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An evaluation of blood product utilization rates with massive transfusion protocol: Before and after thromboelastography (TEG) use in trauma

Mitchell Unruh [a], Jared Reyes [a], Stephen D. Helmer [a, b], James M. Haan [a, c, *]

[a] Department of Surgery, The University of Kansas School of Medicine–Wichita, Wichita, KS, USA
[b] Department of Medical Education, Ascension Via Christi Hospital Saint Francis, Wichita, KS, USA
[c] Department of Trauma Services, Ascension Via Christi Hospital Saint Francis, Wichita, KS, USA

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ABSTRACT

Purpose: The purpose of this study was to determine if thromboelastography (TEG) is associated with reduced blood product utilization for trauma patients undergoing massive transfusion protocol (MTP) compared to traditional coagulation tests.

Methods: A retrospective review was conducted on an intent-to-treat basis of trauma patients undergoing MTP (Pre-TEG = Period I vs. Post-TEG = Period II). Traditional coagulation tests guided transfusion during Period I (n = 20) and the intent was that TEG guided transfusions during Period II (n = 47). Blood product administration and outcomes were compared.

Results: Intent-to-treat analysis demonstrated a significant reduction in red blood cell transfusions (11 vs. 6 units, $P = 0.001$), number of patients receiving fresh frozen plasma (85.0 vs. 17.0%, $P < 0.001$), and platelets (75.0 vs. 38.3%, $P = 0.006$) in Period II. No difference was seen between Periods I and II in ICU days (7.0 vs. 11.0 days, $P = 0.073$), hospital length of stay (10.5 vs. 14.0 days, $P = 0.618$), or mortality (55.0 vs. 31.9%, $P = 0.076$).

Conclusion: Use of TEG-guided transfusion in the critically-ill trauma patient conserved blood product utilization and appears to offer similar outcomes when compared to traditional coagulation tests.

Introduction

Trauma remains a leading cause of death worldwide,[1] and trauma-related acute hemorrhagic shock with associated coagulopathy can contribute significantly to a trauma patient's morbidity and mortality. Blood loss from trauma often results in the triad of coagulopathy, hypothermia, and acidosis, further complicating resuscitation and operative control of bleeding. In instances of significant blood loss, massive transfusion protocols (MTPs) are often initiated. Most MTPs have emphasized pre-emptive resuscitation strategies aiming for administration of packed red blood cells (pRBCs), fresh frozen plasma, and platelets in ratios approximating 1:1:1 during the first 24 h following injury.[2–4] Regardless of the MTP protocol used, it is necessary to evaluate the patients coagulable state during resuscitation.

Traditional tests for assessment of coagulability include: partial thromboplastin time (PTT), prothrombin time (PT), fibrinogen level, and platelet count. Historically, these laboratory tests were developed to monitor inheritable coagulopathies, such as hemophilia, and were later adopted to monitor efficacy of anticoagulant therapy.[5] However, PT/INR and PTT have been shown to correlate poorly with bleeding risk in elective general and vascular surgeries.[6] While coagulation tests have been adopted in many protocols for the hemorrhagic trauma patient, traditional coagulation tests are done under non-physiological conditions and delay in processing often means the patient's condition has changed before the results are available to guide management.[7] In an effort to minimize test delays and unnecessary blood component transfusions, various strategies have been evaluated.

Incorporation of thromboelastography (TEG) provides surgeons with a quantitative test of the functional aspect of reversal of trauma induced coagulopathy. Visco-elastic tests, such as TEG, produce tracings that correspond to coagulation disturbances

* Corresponding author. Department of Trauma Services, Room 2514, Ascension Via Christi Hospital Saint Francis, 929 N. Saint Francis St., Wichita, KS, 67214, USA.
E-mail address: James.Haan.Research@viachristi.org (J.M. Haan).

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allowing a more 'targeted' blood component replacement approach.[8] In some trauma centers, TEG has been adopted to guide component-directed resuscitation for the massively-transfused patient which has added additional data for goal-directed resuscitations.[8] It has been hypothesized that utilizing viscoelastic assays such as TEG may more accurately reflect postinjury coagulopathy compared to the traditional coagulation assessments.[9] In previous studies comparing traditional coagulation assays vs TEG, viscoelastic assays such as TEG have been shown to reduce both mortality[9,10] and blood product utilization.[8,11] The purpose of this study was to determine if TEG is associated with reduced blood product utilization for trauma patients undergoing MTP compared to traditional coagulation tests.

