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A Pilot Study of Viscoelastic Monitoring in Pediatric Trauma: Outcomes and Lessons Learned

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Abstract

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Background:

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Examine the characteristics and outcomes of pediatric trauma patients at risk for coagulopathy following implementation of viscoelastic monitoring.

Materials and Methods:

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Injured children, aged <18 years, from September 7, 2014, to December 21, 2015, at risk for trauma-induced coagulopathy were identified from a single, level-1 American College of Surgeons verified pediatric trauma center. Patients were grouped by coagulation assessment: no assessment (NA), conventional coagulation testing alone (CCT), and conventional coagulation testing with rapid thromboelastography (rTEG). Coagulation assessment was provider preference with all monitoring options continuously available. Groups were compared and outcomes were evaluated including blood product utilization, Intensive Care Unit (ICU) utilization, duration of mechanical ventilation, and mortality.

Results:

A total of 155 patients were identified (NA = 78, CCT = 54, and rTEG = 23). There was no difference in age, gender, race, or mechanism. In practice, rTEG patients were more severely injured, more anemic, and received more blood products and crystalloid ($P < 0.001$). rTEG patients also had increased mortality with fewer ventilator and ICU-free days. Multivariate logistic regression and covariance analysis indicated that while rTEG use was not associated with mortality, it was associated with increased use of blood products, duration of mechanical ventilation, and ICU length of stay.

Conclusions:

Viscoelastic monitoring was infrequently performed, but utilized in more severely injured patients. Well-designed prospective studies in patients at high risk of coagulopathy are needed to evaluate goal-directed hemostatic resuscitation strategies in children.

Keywords: Coagulopathy, hemostatic resuscitation, pediatric trauma, rapid thromboelastography, viscoelastic monitoring

Introduction

Severely injured children are at risk for trauma-induced coagulopathy (TIC) that has been shown to increase morbidity and mortality.[1,2] Damage control resuscitation principles including early surgical hemostasis, permissive hypotension, balanced blood product or hemostatic resuscitation, avoidance of hemodilution, and the prevention and correction of acidosis, hypothermia and hypocalcemia have evolved to manage TIC.[1,3] These same strategies have been used to improve outcomes in critically ill adult trauma patients.[4,5,6]

Implementation of goal-directed hemostatic resuscitation requires rapid and accurate assessment of hemostasis. Viscoelastic monitoring using thromboelastography (TEG) and rotational thromboelastometry (ROTEM) have been shown, primarily in adults, to be timelier and more accurate for the assessment of TIC than conventional coagulation tests (CCT) such as platelet count, fibrinogen level, international normalized ratio (INR), prothrombin time (PT), and partial thromboplastin time (PTT).[7,8,9] Rapid TEG (rTEG), in particular, has been shown in adult large prospective observational and prospective randomized trials to be a timely technique for goal-directed hemostatic resuscitation that results in improved morbidity and mortality.[10,11,12] Likewise, when used with children, rTEG has been shown to accurately assess TIC and predict the need for emergent interventions.[9] It should be noted, however, that a recent Cochrane review showed significant variation in the ability of rTEG and ROTEM to accurately assess TIC.[13]

Our institution recently adopted rTEG to assess TIC in our pediatric trauma patients. The purpose of this study is to describe and evaluate our early experience with viscoelastic monitoring in pediatric trauma patients at risk for coagulopathy.

Materials and Methods

After a review of adult and pediatric trauma resuscitation literature and current practice, a viscoelastic monitoring strategy utilizing rTEG was designed and implemented for pediatric trauma patients at risk for TIC. Patients deemed at risk for TIC included those with an admission Glasgow Coma Score (GCS) <14 or penetrating trauma to the torso ("t-shirt/boxer shorts" distribution) and were to receive CCT and rTEG.

Didactic education and real-time coaching were provided for all trauma team providers (emergency medicine and pediatric surgery faculty and fellows) relating to rTEG assessment and implications for clinical management (transfusion and pharmacologic therapy). To maximize process flow and efficiency, citrated blood samples were evaluated in the hospital central laboratory. The rTEG results were made available in the trauma bay immediately through remote graphical software. In addition, all results were available in the electronic medical record.

