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All the bang without the bucks: Defining essential point-of-care testing for traumatic coagulopathy

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Abstract

BACKGROUND—Rapid assessment and treatment of coagulopathy reduces postinjury morbidity and mortality. Although thrombelastography (TEG) may be more accurate and efficient than conventional coagulation tests, it requires significant financial and personnel investments. We hypothesized that point-of-care international normalized ratio (POC INR) may provide a rapid and accurate alternative to TEG.

METHODS—A retrospective review of sequential trauma patients who underwent both POC INR and rapid TEG (r-TEG) testing upon presentation to a Level I trauma center from July 2012 to December 2013 was performed. POC INR was compared with r-TEG values (*R* value, *K* time, α angle, maximum amplitude, percent clot lysis in 30 minutes) and transfusion requirements. Vital signs, admission laboratory values, and injury severity were analyzed. POC INR and venous blood gas testing was performed in the emergency department. All results and Pearson correlations noted were significant if $p < 0.05$.

RESULTS—We identified 628 trauma patients with concomitant r-TEG and POC INR testing. Median Injury Severity Score (ISS) was 13, 20% arrived in shock (base value < −5), 21% were transfused, and 11% died. POC INR correlated with all r-TEG values, with stronger correlations for patients in shock. POC INR and r-TEG had similar correlations with blood products transfused at 4 hours and 24 hours, but only POC INR predicted substantial bleeding and massive transfusion. POC INR also correlated strongly with standard INR testing. POC INR test duration was less than 1 minute, compared with at least 30 minutes for r-TEG. Total cohort charges for POC INR were estimated at $21,980 versus $396,896 for r-TEG.

CONCLUSION—POC INR testing is faster and cheaper than r-TEG. In addition, POC INR correlates not only with r-TEG values but also with acute blood product transfusions. POC INR provides a practical alternative for rapid coagulopathy assessment in the trauma patient at institutions that lack TEG capability.

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AUTHORSHIP

M.D.G. and B.R.H.R. designed this study. M.D.G. and D.J.H. performed the data acquisition and analysis. D.M.G., A.T.M., D.J.H., T.A.P., and B.R.H.R. contributed to the interpretation of data and manuscript writing.

DISCLOSURE

The authors declare no conflicts of interest.

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Keywords

INR; TEG; coagulopathy; massive transfusion

Exsanguinating hemorrhage remains the leading cause of preventable death following injury.[1,2] In addition to rapid surgical control of hemorrhage, prompt identification and treatment of acute coagulopathy is necessary to avert ongoing blood loss. The presence and severity of acute traumatic coagulopathy (ATC) on admission are associated with increased transfusion requirements and mortality in trauma patients.[3–7] The rapid identification and treatment of coagulopathy by protocols and principles such as damage-control resuscitation can combat the lethal effects of ATC in both military and civilian populations.[8–14] Timely recognition of ATC may depend on the coagulation test performed upon arrival to the emergency department (ED). Plasma-based conventional coagulation tests (CCTs) are traditionally used and include prothrombin time (PT) and its standardized international normalized ratio (INR), activated partial thromboplastin time, and fibrinogen level. Of these CCTs, INR alone has been included in a set of physiologic and hemodynamic triggers that correlate with the need for massive transfusion, including systolic blood pressure less than 90 mm Hg, hemoglobin less than 11 g/dL, temperature lower than 35.5°C, INR greater than 1.5, and base deficit of 6 or greater.[6,15] Admission INR has further been identified as the most predictive individual trigger for any transfusion, including the need for massive transfusion.[15]