Methods

Patient selection and study periods

Using the trauma registry of our American College of Surgeons verified Level I trauma center, a retrospective chart review was conducted of all trauma patients who underwent MTP activation from January 1, 2014–December 31, 2014 (Period I) and July 1, 2015–June 30, 2016 (Period II). Period I represented a time in which patient coagulability was assessed and blood product utilization was guided using traditional coagulation tests (platelets, INR, aPTT, and fibrinogen) and comprised our control group. Period II represented the period in which TEG was fully implemented as the standard for assessment of coagulopathy and comprised our comparison group. All patients underwent TEG on arrival with real-time resulting curve monitored on computers in admission bay, operating room and in the ICU. Average time to start was 10 min with follow-up based on clinician preference. Normal TEG values at our institution are: R time = 5–10 s, K time = 1–3 s, α angle = >53°, maximal amplitude (MA) = 50–100 mm, and Ly 30 = <3%. Any abnormal value; R time, K time, α angle, MA were then treated. Our institutional guideline for blood product administration based upon TEG results is as follows: R time >10 s = transfuse 2 units FFP, K time >3 s = transfuse 1 unit Cryoprecipitate, α angle <53% = transfuse 1 unit cryoprecipitate, MA < 50 mm = transfuse 1 unit platelets, LY30 > 3% = transfuse transexamic acid. While these guidelines exist, actual administration of specific products was at the discretion of the attending physician. TEG results were obtained using the TEG-5000 Analyzer (Haemonetics Corp, Stoughton, MA). We did not use patient data during the 6-month implementation interval between the two periods as TEG utilization was intermittent. We allowed this 6-month interval for transition as to allow for adoption of TEG as the primary laboratory test for evaluation of blood coagulability.

Massive transfusion protocol

In our institution, the initiation of a MTP has been at the attending physician's discretion based on a suspected need for large volume blood product resuscitation. In both study periods, when MTP was activated transexamic acid was infused in the trauma bay on arrival and at least 4 units of pRBCs, 4 units of plasma and 1 unit of platelets were made available. Initially a cooler with 4 units or pRBC's arrives immediately followed by a second cooler with thawed fresh frozen plasma and platelets within 15 min. Per the institutional protocol, the route, timing, amount, and ratio of blood product administration is left to the physician's discretion; however, the protocol does emphasize a goal ratio of 1:1 of packed red blood cells to plasma. All study patients received at least one unit of pRBC's. A MTP can be terminated at the ordering physician's discretion and must be renewed if MTP is carried beyond 24 h after initiation. Additionally, the MTP can deviate from the 1:1:1 goal if at any time during interim coagulation studies indicate (and clinically observed coagulation) FFP and platelets are not needed.

Data collection

Data collected included patient demographics, initial vital signs, measures of injury severity [Injury Severity Score (ISS), initial Glasgow Coma Scale (GCS) score], presence of clinical symptoms of hypovolemia such as tachycardia (heart rate > 90 bpm) and/or hypotension (systolic blood pressure <90 mmHg), TEG results, type of blood products transfused and number of units transfused per patient, interventions (operative interventions included major vascular procedures, thoracic operative procedures [thoracotomy, lobectomy], combined thoracic and abdominal [thoracotomy with exploratory laparotomy], abdominal operative procedures [exploratory laparotomy, hollow viscus and/or solid organ resection], combined abdominal and orthopedic operations, orthopedic operations, interventional radiology procedures, and other minor procedures [chest tube placement, bronchoscopy, central line placement, intracranial pressure monitor placement, tracheostomy, gastrostomy tube placement]), intensive care unit (ICU) admission, ICU length of stay, ventilator days, length of hospital stay, and mortality.

Data analyses

Data were evaluated by intention-to-treat analysis based on the time-period of presentation. The primary end-point was blood product utilization. As secondary outcomes, we assessed ICU admissions, ICU days, ventilator requirement, ventilator days, and mortality. As resuscitation for some patients during Period II were guided by traditional coagulation tests, we also performed an as-treated analysis to compare patients in which TEG was initiated and those patients in which TEG initiation was not found in the medical record.

