Evaluation of military trauma system practices related to damage-control resuscitation

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BACKGROUND: The Joint Theater Trauma System (JTTS) was developed with the vision that every soldier, marine, sailor, and airman injured on the battlefield would have the optimal chance for survival and maximum potential for functional recovery. In this analysis, we hypothesized that information diffusion through the JTTS, via the dissemination of clinical practice guidelines and process improvements, would be associated with the acceptance of evidence-based practices and decreases in trauma practice variability.

METHODS: The current evaluation was designed as a single time-series quasi-experimental study as a preanalysis and postanalysis relative to the implementation of clinical practice guidelines and process improvement interventions. Data captured from patients admitted to hospital-level (Level III) military treatment facilities in Iraq and Afghanistan from 2003 to 2010 were retrospectively analyzed from the Joint Theater Trauma Registry (JTTR) to determine the potential impact of process improvement initiatives on clinical practice.

RESULTS: The JTTS clinical practice guidelines for massive transfusion led to increased compliance with balanced component transfusion and decreased practice variability. During the course of the evaluation period, hypothermia on presentation decreased dramatically after the publication of the hypothermia prevention and management clinical practice guideline.

CONCLUSION: Developed metrics demonstrate that evidence-based quality improvement initiatives disseminated through the JTTS were associated with improved clinical practice of resuscitation following battlefield injury. (*J Trauma Acute Care Surg.* 2012;73: S459 S464. Copyright © 2012 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Therapeutic/care management study, level IV.

KEY WORDS: Military; trauma system; performance improvement; resuscitation; outcomes.

The military trauma system has evolved and matured very quickly during the 10 years of war in Afghanistan and Iraq. Civilian trauma systems have improved outcomes in the United States for decades, but the concept had not been adopted by the US military at the time of the invasion of Afghanistan.[1] Rudimentary elements of a contemporary trauma system were present in the Vietnam War,[2] such as data collection and issuance of wartime health policy,[3] but formal establishment of a military trauma system occurred with the creation of the Joint Theater Trauma System (JTTS) in 2004. Since that time, the JTTS has been associated with several trauma system improvements related to hypothermia, damage-control resuscitation (DCR), compartment syndrome, burn care, hemorrhage, thromboembolic events, interfacility transfer, and training.[1,4–6] The military medical departments of the United Kingdom, Canada, and Australia have also recognized the value of establishing a trauma system during the wars in Afghanistan and Iraq.[7–9] In 2011, the Joint Trauma System (JTS) was accepted as the trauma system for the entire US Department of Defense.

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The main priorities of the JTTS have been to promote system performance improvement and to promote evidence-based combat trauma care.[10] This two-part evaluation seeks to measure the impacts on clinical practice and change in patient outcomes from information and interventions implemented and disseminated through the JTTS, specifically, clinical practice guidelines (CPGs) for hypothermia prevention and DCR and establishment of a forward deployed trauma system team for trauma registry data collection and in-theater performance improvement activities. Hypothermia and DCR are presented together because they both relate to initial resuscitation management and both were implemented early enough in the 10-year period to allow measurement of long-term effects on the trauma system.

Blood Component Ratio Compliance

Blood transfusion has been a part of US combat casualty care since World War I. Whole-blood transfusion was widely used among American and British Commonwealth forces by the end of World War I.[11] After an initial attempt to use plasma and albumin, whole-blood transfusion continued to be the primary method of resuscitation during World War II, the Korean War, and the Vietnam War. Blood component therapy, particularly packed red blood cells (pRBCs), became the primary transfusion method during the Gulf War, Somalia, and Balkan conflicts.[12]

Hemorrhage remains one of the most frequent preventable causes of combat death.[13,14] In 2004, the US Central Command's JTTS published a CPG advocating DCR for

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massive transfusions. This CPG describes a balanced resuscitation strategy in which fluids, blood products, and other adjunctive methods are used to reverse or prevent coagulopathy and aid in the management of ongoing hemorrhage. damage-control surgery is not a new concept,[15] but combining it with hemostatic resuscitation to prevent uncontrolled coagulopathic hemorrhage has been an important advance during the course of the Iraq and Afghanistan wars.[16,17]

Although fresh whole blood (FWB) continues to be a resuscitation option in theater, it may be less preferable than blood component therapy for a variety of logistical, doctrinal, and safety issues.[18] Although all blood components may not be available at many far-forward locations,[19] the availability of blood components at hospital-level care and fairly equitable effectiveness to whole-blood transfusion make blood component transfusion the current method of choice in the military trauma system.[20]

This evaluation sought to measure the effect of the DCR on the combat casualty outcomes in Iraq and Afghanistan. Aggregate clinical practice was measured by overall compliance with the 1:1:1 (pRBC/plasma/platelets [PLTs]) guideline recommendations. In addition, the use of FWB over time was evaluated when compared with 1:1:1 component ratio compliance over the same period. Finally, overall compliance with the guideline was overlaid with mortality for the same patient population to assess the effect on patient outcomes.

