Published in final edited form as:

Surgery. 2018 September ; 164(3): 489–493. doi:10.1016/j.surg.2018.04.029.

Rapid and Efficient: Native and Kaolin Compared to Rapid Thrombelastography in Trauma Patients

Julia R Coleman, MD, MPH^{1,*}, Ernest E Moore, MD², Michael P Chapman, MD³, Anirban Banerjee, PhD⁴, Christopher C Silliman, MD, PhD⁵, Arsen Ghasabyan, MPH⁶, James Chandler⁷, Jason M Samuels, MD⁸, and Angela Sauaia, MD, PhD⁹

^{1,3,4,5,8,9}University of Colorado-Denver, 12631 E. 17th Ave., C302, Aurora, CO 80045

^{2,6,7}Denver Health Medical Center, 777 Bannock St, Denver, CO 80204

Abstract

Background—Several thrombelastography (TEG) functional assays have been developed to guide transfusion in injured patients, but how this acceleration of TEG affects its ability to predict massive transfusion (MT) is unknown. The objective of this study is to compare citrated native (CN-), citrated kaolin (CK-), and citrated rapid (CR-) TEGs for their prediction of MT after trauma. We hypothesized that CN-TEG best predicts MT.

Methods—Data were collected as part of a prospective study of trauma activation patients. CN-TEG, CK-TEG and CR-TEG were performed for all patients. Logistic regression was used to assess the predictive performance of different TEG assays for MT.

Results—343 patients had data for all three TEGs and 16.6% (57) required MT. Compared to CR-TEG, CK-TEG performed better for ACT/R and CN-TEG for MA and angle. Yet, the 95% confidence intervals overlapped considerably, suggesting the CR-TEG produced comparable results to the other assays for ACT, MA, and angle.

Conclusions—There was substantial overlap in the performance of the different TEG assays, suggesting CR-TEG is a rapid and effective method to guide hemostatic resuscitation in trauma patients and does not perform inferiorly to the CN- or CK-TEG despite the addition of activation factors.

Background

Trauma-induced coagulopathy (TIC) is present in a large proportion (25–35%) of severely injured patients who present to the emergency department and is the leading cause of

*Corresponding author: Dr. Ernest E Moore (ernest.moore@dhha.org, 303-724-2680).

This is a Society of University Surgeons paper, submitted after presentation at the Academic Surgical Congress (January 30th–February 1st, 2018) in Jacksonville, FL on February 1st, 2018.

Disclosure of Financial Interests and Potential Conflicts of Interest

There are no financial disclosures and conflicts of interest to disclose for any of the authors.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

preventable death after trauma(1, 2). Uncontrolled hemorrhage accounts for up to 40% of deaths in the severely injured hospitalized patients, and half of those deaths occur in the first two hours from injury(3, 4). Thus, prompt detection of TIC is crucial and has been linked to improved survival in trauma patients(5). Early detection, however, is limited by the predictive ability of conventional coagulation assays (CCAs), including prothrombin time, international normalized ratio (PT-INR) and partial thromboplastin time (PTT). Consequently, thrombelastography (TEG), a viscoelastic assay that delivers a more comprehensive assessment of homeostatic capacity, has been adopted increasingly for resuscitation of severely injured patients, and the use of TEG in goal-directed hemostatic resuscitation has been shown to dramatically improve survival(6).

Citrated, native TEG (CN-TEG) has been well-established for its role in point-of-care resuscitation but poses challenges for clinicians due to the delay in result time (similar to conventional coagulation assays). This delay of up to 30 minutes can have detrimental clinical implications. To address this predicament, several functional TEG assays have been developed to decrease the time to available data to guide transfusion in trauma and hemorrhage(7). These assays involve addition of various agonists: kaolin (citrated kaolin TEG; modeling contact activation, or the intrinsic pathway) and tissue factor (citrated rapid TEG; modeling the extrinsic pathway)(8, 9). How this acceleration of TEG affects its efficiency and accuracy is unknown, particularly in its ability to predict need for massive transfusion (MT). This is relevant given the use of TEG in the clinical setting to rapidly guide hemostatic resuscitation. The objective of this study is to compare CN-TEG, citrated, kaolin (CK-TEG) and citrated, rapid (CR-TEG) TEGs for their prediction of MT after trauma. We hypothesize that CN-TEG (without acceleration from added activators), though requiring more time, best predicts MT.