For analyses, comparisons of continuous and categorical data were conducted using t tests and Chi-square analysis, respectively. For continuous variables that were not normally distributed, a Mann-Whitney *U* test was used to compare medians. All statistical tests were two-sided, and analyses were considered significant when the resultant *P* value was $\leq$0.05. All analyses were conducted using SPSS release 19.0 (IBM Corp., Armonk, New York). This study was approved for implementation by the Institutional Review Board of Ascension Via Christi Hospitals Wichita, Inc.

Results

Patient selection

A total of 81 patient medical records were retrospectively reviewed, 26 in Period I and 55 in Period II. In Period I, one of the 26 patients reviewed was excluded due to MTP being initiated at a different hospital and 4 more were excluded because MTP was never initiated but did meet our database search criteria. One additional patient was excluded for severe liver cirrhosis documented at the time of the initial trauma evaluation. In Period II, 5 of the 55 patients were excluded due to no involvement of the general surgery trauma team in a massively transfused patient, all of which were admitted to orthopedic surgery and 3 additional patients were excluded because MTP was never initiated, but they were initially identified from our data query. Thus, a total of 20 patients in Period I and 47 patients in Period II met study inclusion criteria and were the subjects of subsequent analyses.

Table 1
Patient demographics and mechanism of injury (Intent-to-treat analyses).

Parameter	Period I Number (%)	Period II Number (%)	*P* value
Number of observations	20 (29.9%)	47 (70.1%)	–
Age (y)[a]	52.3 ± 19.5	45.3 ± 17.5	0.156
Male sex	17 (85.0%)	34 (72.3%)	0.356
Race			0.378
White	17 (85.0%)	43 (91.5%)	
Black	2 (10.0%)	3 (6.4%)	
Asian	0 (0.0%)	1 (2.1%)	
Other	1 (5.0%)	0 (0.0%)	
Mechanism of injury			0.528
Blunt	17 (85.0%)	36 (76.6%)	
Penetrating	3 (15.0%)	11 (23.4%)	

[a] Mean ± SD.

Intention-to-treat analyses

Intention-to-treat analyses are displayed in Tables 1–3. Demographics (age, gender, race), mechanism of injury, and initial vitals were similar between study periods (Tables 1 and 2). Injury severity as measured by ISS, AIS values and GCS scores were also similar between study periods (Table 2). While symptoms of hypovolemia such as hypotension and tachycardia were similar between study periods, hemoglobin (9.9 vs. 11.6, $P = 0.016$) and hematocrit values (29.7 vs. 34.5, $P = 0.022$) were both higher in Period II (Table 2). Partial thromboplastin time, INR, fibrinogen, creatinine and anticoagulant use were all similar between study periods.

In Period II, there was a significant reduction in the amount of red blood cell transfusions (6 vs. 11 units, $P = 0.001$), the proportion of patients receiving fresh frozen plasma (17 vs. 85%, $P < 0.001$), and the proportion of patients receiving platelets (38.3 vs. 75.0%, $P = 0.006$) in MTP activations (Table 3). While the proportion of patients receiving platelets and fresh frozen plasma were significantly reduced in Period II, the units of platelets and fresh frozen plasma administered to patients needing them were not significantly different between Periods I and II. There was no significant study period effect on cryoprecipitate use, interventions performed, ICU admissions or ICU days, mechanical ventilation use, or hospital length of stay (14 vs. 10.5 days, $P = 0.618$); although a trend toward increased ICU days (11 vs. 7 days, $P = 0.073$), and reduced mortality (32 vs. 55%, $P = 0.076$) was observed in Period II compared to Period I.