Hypothermia Prevention and Management

Hypothermia is a major concern in the initial management of trauma patients. Several physiologic processes important to trauma care are significantly affected by hypothermia.[21] Spontaneous hypothermia,[22] as opposed to induced hypothermia, creates several problems in addition to the underlying injury, including cold diuresis, impaired drug clearance, decreased cerebral blood flow, pulmonary edema, and multiorgan dysfunction.[23–25] Perhaps most important is the contribution to coagulopathy.[26] Hypothermia can strongly inhibit the coagulation cascade, affecting both enzyme and PLT function.[27–30] In addition, hypothermia has been associated with greater operative blood loss as well as a higher rate of postoperative wound infection and longer hospital stay.[31] Hypothermia has previously been identified as an independent predictor of mortality in trauma patients,[32,33] but more recently, it was found to be predictive as it relates to severity and coagulopathy.[34]

Hypothermia was identified early in the Afghanistan and Iraq wars as having a significant impact on combat trauma care.[35,36] In 2004, the military deployed its first JTTS team into Iraq, consisting of a trauma physician and six trauma nurse coordinators (TNCs). The team deployments have continued on regular rotations since, growing to its current size of 17 personnel. In 2006, the JTTS published a CPG for hypothermia prevention, monitoring, and management across all echelons of the military trauma system. This was associated with a significant decrease in the incidence of hypothermia a year after the implementation across the trauma system.[37] The CPG heavily emphasizes hypothermia prevention since prehospital mitigation of heat loss might be the most effective intervention for seriously injured patients rather than rewarming upon arrival to the hospital.[38]

This secondary evaluation end point of this analysis was to measure the impact of the military trauma system guidance on the incidence of hypothermia in the Afghanistan and Iraq wars. Specifically, it attempts to measure the effect of the CPGs and the dedicated performance improvement personnel assigned within the trauma system.

PATIENTS AND METHODS

Resuscitation

For this evaluation, the JTS Blood Transfusion Database, maintained at the US Army Institute of Surgical Research, was queried for select demographic and blood product data elements. The patient population included all US military trauma patients admitted to hospital-level treatment facilities who received a massive transfusion in Iraq and Afghanistan from January 1, 2003, to December 31, 2011. Massive transfusion was defined as 10 or more units of pRBCs and/or FWB within the first 24 hours following injury. All patients who arrived at Level III facilities who were coded killed in action (KIA) were excluded from analysis.

The evaluation analysis was designed to incorporate both epidemiologic and quality improvement measures to assess the component therapy use and overall JTS impact. All data were evaluated using SAS 9.2 software (Cary, NC). Categorical data were summarized using percentages or crude rates. To compare component therapy compliance with noncompliance, we used standard χ^2 tests for analysis when the expected frequencies were greater than five per group. Furthermore, continuous variables were tested for normality. Means and SDs are reported as summary statistics for variables that met the criteria for normality. Compliance versus noncompliance is compared by using independent Student's t tests.

System-wide average blood product use for each massive transfusion patient was trended over time for individual components by year using basic univariate analysis techniques. Specific components analyzed included units of pRBCs, fresh frozen plasma (FFP), PLTs, and whole blood.

In an effort to analyze adherence to the recommended component ratio outlined in the CPG, we calculated the ratios of FFP to pRBCs, and that ratio of PLTs to pRBCs was calculated for each patient. A binomial variable was then created to determine compliance/noncompliance with the recommended use. If both ratios were within the range of 1:0.5 to 1:1.5, patients were considered to be CPG compliant. All patients who fell outside this range were considered noncompliant. The aggregate percentage of compliance with the DCR CPG was then plotted for each year. Crude patient mortality rates were also plotted to link overall compliance with patient outcomes.

Hypothermia

This aspect of the evaluation used data from the Joint Theater Trauma Registry, maintained by the JTS at the US Army Institute of Surgical Research. The patient population includes all US military trauma patients admitted to a hospital-level treatment facility (US Level III or NATO Role 3) in Iraq or Afghanistan from January 1, 2002, to December 31, 2011.

