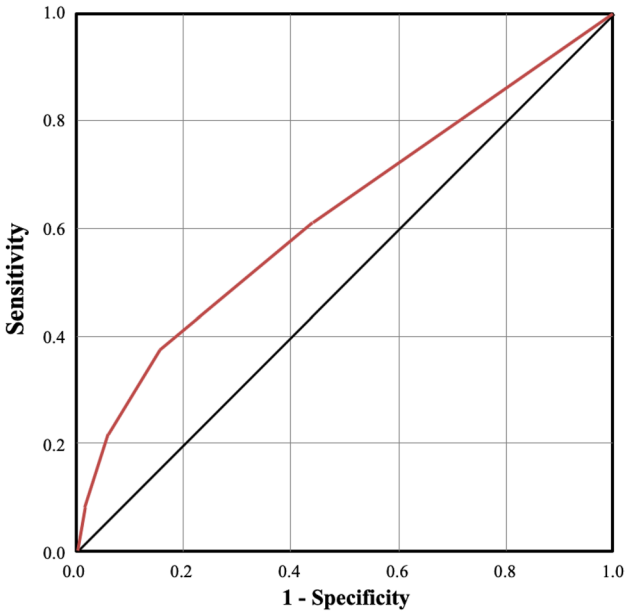

Fig. 3 A receiver operating characteristic curve of COAST on this validation, which plots the true positive rate against the false negative rate at different cut-points to demonstrate the value of the model

Table 5 Outcomes of COAST positive and COAST negative cases

	COAST ≥ 3 ($n = 1159$)	COAST < 3 ($n = 14{,}211$)
INR	1.62 (1.27)	1.22 (0.59)
aPTT (seconds)	45.5 (31.6)	30.3 (13.9)
Platelets ($\times 10^3$ cells/μL)	181.2 (93.9)	217.2 (77.7)
Haemoglobin (g/dL)	10.3 (2.9)	12.8 (2.2)
Base excess (mmol/L)	− 7.5 (6.8)	− 2.1 (4.4)
PRBC (units)	4.6 (8.3)	0.7 (2.8)
FFP (units)	3.4 (7.9)	0.5 (2.5)
Massive transfusion (≥ 10 units PRBCs)	176 (15.3%)	230 (1.6%)
Emergency surgery	575 (49.6%)	4005 (28.2%)
Hospital LOS (days)	17 [3–34]	16 [9–27]
24-hour mortality	252 (21.7%)	770 (5.4%)
In-hospital mortality	442 (38.1%)	2064 (14.5%)

Values are reported as mean (SD), number (percentage) and median [IQR]

INR international normalised ratio, *aPTT* activated partial thromboplastin time, *PRBC* packed red blood cells, *FFP* fresh frozen plasma

very quickly following their extrication. Subjective diagnosis of abdominal or pelvic content injury was changed to abdominal AIS > 3 as it was the most fitting surrogate available on the database. While similar, AIS is probably more reliable and reproducible as part of a score to be implemented widely.

In the present study, the number of included cases was substantially limited by the availability of data. We chose to only include cases in which information on three or more of the predictor variables was available. Centres registered with the TR-DGU® are able to collect either the "standard dataset" or the "reduced dataset", the latter of which includes less information and fewer variables. Temperature was inconsistently recorded in cases with the reduced dataset, therefore, we elected to exclude cases with the reduced dataset to minimise the effect of this. Abdominal injury, long-on-scene, blood pressure and chest decompression were recorded adequately. A subgroup analysis was not performed to investigate the effect of pre-injury anticoagulant and antiplatelet use because this information was only routinely collected from 2015 onwards, meaning only approximately 20% of cases had this data available. In addition, among major trauma patients who are generally younger, the frequency of anticoagulant and antiplatelet use is usually low.