Patients/Methods

Study Design

This is an analysis of prospectively collected data from our Trauma Activation Protocol (TAP), a registry which includes all trauma activation patients who sustained blunt or penetrating trauma from 2015 to 2017 at Denver Health Medical Center (DHMC), an American College of Surgeons-verified and Colorado state-certified, academic, Level-1 trauma center. The TAP study was approved by the Colorado Multiple Institution Review Board (COMIRB#13-3087) and performed under waiver of consent. Clinical data were collected by trained research professional assistants and included: age, sex, mechanism, body mass index (BMI), new injury severity score (NISS), field and hospital arrival systolic blood pressure (SBP), heart rate, Glasgow Coma Scale (GCS), INR, PTT, PT, fibrinogen, and base deficit, as well as number of units of blood products transfused: red blood cells (RBCs), frozen plasma (FP24, plasma frozen within 24 h of collection), platelets, and cryoprecipitate, and the volume of crystalloid infused. Traumatic brain injury (TBI) is defined as an abbreviated injury scale (AIS)-head 3.

Participants

Criteria for inclusion in TAP were adult patients (≥ 18 years old) who presented to DHMC as a Trauma Activation, either by ground or air transport from the scene of injury, an emergency department walk-in, or non-transfer patients upgraded to a Trauma Activation on arrival. The criteria were traumatic injury with *any* of the following: 1) GCS < 8 with presumed thoracic, abdominal, or pelvic injury, 2) respiratory compromise, obstruction, and/or intubation with presumed thoracic, abdominal, or pelvic injury, 3) blunt trauma with SBP < 90 mm Hg, 4) mechanically unstable pelvic injury, 5) penetrating injuries with injury to neck and/or torso with SBP < 90, mm Hg, gunshot wound penetrating the neck/torso or stab wounds to the neck/torso that require endotracheal intubation, 6) amputation proximal to the ankle or wrist or 7) the emergency medicine attending or chief surgical resident suspects the patient is likely to require urgent operative intervention. Exclusion criteria included any patient < 18 years, patients whose initial blood sample was not collected within one h of injury, infusion of blood products prior to the collection of blood samples, patients presenting as consultations from external hospitals, documented chronic liver disease (total bilirubin > 2.0 mg/dL) or advanced cirrhosis discovered on laparotomy, known inherited defects of coagulation function (e.g. hemophilia or Von Willebrand's disease), subsequent downgrades from Trauma Activation to Trauma Alert to non-trauma status in the emergency department, and patients who were pregnant or prisoners. Patients were removed from the study if any of these criteria became known after activation.

Procedures

Whole blood samples were collected at the scene by trained paramedics or on presentation in citrated vacuum tubes (3.5 mL, 3.2% sodium citrate, Greiner Bio-One, Monroe, North Carolina) within one h of injury. A team of trained research professional assistants on 24/7 scheduled for prospective studies completed viscoelastic assays within two h after blood collection. While TEG assays may have been conducted at slightly different times between patients (though all within 2 h), for each individual patient, their assays were run simultaneously. CN-TEG, CK-TEG and CR-TEG were performed concomitantly for all patients using the TEG 5000 Thrombelastography Hemostasis Analyzer (Haemonetics, Niles, IL). As described, the functional assays, in contrast to CN-TEG, involve addition of various agonists: kaolin (CK-TEG) and tissue factor (CR-TEG). CN-TEG and CK-TEG yield the following variables: reaction time (R; time elapsed from initiation of test until onset of clot formation, minutes), angle (rate of clot strength increase, degrees), maximum amplitude (MA; maximal clot strength achieved, millimeters), and percent clot lysis 30 min after reaching MA (LY30, %). The CR-TEG provides the same measurements, except instead of R, CR-TEG provides activating clotting time (ACT; time to beginning of clot formation in seconds). The ACT obtained from CR-TEG is considered comparable to the measurement of R estimated by CN-TEG and CK-TEG(10, 11). R and ACT have been correlated with coagulation factor activity and thrombin generation, the angle with fibrinogen concentration and function, the MA with platelet and fibrin interactions, and LY30 with fibrinolysis(12). LY30, regardless of assay, due to its multimodal distribution, was expressed as three categories as published previously (13): fibrinolysis shutdown (0–0.8%), physiologic (0.9–2.9%), and hyperfibrinolysis (> 3%).