Despite the universal availability and implementation of INR testing in hospital laboratories worldwide, recent literature suggests that CCTs may not be optimal for identification of acute coagulopathy in trauma patients. CCTs are *in vitro* acellular assessments of platelet-poor plasma that are neither time nor temperature sensitive.[16,17] There has been increased interest in whole-blood viscoelastic hemostatic assays, such as thrombelastography (TEG), to address the need for a rapid, real-time assessment of coagulopathy. Compared with CCTs, rapid TEG (r-TEG) values have been shown to be faster and less expensive measures of coagulopathy. TEG more strongly correlates with blood product transfusion in severely injured trauma patients and more accurately assesses coagulopathy in stable trauma and surgical patients when compared with CCTs.[16,17] However, TEG and other viscoelastic tests are subject to a unique set of preanalytic and analytic factors that may impact test reliability and reproducibility.[18] Sample storage time and the use of citrated samples can affect reproducibility of TEG results, and artifacts have been observed, which potentially confound interpretation of TEG values.[19]

Rapid and reproducible methods of identifying coagulopathy and the need for blood transfusion are vital to decrease mortality from hemorrhage, as these deaths occur quickly, most commonly within 6 hours after injury. Point-of-care (POC) testing refers to laboratory assessments performed at the bedside or near the site of medical care, allowing more efficient evaluation. As technology has advanced, more POC devices have become available to bring the benchtop to the patient's bedside by providing physicians with real-time

information. POC assessment of INR is now available with multiple microcoagulation devices but has had limited evaluation in the setting of trauma and no direct comparison to viscoelastic hemostatic assays. We hypothesized that POC INR testing may provide a rapid and accurate alternative to r-TEG for the identification of coagulopathy in the injured patient.

PATIENTS AND METHODS

Study Setting

University of Cincinnati Medical Center is an American College of Surgeons–verified Level I trauma center that serves 1.8 million people in the tristate area of southwestern Ohio, northern Kentucky, and southeastern Indiana. The trauma services perform nearly 3,800 trauma evaluations and 2,900 admissions annually. The most severely injured are initially evaluated in the specialized shock resuscitation unit (SRU) then cared for in a 34-bed surgical intensive care unit. This study was approved by the institutional review board of the University of Cincinnati.

Patients

This was a single-center, retrospective cohort study of trauma patients evaluated at the University of Cincinnati Medical Center who underwent paired POC PT/INR and r-TEG testing immediately upon presentation to the SRU from July 2012 to December 2013. Patient data were extracted from the institutional American College of Surgeons trauma registry and supplemented with additional queries into the electronic medical record for laboratory and blood transfusion data. Patient demographics including age, sex, race, and mechanism of injury (penetrating or blunt) were collected. Vital signs on arrival to the ED and initial Glasgow Coma Scale (GCS) score were reviewed. Abbreviated Injury Scale (AIS) scores and Injury Severity Score (ISS) were calculated. Intensive care unit length of stay, hospital length of stay, and mortality at the time of discharge were determined. Time from admission to death was noted for all nonsurvivors.

Laboratory Testing

Our ED contains a satellite POC laboratory located adjacent to the SRU. The POC laboratory performs baseline tests on trauma patients, including venous blood gas (VBG), hemoglobin, lactate, INR, blood urea nitrogen, creatinine, and serum ethanol level. Protocols for the selected tests performed are based on level of trauma activation for the highest-level activations and can be added for lower-level activations based on physician discretion.

All blood samples were collected on admission as soon as intravenous access was achieved. POC INR testing was performed within the POC laboratory on a Hemochron Signature Elite (International Techidyne Corporation, Edison, NJ) microcoagulation system. The Hemochron Jr. Prothrombin Time (PT) test is a single-stage quantitative assay for hemostasis assessment of the extrinsic coagulation pathway, generating an INR after mathematical conversion. The test requires only 50 μL of fresh whole blood placed in a disposable cuvette. Sample and reagent mixing and test initiation are performed automatically, requiring no operator interaction. Two LED optical detectors within the test

channel of the cuvette detect clot formation as the sample is oscillated. As fibrin formation begins, blood flow is impeded, and the movement between the two detectors slows. The instrument recognizes that a clot end point has been achieved when the movement decreases below a predetermined rate. INR results are determined within 1 minute of test start time. The manufacturer-verified analytic measurement range is INR of 1.0 to 6.8.[20] Error values may be reported as INR greater than 10, and the test should then be repeated for verification. For those patients who also underwent standard PT testing, the analysis was performed per standard protocol on a platelet-poor plasma specimen in the main hospital laboratory.