The temperature used was the initial emergency department temperature recorded in the trauma registry at the first hospital-level facility in the chain of evacuation. Hypothermia was defined as less than 36°C, in line with the JTTS CPG and the American College of Surgeons guidelines for trauma patients.[39,40] The recorded temperature was not adjusted for the route taken to remain consistent throughout the entire period. All patients who arrived at Level III facilities who were coded KIA were excluded from the analysis.

The hypothermia segment of the JTS evaluation project was designed primarily to evaluate annual hypothermia trends for the last decade of war and assess the overall impact of JTS CPGs regarding patient warming. All data were evaluated using SAS 9.2. The registry data identified 26,068 US military trauma patients who were admitted to a US hospital-level facility during the 10-year period. Of those, 19,970 (76.6%) had a recorded emergency department temperature. Initial emergency room temperatures were assessed for all patients and categorized into two binary variables, hypothermic and nonhypothermic, based on the previously mentioned American College of Surgeons guidelines. Annual hypothermia rates were calculated as the total number of hypothermic patients over the total number of living (non-KIA) trauma admissions recorded for the year. These annual rates were then compared with overall patient volume for the 10- year period stratified by the military theater of operation. In addition, the introduction of the deployed JTTS personnel in 2004 and the introduction of the CPG in 2006 were overlaid on the timeline to allow a single time-series analysis.

RESULTS

The impact evaluation of aggregate blood component use shows steady trauma system progress toward the 1:1:1 ratio recommendations described in the JTTS DCR CPG. Figure 1 shows an aggregate component ratio of 1:0.35:0.05 (RBC/FFP/PLT) in 2004, the year the first massive transfusion CPG was published, to a ratio of 1:1.09:1.02 in 2011. All components see a steep increase in use in 2005, the first full year this CPG was implemented, with a flattening of the trend between 2005 and 2009. In 2010, average use of each blood component reached the highest points in the wars, and 2011 showed the greatest compliance to the recommended blood component ratio. During the same period (Fig. 2), the percentage of massive transfusion patients receiving whole blood as part of the transfusion dropped from more than 60% in 2003 to 2004 to less than 25% in 2007 to 2010 but increased to 31% in 2011. The decrease in whole blood use generally has an inverse association with increased compliance with component therapy until 2009 when whole-blood use levels off, corresponding to the Afghanistan "surge."

Figure 3 displays crude adherence to the CPG's component therapy recommendations overlaid with the mortality outcomes in the same massive transfusion population. The clear trend is that as adherence to component therapy increases, mortality decreases. The trend is interrupted in 2008, however. Overlaying the overall operational efforts on to the chart indicates that the trend is a repeating pattern with the transition point being 2008, when the Iraq surge ended and the higher proportion of combat operations shifted to Afghanistan. This second part of the bimodal trend shows continued improvement of the trauma system to a component therapy adherence rate of almost 68% and a mortality of less than 9.5% for massive transfusion patients in 2011.

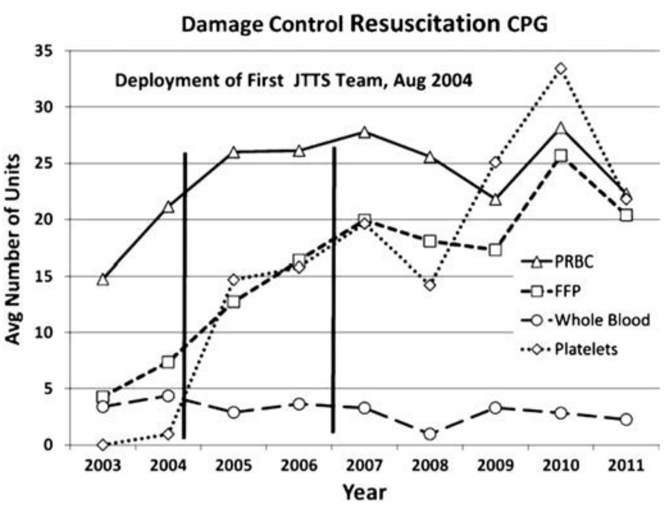

Figure 1. Average component units per massive transfusion.

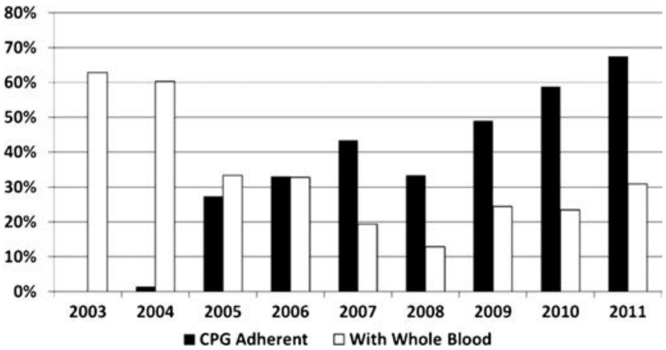

Figure 2. Percentage of massive transfusions with 1:1:1 ratio adherence and whole-blood utilization.