The outcome of interest was MT, defined as > 10 units of RBCs transfused in the first six h or death within six h of presentation. Death within six h of presentation was included to account for survivor bias, given some patients may not survive six h and/or to received > 10 units of RBCs during this time period. MT was triggered if the patient was perceived to have ongoing blood loss and on activation of MT, the blood bank delivered four units of type-O, Rh-negative, RBC units and two of type-A plasmas (FP24) units. The protocol for MT of blood products has been described previously (12) and includes initial empiric transfusion of FFP:RBC 1:2. MT was stopped as clinically indicated once control of bleeding was achieved and/or the patient was hemodynamically stable.

Statistical Analysis

Statistical analyses were performed using SAS for Windows version 9.4 (SAS Institute, Cary, NC), and power calculations were conducted using PASS 14 Power Analysis and Sample Size Software 2015 (NCSS, LLC, Kaysville, Utah, USA). Categorical variables were compared using Chi-square or Fisher Exact test as appropriate. Continuous variables were expressed as median values (interquartile range, IQR) and compared using the Wilcoxon test. The predictive performance of the different assays for MT was assessed using the area under the receiver operating characteristics curve (AUROC). The AUROCs for the TEG assays were compared using the DeLong et al test(14). To assess the predictive performance of LY30, we compared its sensitivity, specificity, positive predictive value, and negative predictive value for MT. All tests were two-tailed and significance established at $p < 0.05$.

Results

611 patients were enrolled in the TAP study from 2015 to 2017, but only 343 patients had data for all three TEGs (CN-, CK-, and CR-TEG)(Table 1, Figure 2). The majority of patients were male (78.7%), and the median age was 32.0 years (IQR 25.6–45.8). Approximately half of the patients presented after blunt trauma, and the median NISS was 18 (IQR 6–34). Overall, 41.4% of the patients required RBC transfusion during the first six hours and 16.6% of patients ultimately required MT.

The median ACT in CR-TEG was the same among the MT and non-MT patients (121 s)($p = 0.274$). With CK-TEG and CN-TEG, the median R time was approximately one minute greater in the MT group versus non-MT group ($p < 0.0001$ and 0.0020 , respectively). Compared to CR-TEG and CN-TEG, CK-TEG performed better for ACT/R ($p = 0.0038$) with an AUC of 0.703, compared to 0.598 for CR-TEG ACT and 0.643 for CN-TEG R. The median angle was less in the MT group versus non-massive transfusion group on all three TEGs. Compared to CR-TEG and CK-TEG, CN-TEG did not perform better for angle, with an AUC of CN-TEG of 0.763 compared to 0.765 for CK-TEG and 0.686 for CR-TEG, ($p = 0.3323$). The median MA was also less in the MT group, compared to the non-MT group in all three TEGs. Compared to CRTEG and CK-TEG, CN-TEG tended to perform better for MA with AUC of 0.827 compared to 0.798 for CK-TEG and 0.796 for CR-TEG, ($p = 0.0766$).

CK-TEG was the only assay with a statistically significant superior performance for ACT-R, while there was no statistically significant difference between the assays for angle or MA. On further examination, the 95% confidence intervals overlapped considerably (Table 2), suggesting the CR-TEG produces comparable results to the other functional assay for ACT, MA, and angle. When all TEG measurements for each assay (CR-, CN-, CK-TEG) were in the model (ACT/R+MA+angle) on logistic regression, there was no differences in predictive performance compared to CR-TEG ($p=0.5300$), and the majority of AUCs were > 0.6 for all assays (Figure 1).

LY30 $> 3\%$ had a low positive predictive value for MT in all three TEG assays, but CK-TEG LY30 had the greatest negative predictive value of MT of 93.7% (compared to 93.4% in CN-TEG LY30 and 92.0% in CR-TEG LY30). For CK-TEG, LY30 AUC was 0.614 (CI 0.490–0.738) for CK-TEG and was not different compared to 0.582 (CI 0.450–0.716) for CN-TEG and 0.527 (CI 0.393–0.661) for CR-TEG ($p=0.3506$).