In the current study, r-TEG testing was performed on a Thrombelastograph 5000 (Haemonetics, Braintree, MA) located in the main hospital laboratory. All r-TEG samples were collected in a citrated tube and transported to the main hospital laboratory where the citrate was immediately reversed with calcium chloride according to manufacturer recommendations and reagents. A standard r-TEG was then performed using 300 μL of whole blood and tissue factor as the coagulation activator. Whole blood aliquots and TEG reagents were manually pipetted into the TEG sample cups by trained laboratory personnel to initiate the test. The normal ranges of TEG values were as follows: *R* value of 22 seconds to 44 seconds, *k* time of 34 seconds to 138 seconds, α angle of 64 degrees to 80 degrees, maximum amplitude (MA) of 52 mL to 71 mL, and percent clot lysis in 30 minutes (LY30) of 0%. Minimum time to LY30 result and TEG completion was 30 minutes from MA result, as defined by the manufacturer.

Staff laboratory technicians performed all POC testing and r-TEGs as well as the manufacturer-recommended quality control (QC) analysis. QC of POC INR was performed with 1-minute electronic verification every 8 hours, and liquid QC was performed for each new lot of cuvettes. For TEG, manufacturer-recommended 30-minute liquid QC was performed every 8 hours, using normal and abnormal sample reagent controls per channel with each QC evaluation. Hospital laboratory charges were $35 per INR and $632 per r-TEG. VBG analysis was also performed in the ED POC laboratory on an ABL-90 FLEX (Radiometer Medical, Copenhagen, Denmark), using 65 μL of fresh whole blood and providing a 17-parameter result in 35 seconds.

Statistical Analysis

Pearson correlation analysis was used to determine the relationship of INR with admission laboratory values, r-TEG values, standard laboratory INR (LAB INR) results, and blood product transfusion.

Bland-Altman analysis was used to compare the agreement between POC INR and LAB INR, which was considered as the criterion standard of PT testing. For this analysis, only valid results (INR < 10) were considered.

Without a criterion standard test of ATC to definitively compare POC INR and TEG accuracy, all coagulation values were then evaluated against blood product administration as a surrogate indicator of clinically significant hemorrhage and traumatic coagulopathy.[21] Multivariate logistic regression analysis was performed to assess the association of POC INR and each r-TEG variable with transfusion of specific volumes of blood products. The

variables included in the multivariate analyses included age, sex, mechanism of injury, ISS, and ED base deficit. Substantial bleeding was defined as patients receiving their first red blood cell (RBC) unit within 2 hours of ED arrival and then receiving at least 5 U of packed RBCs (pRBCs) within 4 hours of arrival.[22] Massive transfusion was defined as receiving greater than 10 U of pRBCs in 24 hours.[23] Coagulopathy was retrospectively defined as admission INR greater than 1.5, r-TEG *R* value of 55 seconds or greater, α angle of 55 degrees or lower, MA of 55 mm or lower, or LY30 greater than 3%.[17]

The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for the POC INR and each r-TEG value for predicting blood product transfusion at 4 hours and 24 hours as well as substantial bleeding and massive transfusion. All analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC), and a $p < 0.05$ was considered significant.

RESULTS

During the 18-month study period, 628 trauma patients met the inclusion criteria, undergoing concomitant r-TEG and POC INR in the ED upon arrival. In addition, 87 of these patients had a concurrent LAB INR performed. Of all analyzed patients, 164 arrived by air ambulance, 432 by ground ambulance, 30 by private transportation, and 2 with unknown modes of arrival. Of the patients, 115 (18%) were transferred to the ED from an outlying facility. Five hundred eighty-three patients (93%) analyzed met criteria for the highest level of institutional trauma activation. Demographics, ED vital signs, ISS, transfusions received, and outcome data for the cohort are shown in Table 1. Following initial evaluation, 144 patients underwent immediate operative intervention, and 280 were admitted from the ED to either the surgical or the neuroscience intensive care unit. Initial laboratory values upon ED arrival are shown in Table 2. Of note, 10 patients in the study group were known to be taking warfarin at the time of injury. These patients were included in the analyses, but none of the 10 patients received blood products within the first 24 hours of admission.