The study was a noninterventional, prospective, observational study approved by the Internal Review Board at Washington University in St Louis School of Medicine. We included traumatically injured children, aged <18 years, at risk for TIC presenting to our Level-1 Pediatric Trauma Center from September 7, 2014, to December 21, 2015. Patients were excluded from analysis if they were discharged from the emergency room, died within 24 h, or had nonsurvivable traumatic brain injury (as determined by the attending neurosurgeon). Demographic data points included age, gender, race, weight, injury mechanism, and severity. Abstracted clinical data included: admission vital signs, admission GCS, initial hematocrit and platelet counts, and initial coagulation parameters (INR, PTT, PT, and rTEG). We abstracted the volumes of transfused red blood cells (RBCs), fresh frozen plasma (FFP), platelet, and crystalloid transfusion that the patients received at the 6 and 24 h time point from admission. Finally, we abstracted the patients' outcome data (ventilator days, ventilator-free days, Intensive Care Unit [ICU], length of stay [LOS], hospital LOS, and 30-day mortality). Blood product and crystalloid volumes were normalized for weight (ml/kg).

Patients were grouped by the coagulation assessment tests performed by the pediatric trauma team on presentation to the trauma bay: no assessment (NA), traditional/CCT, and CCT with rTEG. Final coagulation assessment and resuscitation strategy was at the discretion of the clinical trauma team that included the pediatric surgery attending and emergency medicine faculty.

We assessed the differences in demographics (age, gender, race, weight, and mechanism of injury), clinical variables (EU vital signs, EU-GCS, initial coagulation parameters, injury severity, 6 and 24 h blood product and crystalloid transfusion volumes), and outcome data in each of the study groups. Coagulation assessment groups were compared by contingency tables with Fisher's exact test and by one-way analysis of variance. To determine the independent association between coagulation assessment groups and outcomes we adjusted, *a priori*, for age, gender, race, weight, ISS, RTS, GCS in multivariate logistic regression models and with analysis of covariance. Statistical analyses were performed using SAS 9.4 (Cary, NC).

Results

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There were 155 injured children that met inclusion criteria. Seventy-eight patients had no coagulation assessment (NA) and fifty-four patients had conventional assessment (CCT). Twenty-three received rTEG representing 30% (23/97) of patients receiving hemostasis

assessment (CCT + rTEG) and 15% (23/155) of the total study population. Demographic, injury, and hemostatic characteristics are shown in Table 1. The average age was 7 years with a male predominance of 69.7%. Blunt force trauma accounted for 85.7% of these patients. The overall mortality was 3.9%. The rTEG group was more severely injured as assessed by ISS and RTS, had a lower GCS, were more anemic, and had a higher PTT.

Table 2 displays the unadjusted 6 and 24 hr crystalloid and blood product administered weight-adjusted volumes. Overall, rTEG patients received significantly more RBC, FFP, PLT, total blood products, crystalloid, and total fluid volume when compared to the CCT group at 6 and 24-h. Table 3 displays the unadjusted values for mortality, ventilator days, ICU and hospital LOS, and ventilator and ICU-free days between the groups. rTEG patients showed an increased 30-day mortality as well as increased ventilator days and ICU LOS with lower ventilator and ICU-free days. There was no significant difference in hospital LOS among the groups.

Adjusted analysis of administered fluid volume showed that in the first 6 h, rTEG patients received significantly more RBC, PLT, and colloids with no significant difference seen in the FFP, total blood product, and total volume transfused [Table 4]. There was no difference in mortality comparing the rTEG and CCT groups after adjusting age, gender, race, weight, and injury severity [Table 5].

Discussion

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Early recognition and management of TIC have become an essential principle of traumatic resuscitation. TIC is associated with significantly increased morbidity including higher transfusion requirements, greater incidence of multi-organ dysfunction syndrome, thromboembolism, longer ICU and hospital LOS, and longer ventilator days.[14,15,16] Conventional coagulation tests (PT, INR, PTT, and PLT) are suboptimal for diagnosing and characterizing TIC.[17] Furthermore, with result times that average 60 min, conventional tests do not provide timely results for the severely injured trauma patient who requires immediate, life-saving intervention.[7,17,18]