As-treated analyses

As-treated analyses are displayed in Tables 4–6. Demographics (age, gender, race), mechanism of injury, and initial vitals were similar between patients undergoing MTP without and with use of TEG (Tables 4 and 5). Injury severity as measured by ISS, AIS values and GCS scores were also similar between study groups (Table 5). Initial hemoglobin (11.7 vs 10.5, $P = 0.056$) and initial hematocrit (35.1 vs 31, $P = 0.031$) were both higher in patients resuscitated with use of TEG (Table 5). As with the intent-to-treat analyses, PTT, INR, fibrinogen, creatinine, and anticoagulant use were all similar between study groups. Mean TEG laboratory results for patients in the TEG group were as follows: R time = 4.1 ± 2.5 s (range 2–15), K time = 2.4 ± 2.0 s (range 1.2–11), α angle = 63.2 ± 10.2° (range 31–73), MA = 56.2 ± 8.9 mm (range 42–71), and Ly30 = 2.8 ± 7.7% (range 0–37).

A TEG-directed algorithm for transfusion of blood products was associated with a significant reduction in the amount of red blood cells transfused (5 vs. 10.5 units, $P < 0.001$), the proportion of patients receiving fresh frozen plasma (3 vs. 70.6%, $P < 0.001$), and the proportion of patients receiving platelets (30.3 vs. 67.6%, $P = 0.002$) in MTP activations (Table 6). However, similar to our intent-to-treat results, the units of platelets and fresh frozen plasma administered to patients needing them were not significantly different between patients undergoing MTP with or without use of TEG. Utilization of TEG also did not significantly alter interventions performed, ICU admissions or ICU days, mechanical ventilation use, hospital length of stay (13 vs. 12.5 days, $P = 0.618$), or mortality (33.3 vs 44.1%, $P = 0.365$).

Of note, there was one transfusion outlier. This was a 55-year-old MVC patient transferred from a level-3 trauma center 2 h from our trauma center that received 7 units pRBCs, 6 units FFP, and an undetermined amount of platelets prior to arrival at our center. The patient was in shock on arrival with a positive FAST. The MTP was instituted and the patient was taken to the operating suite. Initial

Table 2
Initial vital signs, injury severity and initial laboratory values (Intent-to-treat analyses).[a]

Parameter	Period I	Period II	*P* value
Number of observations	20 (29.9%)	47 (70.1%)	–
Initial vitals			
Systolic blood pressure (mmHg)	92.1 ± 45.9	100.6 ± 37.8	0.431
Diastolic blood pressure (mmHg)	64.3 ± 35.3	67.2 ± 29.6	0.729
Heart rate (bpm)	91.3 ± 51.3	111.8 ± 38.1	0.074
Temperature (°C)	36.3 ± 0.5	36.0 ± 1.3	0.284
Injury Severity Score	25.6 ± 13.2	27.6 ± 14.1	0.586
Head/Neck AIS	0 (0–2.75)	1 (0–3)	0.488
Face AIS	0 (0–0)	0 (0–0)	0.429
Chest AIS	3 (0–3)	3 (2–3)	0.510
Abdomen AIS	2.5 (0–3.75)	2 (0–4)	0.589
Extremity AIS	2.5 (2–3)	2 (0–3)	0.784
External AIS	1 (0–1)	0 (0–1)	0.017
Glasgow Coma Scale score	9.5 (3–14.8)	14 (3–15)	0.383
Positive symptoms of hypovolemia	15 (75.0%)	41 (87.2%)	0.282
Hemoglobin (gm/dL)	9.9 ± 2.9	11.6 ± 2.5	0.016
Hematocrit (%)	29.7 ± 8.2	34.5 ± 7.2	0.022
Partial thromboplastin time (s)	34.0 (28.3–46.7)	30.9 (26.4–41.1)	0.514
International normalization ratio	1.3 (1.2–1.4)	1.2 (1.1–1.5)	0.604
Fibrinogen (mg/dL)	98.5 ± 50.6	115.1 ± 35.2	0.504
Creatinine (mg/dL)	1.1 (1.0–1.3)	1.1 (0.9–1.5)	0.854
Anticoagulation use	2 (10.0%)	2 (4.3%)	0.614

[a] Data are expressed as the number (%), mean ± SD, or median (interquartile range).