Laboratory Value Correlations

POC INR demonstrated weak but significant correlation to hemoglobin and platelet count on admission but no significant correlation to lactate, pH, or base deficit (Table 2). As noted in Table 1, a total of 129 patients (20%) met criteria for shock, as defined by a base excess value of lower than −5. Of these patients who arrived in shock, correlations of POC INR to other admission laboratory values were slightly stronger but remained modest. POC INR in shock patients had the strongest correlation with platelet count but did not correlate with lactate. In addition, there was no correlation of any coagulation parameter with ethanol level or admission creatinine level.

Coagulation Assay Comparisons

POC INR demonstrated modest correlations with r-TEG values for the overall population, and these correlations were stronger for patients who presented in shock (Table 2).

POC INR was compared with LAB INR for 87 patients who had both tests drawn in the ED, using both Bland-Altman analysis for value agreement and Pearson correlation. Subgroup analysis was also performed to evaluate comparison of LAB INR to POC INR values lower than 10 to limit systematic laboratory errors, to POC INR of 1.5 to 10 to evaluate coagulopathy without laboratory error, and to a subgroup of patients with a base value lower than −5 to analyze those patients in shock (Table 3). POC INR demonstrated very strong and significant correlation to LAB INR for values lower than 10 and maintained this correlation for patients with POC INR greater than 1.5. The mean difference between POC and LAB INR values was only 0.15.

Correlation of POC INR and r-TEG values to the number of blood product units transfused in the first 4 hours and 24 hours after admission was assessed. *R* time values consistently demonstrated no correlation with the volume of blood products administered. POC INR, *k* time, α angle, MA, and LY30 all demonstrated weak correlations to pRBCs and fresh frozen plasma transfused in the first 4 hours and slightly stronger correlations to pRBCs, fresh frozen plasma, platelets, and cryoprecipitate transfused by 24 hours (Table 4).

Multiple Logistic Regression Analysis

Multivariate logistic regression was performed to evaluate the association of POC INR and r-TEG values with substantial bleeding and massive transfusion (Table 5). This analysis demonstrated that POC INR, but not r-TEG, was independently associated with substantial bleeding as well as massive transfusion.

Sensitivity and Specificity Analyses

The utility for each individual coagulation test to predict substantial bleeding and massive transfusion was analyzed (Table 6). Each parameter had a high specificity and NPV coupled with fairly low sensitivity and very low PPV. POC INR had the highest area under the curve (AUC) for both substantial bleeding and massive transfusion prediction, suggesting fair performance in the prediction of transfusion. By contrast, all TEG AUCs were less than 0.7, suggesting poor performance for any of these individual parameters in predicting substantial bleeding or massive transfusion.

Coagulation Test Charges

When taking into account our hospital laboratory charges of $35 per POC INR and $632 for each r-TEG, cohort charges for POC INR were estimated at $21,980 versus $396,896 for r-TEG.

DISCUSSION

Prevention of early death from hemorrhagic shock following injury has been furthered by two recent advances in resuscitation: use of balanced blood products within the construct of massive transfusion protocols and increasing identification and understanding of ATC. These developments have been strengthened by the validation of physiologic and laboratory values as triggers of massive transfusion, such as INR, as well as the increasing application of viscoelastic coagulation testing. This is the first study to compare two methods of true POC

coagulation analysis in a trauma population. The present study demonstrates that POC INR is equivalent and potentially superior to r-TEG in the prediction of posttraumatic hemorrhage and identification of ATC.