The current sample allowed us to detect 0.07 to 0.08 points difference between the AUROCs with 95% confidence and 80% power, assuming, based on preliminary data, that the reference group had AUROCs from 0.65 to 0.80 and the correlation between tests was high with Spearman Rho = 0.80 to 0.70 (MA, LY30). For lesser correlations (ACT/R, Angle), with Spearman Rho = 0.45 to 0.65, the sample allowed for the detection of differences of 0.13 to 0.14.

Discussion

The objective of this study is to compare CN-TEG, CK-TEG, and CR-TEG for their prediction of MT after trauma. The role of TEG in point-of-care based resuscitation in trauma has been well validated(6, 15) and thus, adoption of TEG-guided resuscitation has become more widespread, with a recent report indicating that 23% of American College of Surgeons Trauma Quality Improvement Program (ACS-TQIP) Level I hospitals incorporate TEG into their MT protocol and strategy(16). A number of prospective studies have described lesser mortality and death from exsanguination when TEG-guided resuscitation is employed(17) and have demonstrated superiority of TEG compared to CCAs for predicting transfusion requirement(18). Our group reported a randomized control trial in which patients were randomized to CCA-guided resuscitation versus citrated rapid TEG-guided resuscitation and demonstrated improved 28-day survival in the latter group(6).

Over time, a number of TEG assays have been developed to not only expedite the time to results but to better characterize specific hemostatic parameters. The CK-TEG involves clot initiation by addition of activating solution consisting of kaolin (a mineral clay, hydrated aluminum silicate, which activates factor XII), phospholipids and buffered stabilizers. This assay simulates the intrinsic pathway of coagulation. Interpretation of these results needs to be performed with a degree of clinical skepticism, however, because some data with citrated kaolin TEGs have described a pattern of secondary fibrinolysis that does not correlate with the clinical picture of a patient nor the hematologic markers of fibrinolysis. This pattern may suggest that this observed lysis is caused by platelet-mediated hyper-retraction or a pathway involving factor XII, kallikrein, bradykinin, and consequent fibrinolysis(19). Furthermore,

evidence suggests that the kaolin pathway can also have multiple effects on platelets, such as release of platelet factor 3 and cytoskeletal structure related to clot retraction, confounding the analysis of MA and lysis(20). In contrast to CK-TEG, the extrinsic pathway of coagulation is simulated through the CR-TEG. This assay involves addition of kaolin and tissue factor (cell surface glycoprotein that binds to coagulation factor VII), causing a thrombin burst and even more rapid results. This assay can provide early results (ACT, K) within six minutes and later results (angle, MA) within 15 minutes. This compares to at least 20 minutes for kaolin TEGs and 30 minutes for native TEG and CCAs(15),(21). In general, these “activated” assays (CR-TEG, CK-TEG) cause a shortening of the reaction time (representing fibrin formation) and kappa value (time interval from R to where fibrin cross-linking provides a pre-defined resistance), as well as an increase in angle (rate at which clot strengthens), and maximum amplitude (maximal clot strength). Criticism of these accelerated assays is that they can mask coagulation abnormalities, particularly because the CR-TEG causes such a rapid, massive thrombin burst. For this reason, CN-TEG, for example, remains relevant for use in research due to its ability to dampen false signals.

The role of various TEG assays in predicting MT has not been investigated in a comparative fashion between CN-, CK-, and CR-TEG. Thus, this study contributes to a gap in the literature on TEG-based resuscitation of MT patients. In this study, our hypothesis that CN-TEG without the addition of activators would have the best predictive value for MT, was not supported. Rather, the results indicate that despite the ability of activators to potentially mask coagulation aberrancies, CR-TEG is not an inferior method to guide MT in patients compared to CN- or CK-TEG. While ACT/R is relatively weak in all assays, angle and MA correlate well with MT requirement. This is particularly beneficial knowledge, given the rapidity of results of CR-TEG in the setting of active resuscitation of an unstable trauma patient. The only other existing studies comparable to ours include two observational studies of 182 and 404 trauma patients respectively, in which the predictive ability of early amplitude (at 5 and 10 minutes) of CR-TEG and CK-TEG for transfusion and mortality was compared(22, 23). CR-TEG predicted mortality in transfused patients, while CK-TEG did not in one study(22), and CR-TEG had the strongest correlation between its early amplitude and massive transfusion in both studies(23). The reported data support these studies and other existing literature which describe CR-TEG’s predictive ability for transfusion and MT. In a study of 272 severely injured patients at a Level I trauma center, CR-TEG ACT, R, and MA predicted transfusion of RBCs within the first hour of arrival, and all CR-TEG measurements predicted transfusion of RBCs within the first two hours(15). The LY30 from the CR-TEG has also been shown to correlate with MT and mortality at 24 hours and 30 days, though this correlation is not as strongly indicated in our study (AUC 0.527)(24). CK-TEG has also been demonstrated in other studies to have similar prediction of MT compared to CR-TEG, albeit with a greater time to results. On examining a total of 182 trauma patients from a level I trauma center, Johansson et al found that MA, G and LY30 from both CK-TEG and CR-TEG were both predictors of MT (17).