Table 3
Transfusion details and hospital outcomes (Intent-to-treat analyses).[a]

Parameter	Period I	Period II	*P* value
Number of observations	20 (29.9%)	47 (70.1%)	–
Received pRBCs	20 (100%)	47 (100%)	>0.999
pRBCs transfused (units)	11 (8–13)	6 (3–10)	0.001
Received fresh frozen plasma	17 (85.0%)	8 (17.0%)	<0.001
Units of fresh frozen plasma	4 (3–8.5)	4.5 (2–7.5)	0.588
Received platelets	15 (75.0%)	18 (38.3%)	0.006
Units of platelets	2 (1–2)	1.5 (1–3)	0.464
Received cryoprecipitate	3 (15.0%)	2 (4.3%)	0.153
Units of cryoprecipitate	2 (1 - n/a)	1 (1–1)	0.400
Interventions performed			0.716
Vascular	0 (0.0%)	1 (2.1%)	
Thoracic	1 (5.0%)	3 (6.4%)	
Combined thoracic/abdominal	1 (5.0%)	7 (14.9%)	
Abdominal	7 (35.0%)	13 (27.7%)	
Combined abdominal/Orthopedic	0 (0.0%)	4 (8.5%)	
Orthopedic repairs	5 (25.0%)	10 (21.3%)	
Interventional radiology	0 (0.0%)	1 (2.1%)	
Minor procedures	5 (25.0%)	6 (12.8%)	
None	1 (5.0%)	2 (4.3%)	
Intensive care unit admission	19 (95.0%)	41 (87.2%)	0.665
Intensive care unit days	7.0 (3.0–14.0)	11.0 (4.0–22.0)	0.073
Mechanical ventilation	18 (90.0%)	41 (87.2%)	>0.999
Ventilator days	5.5 (2.0–10.0)	9.0 (2.0–15.5)	0.350
Hospital length of stay (d)	10.5 (1.5–23.5)	14 (6–31)	0.618
Mortality	11 (55.0%)	15 (31.9%)	0.076

[a] Data are expressed as the number (%) or median (interquartile range).

exploratory laparotomy resulted in distal splenectomy, small bowel resection, over sewing of mesenteric bleeding vessels, left diagram repair, followed by anterolateral thoracotomy with ligation of intercostal arteries and aortic packing. Patient also underwent orthopedic debridement and external fixation of the pelvis. He was then transported to the ICU in shock and was stabilized and on later imaging was noted to have subarachnoid hemorrhage and subdural hematoma. On second look laparotomy no further ischemia was observed, but the patient had elevated intracranial pressure. The patient had a very poor prognosis and family elected comfort care. The MTP continued for 24 h in order to delineate extent of injury and allow family travel time to reach our trauma center.

Subset analysis was conducted for blunt and penetrating injury patients with regards to blood product use (Table 7). Patterns of use of blood products for the blunt and penetrating populations were similar to one another and in concordance with that seen in the overall population, although it must be noted that there were only 14 patients that suffered penetrating injury and only 4 of these were in the group treated using traditional coagulation tests to guide blood product administration.

Comments

Rationale for use of TEG to direct MTP

Patients undergoing transfusion of blood products have been shown to have increased morbidity and mortality when excessive or inappropriate transfusions have been administered.[12–14] Because of the proven deleterious effects of administering blood products to patients various strategies have been employed to minimize transfused blood products. Previous studies have demonstrated mixed outcomes on the effectiveness of TEG utilization in the trauma patient.[2,9,11] However, TEG-directed resuscitation of trauma patients requiring massive transfusion has been shown to offer improved mortality,[11] conservation of blood product transfusions,[8,11] and overall reduced cost.[8]

TEG associated effect on red blood cell transfusions

Our study was a small, single-institution study that demonstrated a significant reduction in the volume of red blood cells transfused after TEG-directed therapy was implemented. On an as-treated basis, we documented a 52.4% decrease in the volume of red blood cells administered when using TEG to guide resuscitation which is similar to the 46.8% reduction observed by Mohamed et al.[8] Unlike Gonzalez et al.[11] who found a similar amount of red blood cells transfused, our results demonstrated fewer red blood cell units transfused with TEG. While red blood cell transfusion is not specifically directed by TEG, alleviation of trauma-induced coagulopathy and improved hemostasis would be reflected in overall blood product utilization, coagulopathy reversal, and less total red blood cell units transfused.