INR has consistently been identified as one of the strongest predictors of the need for both substantial and massive transfusion in both civilian and military populations.[6,15,17,24,25] As such, INR has been validated in multiple retrospective studies as a trigger for the initiation of massive transfusion protocols in bleeding trauma patients. In addition, *in vitro* testing has shown that INR is a more reliable marker of coagulation factor deficiencies than activated partial thromboplastin time.[26] Our multivariate logistic regression results support the continued use of INR as an independent variable associated with both substantial bleeding and massive transfusion.

Despite the validation of INR as an accurate predictor of blood product needs in the trauma patient, the notable weaknesses of the test can be attributed to its lack of speed and use of platelet-poor plasma as opposed to whole blood samples. Both of these limitations may be addressed with the implementation of real-time POC INR testing. Standard INR testing can take up to 40 minutes to result, limiting the real-time applicability of LAB INR to timely ATC identification and treatment. By contrast, POC INR testing has been shown to be practical and reliable in the ED setting, rarely overestimating coagulopathy, and have results comparable with LAB INR.[27] Additional studies have demonstrated a wide range of differences between POC and standard results as well as variability among POC devices, which introduces concern regarding the reliability and reproducibility of POC results.[28,29]

Few studies have addressed the use of POC INR devices specifically in the setting of injury and ATC. Using a Coagcheck XS POC microcoagulation system, Mitra et al.[30] found that POC INR had a sensitivity of 63% and specificity of 88% compared with LAB INR and concluded that POC INR was unreliable in diagnosing ATC. By contrast, a preliminary study conducted by David et al.[31] using the Hemosense monitor found no significant difference between POC and LAB INR values with a strong correlation between the two tests in evaluating 48 trauma patients. These POC INR values resulted nearly 60 minutes earlier than the standard laboratory tests, confirming additional benefit compared with LAB INR testing. As in our study, Gauss et al.[32] used the Hemochron Signature Elite POC INR device. In their evaluation of 51 patients screened for acute hemorrhage, these authors found that 27% of POC INR results outside of the defined range of clinically relevant agreement and 19% of POC INR results identified coagulopathy when LAB INR values did not. In comparison with this study, our results show a small mean difference between POC and LAB INR values of only 0.15. There was also strong correlation between POC and LAB INR values for patients who presented with ATC as defined by an INR greater than 1.5. With the strength of agreement and correlation between POC and LAB INR values, our institution no longer obtains routine confirmatory LAB INR in trauma patients, relying instead on POC INR to diagnose ATC.

Recent studies comparing viscoelastic coagulation testing, such as TEG, with INR have demonstrated that INR may overestimate coagulopathy in both the actively bleeding trauma patient and the stable surgical patient.[16,17,33] In addition, *G* values calculated from r-TEG

data correlate with postinjury mortality, whereas INR is not associated with survival.[25,34] Previous studies have demonstrated strong correlations between TEG and LAB INR values in trauma patients.[35,36] However, the agreement between TEG and CCTs has been less accurate in evaluation of coagulopathy in surgical patients and in models of both dilutional and hypothermic coagulopathy.[37,38] The applicability of LAB INR testing in these studies may be limited by the inherent testing process requiring the use of platelet-poor plasma specimens without temperature sensitivity. These weaknesses may be minimized by using whole blood POC INR analysis. Our data show that while there are statistically significant correlations between POC INR and r-TEG values for all trauma patients, the strength of these correlations is considerably improved in patients who present in shock. In these critically injured patients, arguably the most relevant population to accurately and rapidly diagnose ATC, POC INR correlates more strongly with r-TEG parameters than with any other ED arrival laboratory value.