Viscoelastic monitoring techniques such as rTEG and ROTEM have been developed to fill this clinical deficiency. In contrast to CCT, in a large sample of severely injured adult trauma patients, rTEG has accurately identified TIC while providing rapid, actionable data to guide blood product transfusion therapy.[7,8,17] A recent, randomized, prospective trial in adult trauma patients with activated massive transfusion protocols showed a survival benefit when patients were managed with a rTEG-based transfusion protocol.[10] The American College of Surgeons Committee of Trauma in their resources for optimal care of the injured patient recommends that TEG be available at Level I and II trauma centers.[19]

With this information in hand, our trauma program undertook a review of existing literature and in an effort to improve the quality of our trauma resuscitation, initiated a viscoelastic monitoring program using rTEG. A previous review of our trauma population led to a practice of assessing for TIC using CCT in patients presenting to the emergency unit with a GCS <14 or penetrating trauma to the torso (“t-shirt/boxer shorts” distribution). These criteria were designed to “over-triage,” but it is in this at-risk population where we felt that viscoelastic monitoring would be most appropriate. In collaboration with laboratory medicine, we adopted rTEG as our viscoelastic monitoring tool to assess for TIC. We developed rTEG criteria based on expert consensus, a comprehensive review of the adult trauma literature as well as the single center, retrospective studies that have been published on children. Viscoelastic monitoring

is well established at our institution in both the operating room and ICU. Our implementation strategy included didactic education and real-time coaching of emergency medicine and pediatric surgery faculty and fellows – the leaders of all trauma resuscitations. Ultimately, final coagulation assessment and resuscitation strategy are left to the discretion of the clinical trauma team.

The results of this study reflect our institution's initial experience with viscoelastic monitoring. We found that despite our efforts to educate providers, rTEG was performed in only 15% of patients deemed “at risk” for TIC. This result is not surprising. Our entry criteria were designed to be overly sensitive; many of the “at risk” patients, when assessed in the trauma bay do not meet an “eye test” definition of critically ill and would not warrant assessment of coagulopathy. For example, a patient with an upper lateral thigh “through-and-through” firearm injury who presents with a normal heart rate and a normal blood pressure and without notable blood loss or hard signs of vascular injury would technically meet the “at risk” definition for TIC but would likely not benefit from additional testing. In the absence of a strict protocol, this reflects responsible clinical judgment and appropriate utilization of resources. Unsurprisingly, patients that did undergo rTEG assessment of coagulopathy presented with more severe injuries. This reflects the need for more comprehensive hemostatic data to direct medical therapy for the more critically ill population. Unfortunately, at this time, the pediatric trauma community lacks specific, robust, validated criteria for early identification of traumatic coagulopathy. In addition, in children, the impact of age and developmental stage on admission, vital signs, and the unique physiologic age-dependent characteristics makes established adult predictive systems less reliable.

Unfortunately, only 30% of patients whom the trauma team felt needed coagulation assessment (CCT + rTEG groups) had an rTEG performed. This underutilization may be related to an inadequately designed implementation strategy. It could also reflect a failure to assess provider knowledge of the potential benefits of viscoelastic monitoring and subsequent inadequate education of how to interpret and apply the rTEG results. In addition, the underutilization may be related to systematic deficiencies in communication or the lack of ordering of the rTEG (e.g., the providers meant to obtain an rTEG but only CCT were ordered). These and other potential etiologies are under current investigation. It is our intention to identify opportunities for additional education and design an appropriate process improvement strategy to increase rTEG utilization.

In this series, rTEG patients were more severely injured, received larger volumes of blood product and crystalloids during their initial resuscitation, and not surprisingly had poor outcome with respect to the duration of mechanical ventilation, ICU LOS, and mortality. These results would be expected given the increased resource utilization and morbidity anticipated with patients with higher trauma severity and may represent selection bias. The increase in mortality lost significance when we controlled for injury severity in addition to demographics such as age, gender, race, and weight. The increase in infused volume of blood products and crystalloids persisted in the covariance analysis in addition to increased duration of mechanical ventilation and length of ICU stay. Increased duration of mechanical ventilation and ICU LOS may be due to confounding variables that were not identified in this study. However, the recognition of increased infused blood product and crystalloid volumes stand in contrast to recent adult studies which have shown viscoelastic monitoring directed resuscitation strategies led to a reduction in administered fluid volumes.[10,11,12] Unfortunately, it is difficult to interpret these results given the absence of a strict rTEG-based resuscitation strategy and the limitation of the study design to assess how rTEG was clinically used by providers to direct resuscitation.