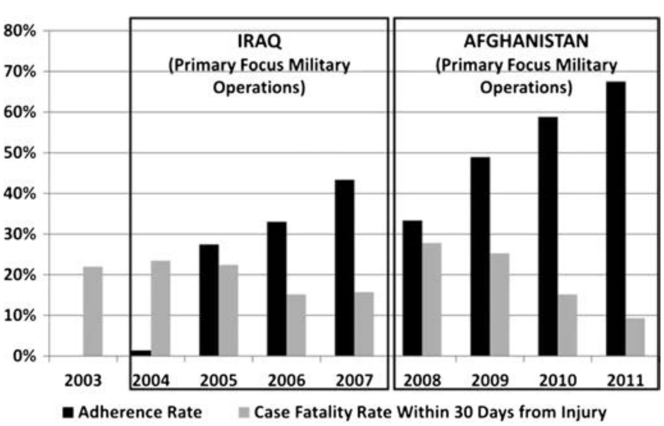

Figure 3. Percentage of massive transfusions adherent to component therapy and percentage of massive transfusions resulting in death.

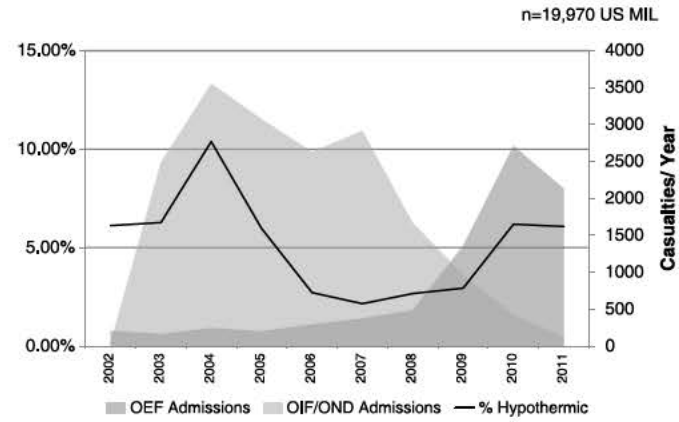

Figure 4. Patients admitted with documented temperature less than 96.8°F (36°C) January 2002 to December 2011 Operation Enduring Freedom and Operation Iraqi Freedom/Operation New Dawn combined.

The proportion of hypothermic patients during the 10-year period was affected by interventions by the trauma system (Fig. 4). A relatively high percentage of trauma patients arrived hypothermic from 2002 to 2004, with the highest rate of the wars in 2004 at 10.3%. The first team of TNCs was deployed to Iraq in August 2004. In the successive 2 years, the percentage of hypothermic patients dropped off dramatically from more than 10% in 2004 to less than 3% by 2006. The hypothermia CPG was published in October 2006. From 2006 through 2009, the system hypothermia rate remained less than 3% despite an increase in trauma admissions in 2007. In 2010 and 2011, the percentage of hypothermic admissions rose to early war levels of approximately 6% per year.

Further analysis of the entire sample together produces other relevant findings. During the entire 9-year period, severe injury, defined as an Injury Severity Score (ISS) of 16 or higher,[41] was significantly associated with hypothermia at admission (Table 1). In addition, casualties arriving hypothermic were significantly more likely to develop the complication of coagulopathy during hospitalization at that level of care (Table 2).

DISCUSSION

The evaluation shows that the trauma system CPG has affected clinical practice for resuscitation and whole-blood use. Furthermore, these changes in practice are associated with improved survival outcomes. Several other factors have affected resuscitation practice during the same period. Improvements in blood supply logistics and wider availability of blood products, particularly plasma and PLTs, certainly enabled the change in transfusion practice over time. The deployed JTTS teams, consisting of a theater trauma director and TNCs, providing constant education and performance improvement feedback at each hospital facility, are a key component to the diffusion of evidence-based practices. This element is particularly vital considering the frequent staff turnover and geographic dispersion of the various levels of care. Change in medical military doctrine and new technology to make blood products available as far forward on the battlefield as possible also contributed to the amount and character of transfusions following major trauma. Faster aeromedical evacuation during the course of the wars likely allowed more patients in hypovolemic shock to survive long enough to receive effective resuscitation.