To our knowledge, this is the first study to compare POC INR and r-TEG values both for accuracy of ATC diagnosis and association with blood product transfusion. As in other large population trauma studies, our results demonstrate that POC INR performs similarly or superior to r-TEG values in predicting the use of blood product components and need for massive transfusion.[17,25] Similar to INR, TEG has inherent drawbacks in its practical application. One major limitation is the many variations possible in the technique of testing. While TEG was designed for fresh whole blood specimens with no additional activator, subsequent modifications have included sample anticoagulation with citrate and activation with kaolin or tissue factor. Different iterations of TEG testing may bring variable results that can affect the assessment of coagulopathy.[35] The addition of citrate, for example, can impart systematic differences and artifacts in TEG tracings including longer *R* time and lower MA compared with blood samples without citrate.[39,40] Kashuk et al.[33] demonstrated that native blood specimens provide superior coagulopathy assessment compared with citrated samples in trauma patients. In addition, the accuracy of TEG results can be compromised by patient factors including alcohol, sex, and age.[41,42] Another major drawback in TEG testing is interlaboratory reproducibility. TEG has not yet achieved the level of interlaboratory consistency observed for CCTs, requires manual manipulation and measurement of samples by laboratory personnel, and remains limited by significant time constraints.[18] Several authors have noted that the while earliest r-TEG values (*R* value, *k* time) are available within 5 minutes and late TEG values (α angle and MA) within 15 minutes, total test time requires 30 minutes.[25,35,36] By contrast, POC INR and VBG tests in our institution require less than a minute of testing and are effectively available at the bedside before initiation of r-TEG testing.

A final drawback of TEG testing compared with POC INR is investment, both in labor effort and hospital charges. TEG manufacturer recommendations include 30-minute liquid calibration three times per day with both normal and abnormal samples for each of the two channels, making TEG QC relatively labor intensive at 6 hours per day compared with CCTs.[43] By contrast, the Hemochron POC INR device undergoes a 1-minute electronic calibration every 8 hours, for a total QC time of 3 minutes in 24 hours. In our institution, TEG charges are 18 times higher than POC INR ($632 vs. $35). Notably, the charge for POC VBG is $254. Taken together, cohort charges for patients receiving complete protocol

POC laboratory testing in this study were $181,492, which is still less than half of the total charges for the r-TEG alone. Of course, institutional variation in charges is present, as r-TEG has been shown to result in lower charges at other hospitals.[17]

The limitations of this study include the potential selection bias inherent to all retrospective studies. The patient population analyzed does not include all consecutive trauma patients evaluated, as the designated study population required both POC INR and TEG testing on arrival. In our institution, severely injured patients may be transported immediately from the ED to the operating room before complete laboratory evaluation; thus, some of the most severely injured patients were excluded from analysis. This potentially contributed to the relatively small number of substantially bleeding and massively transfused patients in this study, affecting the low PPVs found in our analysis. Our data set was also not able to capture time from blood collection to coagulation test initiation. Thus, judgments regarding rapidity of coagulation test execution were based solely on test duration. Furthermore, this retrospective study was not designed to substantiate the need for blood products transfused, rather to associate coagulation test results with subsequent blood product use. In addition, a subset of these patients arrived at our institution from other facilities (18%), introducing variable time and treatment strategies occurring between time of injury and presentation. This study is further restrictedby the use of a single POC INR device, so interpretation and application of results are therefore constrained by its potential systematic weaknesses and lack of generalizability to other POC devices. While our coagulation parameter correlation values are similar to those observed in for LAB INR in previous studies, the distribution of values and statistical methods selected could affect result analysis and interpretation. Any potential variances were attempted to be minimized by the large sample size of this study.[17]

In conclusion, our data suggest that POC analysis is a rapid and accurate method of determining INR in the trauma population. Similar to the standard plasma-based INR test, POC INR remains strongly associated with blood administration requirements in the actively bleeding trauma patient. POC INR utility is commensurate with the capabilities of viscoelastic testing, providing results in less time and at a lower charge to the patient.

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TABLE 1

Demographic, Injury, and Outcome Characteristics (n = 628)

Age, median (IQR), y	35 (25–53)
Male sex	79.3%
White race	59.2%
Penetrating mechanism of injury	47.6%
GCS, median (IQR)	15 (11–15)
Systolic blood pressure, median (IQR), mm Hg	132 (113–149)
Heart rate, median (IQR), bpm	95 (80–110)
ISS, median (IQR)	13 (5–25)
Shock with base value < −5	19.9%
Any blood product transfusion	21%
Substantial bleeding (>5 pRBCs in 4 h) rate	4.4%
Massive transfusion (>10 pRBCs in 24 h) rate	2.0%
24-h mortality	5.4%
Overall mortality	10.8%

IQR, interquartile range.