Limitations to these data include that though blood was drawn at roughly equivalent time points for patients, TEGs were conducted at various durations of time from venipuncture; however, the TEGs were all conducted within 2 hours of venipuncture, and the various assays were conducted at the same time for each patient. Another limitation is the use of

ROC analysis for LY30, because ROC analysis typically assumes a binomial distribution; however, it has been observed that LY30 plotted against mortality instead has a more inverse parabolic relationship(13), which may explain why we did not see greater AUC's or predictive abilities among the TEG assays.

In conclusion, contrary to what was expected, there was a significant overlap in the performance of the different TEG assays, suggesting CR-TEG is an effective method to guide hemostatic resuscitation in trauma patients; also the CR-TEG lacked superiority to CN- and CK-TEGs, despite addition of activation factors. LY30 > 3% demonstrated utility for prediction of MT with a high negative predictive value in all assays. The thresholds based on CR-TEG for TEG-guided resuscitation with ROC curve analysis revealed the strongest ROC prediction for angle (0.80 AUC) and MA (0.81 AUC) (6). The presented data suggest these thresholds can be utilized with confidence without concern for masking coagulation abnormalities by using an activated TEG(25).

Acknowledgments

We would like to graciously acknowledge of the University of Colorado Department of Surgery for supporting the trauma research fellows, the National Institutes of Health for the T-32 and P-50 grant and TACTIC support which make the trauma research fellows' work possible, the research assistants at Denver Health who helped to collect the data, and Denver Health for supporting ongoing data collection from patients at their site.

References

1. Brohi K, Cohen MJ, Ganter MT, Matthay MA, Mackersie RC, Pittet JF. Acute traumatic coagulopathy: initiated by hypoperfusion: modulated through the protein C pathway? *Annals of surgery*. 2007; 245(5):812–8. [PubMed: 17457176]
2. Sauaia A, Moore FA, Moore EE, Moser KS, Brennan R, Read RA, et al. Epidemiology of trauma deaths: a reassessment. *The Journal of trauma*. 1995; 38(2):185–93. [PubMed: 7869433]
3. Tisherman SA, Schmicker RH, Brasel KJ, Bulger EM, Kerby JD, Minei JP, et al. Detailed description of all deaths in both the shock and traumatic brain injury hypertonic saline trials of the Resuscitation Outcomes Consortium. *Annals of surgery*. 2015; 261(3):586–90. [PubMed: 25072443]
4. Holcomb JB, Tilley BC, Baraniuk S, Fox EE, Wade CE, Podbielski JM, et al. Transfusion of plasma, platelets, and red blood cells in a 1:1:1 vs a 1:1:2 ratio and mortality in patients with severe trauma: the PROPPR randomized clinical trial. *Jama*. 2015; 313(5):471–82. [PubMed: 25647203]
5. Nardi G, Agostini V, Rondinelli B, Russo E, Bastianini B, Bini G, et al. Trauma-induced coagulopathy: impact of the early coagulation support protocol on blood product consumption, mortality and costs. *Critical care (London, England)*. 2015; 19:83.
6. Gonzalez E, Moore EE, Moore HB, Chapman MP, Chin TL, Ghasabyan A, et al. Goal-directed Hemostatic Resuscitation of Trauma-induced Coagulopathy: A Pragmatic Randomized Clinical Trial Comparing a Viscoelastic Assay to Conventional Coagulation Assays. *Annals of surgery*. 2016; 263(6):1051–9. [PubMed: 26720428]
7. Gonzalez E, Moore EE, Moore HB, Chapman MP, Silliman CC, Banerjee A. Trauma-Induced Coagulopathy: An Institution's 35 Year Perspective on Practice and Research. *Scandinavian journal of surgery: SJS: official organ for the Finnish Surgical Society and the Scandinavian Surgical Society*. 2014; 103(2):89–103.
8. Sorensen B, Johansen P, Christiansen K, Woelke M, Ingerslev J. Whole blood coagulation thrombelastographic profiles employing minimal tissue factor activation. *Journal of thrombosis and haemostasis: JTH*. 2003; 1(3):551–8. [PubMed: 12871465]