This was a retrospective study, which limited its scope and necessitated some modifications. The reason for choosing this study type was related to time constraints and the availability of data. The study was ideally to be completed before the initiation of the PATCH-Trauma trial in Germany in 2019, which does not allow sufficient time to complete

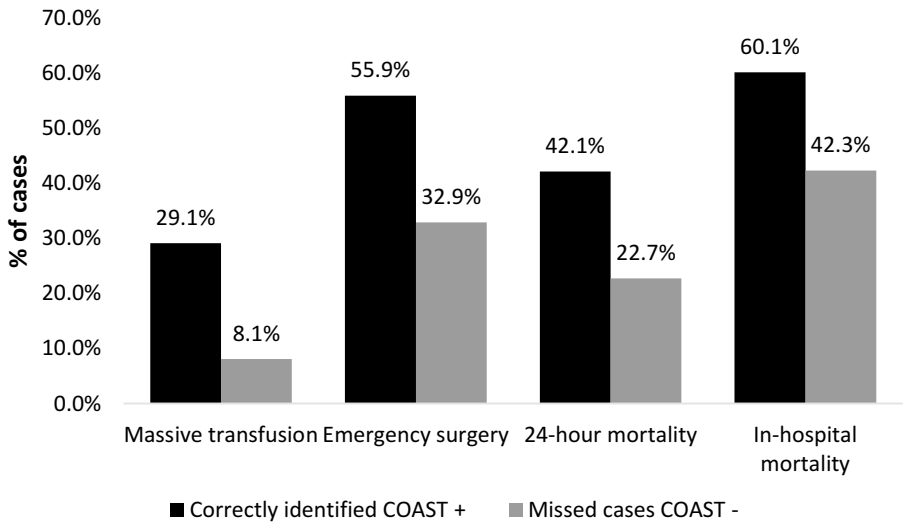

Fig. 4 A comparison between outcomes in coagulopathic patients who had COAST positive and COAST negative scores. Correctly identified COAST + cases are patients who had a COAST score ≥ 3 and laboratory-diagnosed coagulopathy. Missed COAST— cases are patients who had a COAST score < 3 but had a laboratory-diagnosed coagulopathy. Adverse outcomes were more common in correctly identified COAST + cases

a large-scale prospective trial. The TR-DGU® had a large amount of readily-available data which suited the format of the proposed study, thus it was deemed that a large retrospective study would be adequate for our purpose.

Future

The PATCH-Trauma trial is a multi-national prospective randomised controlled trial assessing the efficacy and safety of prehospital tranexamic acid in trauma patients with suspected acute traumatic coagulopathy. Because there is some evidence of harm from TXA in patients who do not require it [21], it is important to administer it only to those who are likely to benefit from it. Therefore, a prediction tool was created to act as an inclusion criterion for the study as laboratory test results would not return early enough to implement this change. In Australia and New Zealand, the PATCH-Trauma trial is already underway and it is planned to begin in Germany in 2019. To replicate the population as closely as possible, the COAST score should be used as an inclusion criterion in Germany also. To that end, the score required external validation to ensure the patient group would be appropriate for inclusion. The score could also be used as an inclusion criterion to enrol a high proportion of patients with ATC into other trials examining treatment of ATC.

Conclusion

This study validated the COAST score on a large, multicentre trauma database in Germany. The score performed moderately well, with a low sensitivity but high specificity. It demonstrated the ability to discriminate patients who have severe coagulopathy, as indicated by the high prevalence of bleeding-related adverse outcomes. A high specificity to select patients with associated poor outcomes makes it appropriate for prospective subject selection in trials on ATC.

Author contribution Data analysis was performed by RL and ST. The manuscript was written by ST. Professors MM, BM and RG edited the manuscript and provided feedback.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethical approval Ethics approval was received from the Ethik-Kommission der Universität Witten/Herdecke (Ethics Committee of the University Witten/Herdecke). The ethics application was number 64–2018.

Availability of data and materials The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

References

1. Victorian Government: Victorian State Trauma System and Registry Annual Report. Services HaH ed. Victoria: Victorian Government, 2017.
2. Prevention CfDCa: 10 leading Causes of Death by Age Group, United States—. In National Vital Statistics System, National Center for Health Statistics. CDC. USA: National Center for Injury Prevention and Control; 2015. p. 2015.
3. Kehoe A, Smith JE, Edwards A, Yates D, Lecky F. The changing face of major trauma in the UK. Emerg Med J. 2015;32:911–5.