TABLE 2

Admission Laboratory and r-TEG Values and Correlation With POC INR Values

	Initial Laboratory Value	All Patients	Patients With Base Value < −5
Hemoglobin, g/dL	13.5 (12.1 to 14.7)	$r = -0.12$, $p = 0.002$ *	$r = -0.27$, $p = 0.002$ *
Platelets, $10^3/\mu L$	238 (196 to 282)	$r = -0.15$, $p = 0.003$ *	$r = -0.33$, $p < 0.001$ *
Lactate, mmol/L	2.75 (1.8 to 4.2)	$r = 0.05$, $p = 0.234$	$r = -0.009$, $p = 0.91$
pH	7.33 (7.27 to 7.38)	$r = -0.03$, $p = 0.446$	$r = -0.29$, $p < 0.001$ *
Base value, mmol/L	−1 (−4.4 to 1.1)	$r = 0.05$, $p = 0.234$	$r = -0.18$, $p = 0.03$ *
POC INR	1.2 (1.1 to 1.3)		
R value, s	45 (35 to 55)	$r = 0.26$, $p < 0.001$ *	$r = 0.49$, $p < 0.001$ *
k time, s	95 (70 to 125)	$r = 0.32$, $p < 0.001$ *	$r = 0.77$, $p < 0.001$ *
α angle, degrees	73.7 (69.5 to 77.4)	$r = -0.23$, $p < 0.001$ *	$r = -0.61$, $p < 0.001$ *
MA, mm	60.9 (56.3 to 65.6)	$r = -0.27$ $p < 0.001$ *	$r = -0.65$ $p < 0.001$ *
LY30, %	1.2 (0.3 to 2.9)	$r = 0.31$, $p < 0.001$ *	$r = 0.50$, $p < 0.001$ *

*Significance defined as $p < 0.05$.

r, Pearson correlation coefficient.

TABLE 3

Relationship Between POC and LAB INR

	Mean Difference	SD	Minimum	Maximum	Correlation	*p*
All POC INR (n = 87)	0.62	1.97	−0.6	8.9	0.4	<0.001 *
All POC INR <10 (n = 82)	0.15	0.36	−0.6	1.7	0.91	<0.001 *
1.5 < POC INR < 10 (n = 22)	0.47	0.49	−0.6	1.7	0.94	<0.001 *
Base value < −5 (n = 24)	0.8	2.24	−0.6	8.0	0.40	<0.001 *

* Significance defined as $p < 0.05$.