Additional limitations of this study include small patient population and potentially unaccounted confounding variables. For example, shock as represented by the base deficit was inconsistently obtained on admission. By consistently obtaining this data, we will be able to further risk stratify and control for injury severity in our patient population using the BIG score (base deficit + [2.5 × INR] + [15-GCS]).[20] This small sample size also limited our ability to perform propensity matching or extensive multi-regression studies. We also were unable to ascertain the role which rTEG played in trauma resuscitation. Future studies will be multi-institutional and will include a trauma team provider assessment of the role of viscoelastic monitoring in the resuscitation of critically injured pediatric patients. In addition, it will include criteria to better define the population at most risk of TIC. Well defined, goal-directed hemostatic resuscitation protocols in children must be developed to appropriately evaluate the role of viscoelastic monitoring in children.

Conclusions

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In summary, this study highlights some of the challenges and limitations in viscoelastic monitoring implementation within a single pediatric trauma center. Education, proper patient identification, and appropriate utilization of rTEG are paramount for successful goal-directed hemostatic resuscitation.

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Conflicts of interest

There are no conflicts of interest.

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Figures and Tables

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Table 1

Demographics and baseline hemodynamics and coagulation values

	No assessment	CCT only	rTEG	*P*
n	78	54	23	
Age (years)	6.8±0.66	9.2±0.79	8.0±1.21	NS
Male (%)	68	70	74	NS
Caucasian (%)	59	72.2	69.6	NS
AA (%)	39.7	20.4	30.4	NS
Weight (kg)	30.1±2.8	41.3±3.4	36.4±5.2	0.04
Blunt trauma (%)	87.2	86.8	78.2	NS
NAT (%)	6.8	7.4	4.4	NS
ISS	9.4±1.21	16±1.45	27.65±2.22	<0.001
RTS	11.4±0.27	10.3±0.32	7±0.47	<0.001
EU HR	118.9±3.59	111.4±4.31	124.6±6.76	NS
EU RR	25.7±1.06	24.1±1.28	27.4±2.01	NS
EU SBP	112±2.3	113±2.8	109±4.3	NS
EU GCS	14.4±0.42	11.6±0.50	7.4±0.77	<0.001
PT	NA	16±0.63	17.4±1	NS
INR	NA	1.74±0.5	1.37±0.79	NS
PTT	NA	29.1±1.7	37.1±2.7	0.014
HCT	35.2±0.7	34.9±0.73	32±1.1	0.041
PLT	312.1±14	391±14.9	281±22	NS
rTEG				
ACT (s)	NA	NA	225±112	NA
R (min)	NA	NA	2.5±0.73	NA
K (min)	NA	NA	1.47±0.12	NA
α angle (°)	NA	NA	91±22	NA

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Table 2

Crystalloids and blood products received at 6 and 24 h

	No assessment	CCT	rTEG	*P*
6 h blood product and crystalloid volumes				
RBC (ml/kg)	0.18±1.25	3.38±1.50	15.54±2.30	<0.001
FFP (ml/kg)	NA	1.47±0.91	7.63±1.38	<0.001
PLT (ml/kg)	NA	0.08±0.28	2.67±0.43	<0.001
Total blood product (ml/kg)	0.18±2.72	6.22±3.27	32.22±5.01	<0.001
Crystalloid (ml/kg)	24.92±3.56	30.2±4.27	64.69±6.55	<0.001
Colloid (ml/kg)	NA	0.3±0.38	1.45±0.59	NS
Total volume (ml/kg)	25.1±5.63	36.78±6.77	98.35±10.37	<0.001
24 h blood product and crystalloid volumes				
RBC (ml/kg)	0.41±1.36	4.51±1.63	17.89±2.50	<0.001
FFP (ml/kg)	NA	2.22±1.06	9.07±1.64	<0.001
PLT (ml/kg)	NA	0.14±0.29	2.52±0.44	<0.001
Total blood product (ml/kg)	0.40±2.88	8.24±3.46	36.1±5.31	<0.001
Crystalloid (ml/kg)	68.37±5.43	71.71±6.52	137.29±10	<0.001
Colloid (ml/kg)	NA	1.71±0.95	1.75±1.46	NS
Total volume (ml/kg)	69.37±7.34	81.66±8.82	175.17±13.52	<0.001