4. (DGU) GTS: TraumaRegister DGU Annual Report 2017. In *Trauma Register DGU* (R L ed. pp. 13. Germany: Deutsche Gesellschaft für Unallchirurgie; 2017:13.
5. Sobrino J, Shafi S. Timing and causes of death after injuries. Proceedings (Baylor University Medical Center). 2013;26:120–3.
6. Davenport R, Manson J, De'Ath H, Platton S, Coates A, Allard S, Hart D, Pearse R, Pasi KJ, MacCallum P, et al. Functional definition and characterization of acute traumatic coagulopathy. Crit Care Med. 2011;39:2652–8.
7. Brohi K, Singh J, Heron M, Coats T. Acute traumatic coagulopathy. J. Trauma Injury Infect Crit Care. 2003;54:1127–30.
8. Haas T, Fries D, Tanaka KA, Asmis L, Curry NS, Schochl H. Usefulness of standard plasma coagulation tests in the management of perioperative coagulopathic bleeding: is there any evidence? Br J Anaesth. 2015;114:217–24.
9. Mitra B, O'Reilly G, Collecutt M, Cameron PA, Phillips L, Davis A. Prospective comparison of point-of-care international normalised ratio measurement versus plasma international normalised ratio for acute traumatic coagulopathy. Emerg Med Australas. 2012;24:363–8.
10. Hunt H, Stanworth S, Curry N, Woolley T, Cooper C, Ukoumunne O, Zhelev Z, Hyde C: Thromboelastography (TEG) and rotational thromboelastometry (ROTEM) for trauma induced coagulopathy in adult trauma patients with bleeding. Cochrane Database Syst Rev 2015:Cd010438.
11. Mitra B, Cameron PA, Mori A, Maini A, Fitzgerald M, Paul E, Street A. Early prediction of acute traumatic coagulopathy. Resuscitation. 2011;82:1208–13.
12. Mitra B, Mazur S, Cameron PA, Bernard S, Burns B, Smith A, Rashford S, Fitzgerald M, Smith K, Gruen RL. Investigators PA-TS: tranexamic acid for trauma: filling the 'GAP' in evidence. Emerg Med Australas. 2014;26:194–7.
13. Mulholland SA, Cameron PA, Gabbe BJ, Williamson OD, Young K, Smith KL, Bernard SA. Prehospital prediction of the severity of blunt anatomic injury. J Trauma. 2008;64:754–60.
14. Collins GS, Reitsma JB, Altman DG, Moons KGM. Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD): the TRIPOD statement. BMJ. 2015;350:g7594.
15. Pham HP, Shaz BH. Update on massive transfusion. BJA. 2013;111:i71–i82.
16. Mitra B, Rainer TH, Cameron PA. Predicting massive blood transfusion using clinical scores post-trauma. Vox Sanguinis. 2012;102:324–30.
17. Maegele M, Brockamp T, Nienaber U, Probst C, Schoechl H, Gorlinger K, Spinella P. Predictive models and algorithms for the need of transfusion including massive transfusion in severely injured patients. Transfus Med Hemother. 2012;39:85–97.
18. Frith D, Goslings JC, Gaarder C, Maegele M, Cohen MJ, Allard S, Johansson PI, Stanworth S, Thiemermann C, Brohi K. Definition and drivers of acute traumatic coagulopathy: clinical and experimental investigations. J Thromb Haemost. 2010;8:1919–25.
19. Peltan ID, Vande Vusse LK, Maier RV, Watkins TR. An international normalized ratio-based definition of acute traumatic coagulopathy is associated with mortality, venous thromboembolism, and multiple organ failure after injury. Crit Care Med. 2015;43:1429–38.
20. Peltan ID, Vande Vusse LK, Maier RV, Watkins TR. An INR-based definition of acute traumatic coagulopathy is associated with mortality, venous thromboembolism, and multiple organ failure after injury. Crit Care Med. 2015;43:1429–38.
21. Binz S, McCollester J, Thomas S, Miller J, Pohlman T, Waxman D, Shariff F, Tracy R, Walsh M. CRASH-2 study of tranexamic acid to treat bleeding in trauma patients: a controversy fueled by science and social media. J Blood Transfusion. 2015;2015:874920.