TABLE 4

Correlation With Blood Product Transfusion

	POC INR	*R* time	*k* time	α angle	MA	LY30
pRBC 4 h	$r = 0.1$	$r < 0.001$	$r = 0.1$	$r = -0.08$	$r = -0.1$	$r = 0.09$
	$p = 0.009^*$	$p = 0.98$	$p = 0.01^*$	$p = 0.046^*$	$p = 0.01^*$	$p = 0.02^*$
Plasma 4 h	$r = 0.11$	$r = -0.003$	$r = 0.1$	$r = -0.07$	$r = -0.11$	$r = 0.08$
	$p = 0.007^*$	$p = 0.92$	$p = 0.009^*$	$p = 0.07$	$p = 0.006^*$	$p = 0.04^*$
Platelets 4 h	$r = 0.03$	$r = 0.004$	$r = 0.06$	$r = -0.05$	$r = -0.06$	$r = 0.05$
	$p = 0.49$	$p = 0.92$	$p = 0.15$	$p = 0.22$	$p = 0.1$	$p = 0.2$
Cryoprecipitate 4 h	$r = 0.03$	$r < 0.001$	$r = 0.05$	$r = -0.05$	$r = -0.06$	$r = -0.02$
	$p = 0.51$	$p = 0.98$	$p = 0.19$	$p = 0.23$	$p = 0.13$	$p = 0.6$
pRBC 24 h	$r = 0.14$	$r = -0.002$	$r = 0.11$	$r = -0.08$	$r = -0.12$	$r = 0.18$
	$p = 0.004^*$	$p = 0.95$	$p = 0.006^*$	$p = 0.04^*$	$p = 0.001^*$	$p < 0.001^*$
Plasma 24 h	$r = 0.15$	$r = -0.004$	$r = 0.12$	$r = -0.09$	$r = -0.13$	$r = 0.17$
	$p = 0.001^*$	$p = 0.92$	$p = 0.002^*$	$p = 0.03^*$	$p = 0.001^*$	$p < 0.001^*$
Platelets 24 h	$r = 0.12$	$r = 0.004$	$r = 0.13$	$r = -0.11$	$r = -0.13$	$r = 0.18$
	$p = 0.002^*$	$p = 0.92$	$p < 0.001^*$	$p = 0.006^*$	$p = 0.001^*$	$p < 0.001^*$
Cryoprecipitate 24 h	$r = 0.12$	$r = 0.001$	$r = 0.11$	$r = -0.07$	$r = -0.1$	$r = 0.11$
	$p = 0.003^*$	$p = 0.98$	$p = 0.01^*$	$p = 0.07$	$p = 0.01^*$	$p = 0.003^*$

*Significance defined as $p < 0.05$.

r, Pearson correlation coefficient.

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TABLE 5

Multiple Logistic Regression Analysis for Substantial Bleeding and Massive Transfusion

	Odds Ratio	95% Confidence Interval	*p*
Substantial bleeding			
r-TEG *R* value ≥ 55	1.70	0.721–4.006	0.23
r-TEG α angle ≤ 55	1.64	0.278–9.634	0.59
r-TEG MA ≤ 55	1.08	0.413–2.802	0.88
r-TEG LY30 > 3%	0.57	0.197–1.630	0.29
POC INR > 1.5	3.08	1.142–8.293	0.03 *
Massive transfusion			
r-TEG *R* value ≥ 55	2.67	0.808–8.815	0.11
r-TEG α angle ≤ 55	3.42	0.538–21.694	0.19
r-TEG MA ≤ 55	1.71	0.491–5.927	0.40
r-TEG LY30 > 3%	1.84	0.541–6.225	0.33
POC INR > 1.5	5.12	1.192–21.975	0.03 *

* Significance defined as $p < 0.05$.

TABLE 6

Utility of Each Coagulation Test to Predict Substantial Bleeding and Massive Transfusion

	AUC (95% Confidence Interval)	Sensitivity	Specificity	PPV	NPV
Substantial bleeding					
r-TEG *R* value ≥ 55	0.59 (0.49–0.68)	0.46	0.71	0.07	0.97
r-TEG α angle ≤ 55	0.53 (0.48–0.58)	0.07	0.98	0.17	0.96
r-TEG MA ≤ 55	0.56 (0.47–0.65)	0.32	0.81	0.07	0.96
r-TEG LY30 > 3%	0.51 (0.41–0.57)	0.21	0.77	0.04	0.95
POC INR > 1.5	0.66 (0.56–0.75)	0.43	0.88	0.15	0.97
Massive transfusion					
r-TEG *R* value ≥ 55	0.62 (0.48–0.76)	0.54	0.71	0.04	0.99
r-TEG α angle ≤ 55	0.57 (0.47–0.67)	0.15	0.98	0.17	0.98
r-TEG MA ≤ 55	0.60 (0.46–0.73)	0.38	0.80	0.04	0.98
r-TEG LY30 > 3%	0.58 (0.44–0.72)	0.38	0.78	0.04	0.98
POC INR > 1.5	0.71 (0.56–0.85)	0.54	0.88	0.09	0.99