Our study population presented with lower hemoglobin values (9.9 vs 11.6 gm/dL) and hematocrit values (29.7 vs 34.5%) in Period I as compared to Period II where TEG was being employed. It is only natural that endpoint-resuscitation would result in more red blood cell transfusions to correct this more severe anemia observed upon presentation in Period I patients. It is believed that TEG allowed for the involved clinicians to be able to discontinue resuscitation once a

Table 4
Patient demographics and mechanism of injury (As-treated analyses).

Parameter	MTP without TEG Number (%)	MTP with TEG Number (%)	*P* value
Number of observations	34 (50.7%)	33 (49.3%)	–
Age (y)[a]	49.9 ± 17.9	44.8 ± 18.5	0.259
Male sex	29 (85.3%)	22 (66.7%)	0.074
Race			0.278
White	29 (85.3%)	31 (93.9%)	
Black	4 (11.8%)	1 (3.0%)	
Asian	0 (0.0%)	1 (3.0%)	
Other	1 (2.9%)	0 (0.0%)	
Mechanism of injury			0.077
Blunt	30 (88.2%)	23 (69.7%)	
Penetrating	4 (11.8%)	10 (30.3%)	

[a] Mean ± SD.

Table 5
Initial vital signs, injury severity and initial laboratory values (As-treated analyses).[a]

Parameter	MTP without TEG	MTP with TEG	*P* value
Number of observations	34 (50.7%)	33 (49.3%)	–
Vital signs			
Systolic blood pressure (mmHg)	103.6 ± 44.3	92.5 ± 35.4	0.262
Diastolic blood pressure (mmHg)	68.9 ± 33.8	63.8 ± 28.4	0.507
Heart rate (bpm)	102.2 ± 45.4	109.4 ± 41.0	0.498
Temperature (°C)	36.3 ± 0.5	35.9 ± 1.4	0.186
Injury Severity Score	26.7 ± 14.7	27.2 ± 13.0	0.903
Head/Neck AIS	0.5 (0–3)	1 (0–3)	0.251
Face AIS	0 (0–0)	0 (0–1)	0.240
Chest AIS	3 (0–3)	3 (2.5–3.5)	0.087
Abdomen AIS	2 (0–4)	2 (0–4)	0.169
Extremity AIS	2 (2–3)	2 (0–3)	0.389
External AIS	1 (0–1)	0 (0–1)	0.233
Glasgow Coma Scale score	13 (3–15)	13 (3–15)	0.512
Positive symptoms of hypovolemia	27 (79.4%)	29 (87.9%)	0.350
Hemoglobin (gm/dL)	10.5 ± 2.7	11.7 ± 2.5	0.056
Hematocrit (%)	31.0 ± 7.7	35.1 ± 7.4	0.031
Partial thromboplastin time (s)	33.4 (28.3–43.6)	30.9 (26–52.2)	0.571
International normalization ratio	1.3 (1.1–1.5)	1.2 (1.1–1.4)	0.240
Fibrinogen (mg/dL)	104.1 ± 49.1	116.8 ± 26.0	0.583
Creatinine (mg/dL)	1.2 (1.0–1.5)	1.0 (.9–1.4)	0.067
Anticoagulation use	3 (8.8%)	1 (3.0%)	0.614

[a] Data are expressed as the number (%), mean ± SD, or median (interquartile range).

normal TEG was observed instead of pre-emptive transfusion with a 1:1:1 ratio despite a possibly corrected coagulopathy.

TEG associated effects on other blood product use

Utilizing TEG, the clinicians transfused significantly fewer patients with FFP and platelets in our study. Initiation of FFP transfusion was quite rare when TEG was utilized; in fact during Period II only one patient received FFP via TEG-directed resuscitation. Our findings compare favorably to those of Mohamed et al.[8] and Tapia et al.,[9] who also reported a significant reduction in FFP usage when TEG was used to guide coagulopathy correction rather than adopting a pre-emptive 1:1:1 protocol strategy. However, unlike Mohamed's findings, we observed a significant reduction in platelet transfusions when TEG was utilized.[8] Like Tapia et al.,[9] when FFP or platelets were required, the units of FFP and/or platelets transfused was similar regardless of whether resuscitation was guided by TEG or not. Similar to Mohamed et al.,[8] our cryoprecipitate administration rate with and without TEG was so low, we cannot make strong conclusions regarding those findings.