9. Nielsen VG. A comparison of the Thrombelastograph and the ROTEM. Blood coagulation & fibrinolysis: an international journal in haemostasis and thrombosis. 2007; 18(3):247–52. [PubMed: 17413761]
10. Moore HB, Moore EE, Chin TL, Gonzalez E, Chapman MP, Walker CB, et al. Activated clotting time of thrombelastography (T-ACT) predicts early postinjury blood component transfusion beyond plasma. Surgery. 2014; 156(3):564–9. [PubMed: 24882760]
11. Johansson PI, Bochsén L, Andersen S, Viuff D. Investigation of the effect of kaolin and tissue-factor-activated citrated whole blood, on clot-forming variables, as evaluated by thromboelastography. Transfusion. 2008; 48(11):2377–83. [PubMed: 18657078]
12. Gonzalez E, Pieracci FM, Moore EE, Kashuk JL. Coagulation abnormalities in the trauma patient: the role of point-of-care thromboelastography. Seminars in thrombosis and hemostasis. 2010; 36(7):723–37. [PubMed: 20978993]
13. Moore HB, Moore EE, Liras IN, Wade C, Huebner BR, Burlew CC, et al. Targeting resuscitation to normalization of coagulating status: Hyper and hypocoagulability after severe injury are both associated with increased mortality. American journal of surgery. 2017
14. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics. 1988; 44(3):837–45. [PubMed: 3203132]
15. Cotton BA, Faz G, Hatch QM, Radwan ZA, Podbielski J, Wade C, et al. Rapid thrombelastography delivers real-time results that predict transfusion within 1 hour of admission. The Journal of trauma. 2011; 71(2):407–14. discussion 14–7. [PubMed: 21825945]
16. Camazine MN, Hemmila MR, Leonard JC, Jacobs RA, Horst JA, Kozar RA, et al. Massive transfusion policies at trauma centers participating in the American College of Surgeons Trauma Quality Improvement Program. The journal of trauma and acute care surgery. 2015; 78(6 Suppl 1):S48–53. [PubMed: 26002263]
17. Johansson PI, Sorensen AM, Larsen CF, Windelov NA, Stensballe J, Perner A, et al. Low hemorrhage-related mortality in trauma patients in a Level I trauma center employing transfusion packages and early thromboelastography-directed hemostatic resuscitation with plasma and platelets. Transfusion. 2013; 53(12):3088–99. [PubMed: 23614333]
18. Holcomb JB, Minei KM, Scerbo ML, Radwan ZA, Wade CE, Kozar RA, et al. Admission rapid thrombelastography can replace conventional coagulation tests in the emergency department: experience with 1974 consecutive trauma patients. Annals of surgery. 2012; 256(3):476–86. [PubMed: 22868371]
19. Durila M. Kaolin activated thromboelastography can result in false positive fibrinolytic trace. Anaesthesia and intensive care. 2011; 39(4):775–6. [PubMed: 21823408]
20. Hardisty RM, Hutton RA. THE KAOLIN CLOTTING TIME OF PLATELET-RICH PLASMA: A TEST OF PLATELET FACTOR-3 AVAILABILITY. British journal of haematology. 1965; 11:258–68. [PubMed: 14282063]
21. Jeger V, Zimmermann H, Exadaktylos AK. Can RapidTEG accelerate the search for coagulopathies in the patient with multiple injuries? The Journal of trauma. 2009; 66(4):1253–7. [PubMed: 19359945]
22. Meyer AS, Meyer MA, Sorensen AM, Rasmussen LS, Hansen MB, Holcomb JB, et al. Thrombelastography and rotational thromboelastometry early amplitudes in 182 trauma patients with clinical suspicion of severe injury. The journal of trauma and acute care surgery. 2014; 76(3): 682–90. [PubMed: 24553534]
23. Laursen TH, Meyer MAS, Meyer ASP, Gaarder T, Naess PA, Stensballe J, et al. Thrombelastography Early Amplitudes in bleeding and coagulopathic trauma patients: Results from a multicenter study. The journal of trauma and acute care surgery. 2017
24. Pommerening MJ, Goodman MD, Farley DL, Cardenas JC, Podbielski J, Matijevic N, et al. Early diagnosis of clinically significant hyperfibrinolysis using thrombelastography velocity curves. Journal of the American College of Surgeons. 2014; 219(6):1157–66. [PubMed: 25458237]
25. Einersen PM, Moore EE, Chapman MP, Moore HB, Gonzalez E, Silliman CC, et al. Rapid thrombelastography thresholds for goal-directed resuscitation of patients at risk for massive