Depicts the unadjusted volumes of crystalloid and blood products received at 6 and 24 h, respectively. CCT: Conventional coagulation tests, rTEG: Rapid thromboelastography, RBC: Red blood cell, FFP: Fresh frozen plasma, PLT: Platelet, NS: Not significant, NA: Not available

Table 3

Univariate analysis of clinical outcomes

	Outcomes			
	No assessment	CCT	rTEG	*P*
Mortality (%)	1.28	1.92	18.18	<0.001
Ventilator days	0.23±0.37	1.39±0.44	5.087±0.68	<0.001
ICU LOS	0.87±0.55	3.19±0.66	7.52±1.01	<0.001
Hospital LOS	4.65±3.63	15.7±4.37	16.8±6.70	NS
Ventilator-free days	29.77±0.36	28.61±0.43	25.00±0.66	<0.001
ICU-free days	29.14±0.51	26.85±0.62	22.70±0.96	<0.001

Depicts the unadjusted values for mortality, ventilator days, ICU and hospital LOS, and ventilator and ICU-free days. ICU: Intensive Care Unit, LOS: Length of stay, CCT: Conventional coagulation tests, rTEG: Rapid thromboelastography, NS: Not significant

Table 4

Adjusted analysis of crystalloid and blood product administration at 6 and 24 h

	No assessment	CCT	rTEG	*P*
6 h blood product and crystalloid volumes				
RBC (ml/kg)	2.5±2.2	4.2±2.1	10.2±3.1	0.05
FFP (ml/kg)	1.4±1.4	1.9±1.3	3.8±1.9	NS
PLT (ml/kg)	0.26±0.45	0.42±0.43	2.7±0.63	<0.001
Total blood product (ml/kg)	6.1±4.8	7.2±4.6	17.0±6.8	NS
Crystalloid (ml/kg)	33.7±6.4	35.4±6.1	50±8.9	NS
Colloid (ml/kg)	−0.167±0.633	0.48±0.61	2.1±0.88	0.04
Total volume (ml/kg)	39.6±9.8	43.1±9.4	69.1±13.7	NS
24 h blood product and crystalloid volumes				
RBC (ml/kg)	2.98±2.45	5.29±2.35	11.55±3.42	0.05
FFP (ml/kg)	1.54±1.66	2.69±1.59	4.67±2.32	NS
PLT (ml/kg)	0.23±0.46	0.49±0.44	2.49±0.64	<0.001
Total blood product (ml/kg)	6.70±5.16	9.23±4.94	19.18±7.21	NS
Crystalloid (ml/kg)	78.97±9.62	79.2±9.21	116.68±13.42	0.01
Colloid (ml/kg)	−0.12±1.58	1.76±1.51	2.14±2.21	NS
Total volume (ml/kg)	85.55±12.80	90.26±12.26	138.0±17.87	0.01

Depicts volumes of crystalloid and blood products received at 6 and 24 h, respectively. This analysis was controlled for age, gender, race, weight, ISS, RTS, and GCS. RBC: Red blood cells, FFP: Fresh frozen plasma, PLT: Platelets, CCT: Conventional coagulation tests, rTEG: Rapid thromboelastography, GCS: Glasgow Coma Score, ISS: Injury severity score, RTS: Revised trauma score, NS: Not significant

Table 5

Adjusted analysis of clinical outcomes

	Outcomes			
	No assessment	CCT	rTEG	*P*
Ventilator days	1.33±0.65	1.04±0.62	3.55±0.91	0.014
ICU LOS	2.21±0.88	2.26±0.84	5.56±1.23	0.013
Ventilator-free days	28.7±0.63	28.96±0.60	26.53±0.87	0.014
ICU-free days	27.88±0.84	27.78±0.80	24.64±1.17	0.013

Depicts adjusted values for ventilator days, ICU days, and ventilator and ICU-free days when controlling for age, gender, race, weight, ISS, RTS, and GCS. ICU: Intensive Care Unit, LOS: Length of stay, CCT: Conventional coagulation tests, rTEG: Rapid thromboelastography, GCS: Glasgow Coma Score, ISS: Injury severity score, RTS: Revised trauma score