TEG associated effects on hospital outcomes

In our small study, hospital length of stay was similar for patients who underwent TEG-directed resuscitations and conventional coagulation assay resuscitations. Our finding contrasts with Mohamed et al.[8] who reported a 10-day length of stay reduction with implementation of TEG-guided resuscitations. Likewise, we

Table 6
Transfusion details and hospital outcomes (As-treated analyses).[a]

Parameter	MTP without TEG	MTP with TEG	*P* value
Number of observations	34 (50.7%)	33 (49.3%)	–
Received pRBCs	34 (100%)	33 (100%)	>0.999
pRBCs transfused, units	10.5 (7.8–14)	5 (3–7.5)	<0.001
Received fresh frozen plasma	24 (70.6%)	1 (3.0%)	<0.001
Units of fresh frozen plasma	4 (2.3–8)	23 (23–23)	0.080
Received platelets	23 (67.6%)	10 (30.3%)	0.002
Units of platelets	2 (1–3)	1 (1–2.3)	0.237
Received cryoprecipitate	4 (11.8%)	1 (3.0%)	0.356
Units of cryoprecipitate	1.5 (1–2)	1 (1–1)	0.800
Interventions performed			0.841
Vascular	0 (0.0%)	1 (3.0%)	
Thoracic	1 (2.9%)	3 (9.1%)	
Combined thoracic/abdominal	5 (14.70%)	3 (9.1%)	
Abdominal	11 (32.4%)	9 (27.3%)	
Combined abdominal/Orthopedic	2 (5.9%)	2 (6.1%)	
Orthopedic repairs	7 (20.6%)	8 (24.2%)	
Interventional radiology	1 (2.9%)	0 (0.0%)	
Minor procedures	5 (14.7)	6 (18.2%)	
None	2 (5.9%)	1 (3.0%)	
Intensive care unit admission	30 (88.2%)	30 (90.9%)	>0.999
Intensive care unit days	9 (1.8–18)	8 (2.5–17.5)	0.818
Mechanical ventilation	30 (88.2%)	29 (87.9%)	>0.999
Ventilator days	5.5 (1.8–12)	5 (1–14)	0.825
Hospital length of stay (d)	12.5 (2.5–35)	13 (4.5–23.5)	0.618
Mortality	15 (44.1%)	11 (33.3%)	0.365

[a] Data are expressed as the number (%) or median (interquartile range).

Table 7
Transfusion details by mechanism of injury (As-treat analyses).[a]

Parameter	Blunt mechanism			Penetrating mechanism		
	MTP without TEG	MTP with TEG	*P* value	MTP without TEG	MTP with TEG	*P* value
Number of observations	30 (100%)	23 (100%)	–	4 (100%)	10 (100%)	–
Received fresh frozen plasma	20 (66.7%)	1 (4.3%)	<0.001	4 (100%)	0 (0.0%)	<0.001
Units of fresh frozen plasma	5.6 ± 4.9	23.0 ± –	–	5.8 ± 2.6	–	–
Received platelets	19 (63.3%)	6 (26.1%)	0.007	4 (100%)	4 (40.0%)	0.040
Units of platelets	2.0 ± 1.1	2.2 ± 1.6	0.768	3.5 ± 1.9	1.3 ± 0.5	0.265
Received cryoprecipitate	4 (13.3%)	1 (4.3%)	0.267	0 (0.0%)	0 (0.0%)	–
Units of cryoprecipitate	1.5 ± 0.6	1.0 ± –	–	–	–	–

[a] Data are expressed as the number (%) or mean ± SD.

did not experience a change in our ICU days with TEG implementation, whereas Mohamed et al.[8] observed a 2.3-day reduction in ICU days with utilization of TEG. Unlike Gonzalez et al.,[10] who reported a 54% mortality reduction, we did not observe a statistically significant mortality reduction with use of TEG; however, we saw a trend toward improved mortality which may have become statistically significant if we had achieved a larger study size.