transfusion. The journal of trauma and acute care surgery. 2017; 82(1):114–9. [PubMed: 27805995]

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Figure 1.
Comparative Performance of Citrated Native, Citrated Kaolin and Citrated Rapid Thrombelastography for Prediction of Massive Transfusion.

Figure 2.
Flow Diagram for Patient Inclusion (n=343).

Table 1

Demographics, Injury, Physiologic, Hematology, and Outcomes for Patient Population

Demographics	Total (n=343)
Sex = Male, % (n)	78.7% (270)
Age (years), median (25–75 IQR)	32.0 (25.6–45.8)
Ethnicity	-
Caucasian, % (n)	40.5% (139)
African American, % (n)	17.8% (61)
Latino, % (n)	35.6% (122)
Unspecified, % (n)	6.1% (21)
BMI (median, 25–75 IQR)	26.0 (23.4–29.8)
Injury	-
Time of Injury to Arrival (min), median (25–75 IQR)	16 (10–24)
Blunt, % (n)	51.6% (177)
NISS, median (25–75 IQR)	18 (6–34)
GCS, median (25–75 IQR)	14 (6–15)
TBI, % (n)	19.6% (67)
Physiologic	-
SBP (mm Hg), median (25–75 IQR)	120 (91–140)
BD (meq/L), median (25–75 IQR)	- 7 (-11 – -4)
Lactate (mmol/L), median (25–75 IQR)	3.9 (2.6–6.0)
Hematology/Conventional Coagulation Assays	-
INR, median (25–75 IQR)	1.12 (1.02–1.25)
PTT (sec), median (25–75 IQR)	27.2 (24.3–30.4)
Hemoglobin (g/dL), median (25–75 IQR)	13.8 (12.2–15.4)
Platelets (10 ⁹ /L), median (25–75 IQR)	248 (195–300)
Outcomes	-
Mortality, % (n)	13.9% (48)
Survival time (hours)(25–75 IQR)	10.8 (2.8–68.3)
Transfusion (1U RBC) in 1st 24 hours, % (n)	41.4% (142)
# U RBC/6H (25–75 IQR)	5 (2–10)
MT, % (n)	16.6% (57)
# U RBC/6H (25–75 IQR)	18 (14–33)

Table 2

Receiver Operating Characteristics Association Statistics

	ROC Model	Area	Standard Error	95% Wald Confidence Limits	
<u>ACT/R</u> [*]	CR [‡] ACT	0.5984	0.0505	0.4995	0.6973
-	CN [‡] R	0.6431	0.0492	0.5467	0.7395
-	CK [§] R	0.7033	0.046	0.6131	0.7935
<u>Angle</u>	CR ANGLE	0.6859	0.0478	0.5922	0.7795
-	CN ANGLE	0.7628	0.0448	0.675	0.8507
-	CK ANGLE	0.7651	0.0459	0.6753	0.855
<u>MA</u>	CR MA	0.7955	0.0432	0.7108	0.8802
-	CN MA	0.8268	0.0408	0.7468	0.9068
-	CK MA	0.7984	0.0434	0.7133	0.8835

^{*} ACT= activated clotting time, [‡]R=reaction time, MA=maximum amplitude

[‡] CR=citrated rapid,

[‡] CN=citrated native,

[§] CK=citrated kaolin