Limitations to implementation of TEG-directed MTPs

More robust workflow algorithms and transfusion algorithms need to be implemented to standardize the collection, consideration, and implementation of the TEG data into trauma patient's resuscitation. Surgeons have been wary of changes to standard assessments of coagulability because the implications are significant and adjusting to differences in how the values are reported takes time. TEG results at our institution have been somewhat difficult to implement into our routine electronic health record and TEG results report various steps over the course of 30–60 min. While resuscitating a critically-ill trauma patient, it is often impractical to await the completed TEG data before acting upon the information gained early in the TEG tracing. Clinical interventions such as FFP transfusion and platelet transfusions can be completed before the TEG has finished its entire study. Dynamic reporting of the TEG data has yet to be effectively implemented across our entire health-system and thus TEG utilization has been sporadic and inconsistent.

Limitations

Our study is limited by its retrospective design. Inconsistency in clinical charting contributed to areas of missing data, as data were collected prior to knowledge of this study. Also, as the study data were collected retrospectively, clinical decision-making dictated timing of lab orders and what labs were ordered, rather than how and when labs would have been ordered in a prospective study setting, and as such may have affected the results obtained. Our sample size was likely too small to analyze the confounding variables such as mechanism of injury, extent of injury, and extent of hemorrhage of an unpredictable trauma patient. The ability to determine confounding influence of clinical variables was also limited by the retrospective nature of this study. Large randomized prospective trials with strict adherence to transfusion algorithms would be best suited to obtain generalizable conclusions to evaluate the effect of TEG implementation on clinical outcomes and blood product utilization.

Conclusions

Use of TEG-directed transfusion in the critically-ill trauma patient conserved blood product utilization and appears to offer similar outcomes when compared to traditional coagulation tests. Further investigation on how utilization of TEG affects long-term outcomes and transfusion rates of red blood cells, fresh frozen plasma, platelets, and cryoprecipitate is needed.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjsurg.2019.08.027.

References

1. Hess JR, Lindell AL, Stansbury LG, et al. The prevalence of abnormal results of conventional coagulation tests on admission to a trauma center. *Transfusion*. 2009;49:34-39.
2. Afshari A, Wikkelsø A, Brok J, et al. Thrombelastography (TEG) or thromboelastometry (ROTEM) to monitor haemotherapy versus usual care in patients with massive transfusion. *Cochrane Database Syst Rev*. 2011;3:CD007871.
3. Holcomb JB, Tilley BC, Baraniuk S, 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. *J Am Med Assoc*. 2015;313:471–482.
4. Holcomb JB, Zarzabal LA, Michalek JE, et al. Increased platelet:RBC ratios are associated with improved survival after massive transfusion. *J Trauma*. 2011;71(2 Suppl 3):S318–S328.
5. Owen CA. Historical account of tests of hemostasis. *Am J Clin Pathol*. 1990;93:S3–S8.
6. Eckman MH, Erban JK, Singh SK, Kao GS. Screening for the risk for bleeding or thrombosis. *Ann Intern Med*. 2003;138:W15–W24.
7. Marsden NJ, Van M, Dean S, et al. Measuring coagulation in burns: an evidence-based systematic review. *Scars Burn Heal*. 2017;3, 2059513117728201.
8. Mohamed M, Majeske K, Sachwani GR, et al. The impact of early thromboelastography directed therapy in trauma resuscitation. *Scand J Trauma Resusc Emerg Med*. 2017;25:99.
9. Tapia NM, Chang A, Norman M, et al. TEG-guided resuscitation is superior to standardized MTP resuscitation in massively transfused penetrating trauma patients. *J Trauma Acute Care Surg*. 2013;74:378–385.
10. Gonzalez E, Moore EE, Moore HB. Management of trauma-induced coagulopathy with thrombelastography. *Crit Care Clin*. 2017;33:119–134.
11. Gonzalez E, Moore EE, Moore HB, et al. Goal-directed hemostatic resuscitation of trauma-induced coagulopathy: a pragmatic randomized clinical trial comparing a viscoelastic assay to conventional coagulation assays. *Ann Surg*. 2016;263:1051–1059.
12. Napolitano LM. Blood transfusion and the lung: first do no harm? *Crit Care*. 2011;15:152.
13. Clevenger B, Mallett SV. Transfusion and coagulation management in liver transplantation. *World J Gastroenterol*. 2014;20:6146–6158.
14. Pandey S, Vyas GN. Adverse effects of plasma transfusion. *Transfusion*. 2012;52(Suppl 1):65S–79S.