It is important to note that the CPG is not a static document and has undergone periodic review and revision since its publication in late 2004, beginning as the massive transfusion CPG and evolving into the DCR CPG in the latter part of 2006. It is important to note that there was an evolution of practice even before the formal DCR CPG whereby, casualties were receiving more balanced plasma ratios. The likely reason for this practice evolution was practical experience and an evolving body of evidence, which guided therapy before the initial publication of DCR results or the CPG. Although this living document may seem counterproductive to clinician adherence to some, integrating the latest theater evidence, military subject matter expertise, and the most current military and civilian research may contribute to the higher levels of CPG compliance. The CPG is also used as the standard of care for any performance improvement review performed on patient outcomes. It is important to also note that although compliance increased during the period of the conflict, it never reached 100%. This may represent the inherent practice variability associated with any CPGs. Despite this fact, the compliance rate was substantially higher than the rate reported in the civilian trauma literature.[6,14] The reasons for the incremental increase in compliance may be associated with the CPG as a validated resource for providers unfamiliar with injury care, the evolution of the products available for DCR, or some inherent aspect of the hierarchy of the military system.

There are several limitations to conducting such a broad system evaluation. Evaluations are intended to measure the effect of an intervention on a program or system, in this case, DCR on the US military trauma system in Iraq and Afghanistan. Results were not controlled or stratified for ISS, theater of war, military service, type or mechanism of injury, complications, or other factors. Improvements in clinical outcomes are multifactorial, and as such, we can only develop associations between CPG and outcomes, as opposed to direct causation. In addition, adjunct therapies such as factor VIIa, tranexamic acid, or cryoprecipitate were not considered in this initial evaluation of mortality outcomes. Use of thromboelastometry, such as

TABLE 1. Univariate Analysis of Severe Injury and the Occurrence of Hypothermia

	Total Population (N = 19,841)	≥36 °C (n = 18,742)	<36°C (n = 1,099)			
Injury Severity	n (%)	n (%)	n (%)	p	Odds Ratio	95% Confidence Interval
ISS ≥16	1,807 (9.05)	1,508 (8.04)	299 (27.2)	0.0001	4.2714	3.7026 4.9276

TABLE 2. Univariate Analysis of Hypothermia and the Occurrence of Coagulopathy (International Normalized Ratio > 1.5)

	Total Population (n = 19,970)	No Coagulopathy (n = 19,718)	Coagulopathy (n = 252)			
Initial Temperature	**n (%)**	**n (%)**	**n (%)**	***p***	**Odds Ratio**	**95% Confidence Interval**
<36°C	252 (1.26)	197 (1)	55 (21.8)	0.0001	4.9438	3.6432 6.7088

thromboelastography or rotation thromboelastometry, has been in limited use in Iraq and Afghanistan for years. These procedures allow more precise tailoring of blood component therapy to patients that might contraindicate the CPG recommended component ratio. Although some of these patients can be identified in the trauma registry, they were not excluded from the evaluation since it was intended to measure aggregate outcomes of all US military massive transfusions.

The system evaluation shows that trauma system interventions affected the rate of hypothermia at emergency department admission. Hypothermia prevention was a major focus of the first JTTS team that deployed to Iraq in 2004. There is a significant reduction in hypothermia following their on-site insertion into Iraq. This reduction was sustained for 4 years after publication of the JTTS CPG, indicating an institutionalization of the improved care of patients for hypothermia. Several factors could contribute to the recent increase in hypothermic admissions. 2009 was the first year that Afghanistan had more trauma admissions than Iraq since 2002. From 2003 to 2008, Afghanistan accounted for less than 25% of all system trauma admissions. Following the drawdown in Iraq and the surge in Afghanistan, the percentage of system trauma admissions from Afghanistan rose to more than 85% for both 2010 and 2011. Afghanistan has a colder climate than Iraq, and its mountainous terrain makes evacuation more difficult. In addition, the US military conducted large-scale combat operations in the winters of 2010 and 2011 in Afghanistan, increasing the risk of hypothermia compared with earlier years of the war. Seasonality has a definite effect on the rate of hypothermia in Afghanistan. For those 2 years, hypothermia admissions were approximately 2% to 3% during the summer months and 13% to 16% in the winter months.

Severity affecting hypothermia and hypothermia affecting subsequent coagulopathy are expected results. Severely injured patients often require longer evacuation times and more prehospital procedures. Certain injuries and situations may discourage or prohibit use of hypothermia prevention and mitigation measures or devices. Hypothermia's effect on coagulopathy highlights that prehospital interventions, or lack of, can continue affect patient's care beyond just the time of delivery to hospital-level care.

As such a broad system view, this evaluation has several limitations. Although approximately 23% of all admissions did not have an initial temperature recorded for the entire 10-year period, the percentage of missing temperatures was much higher in the first 5 years. It is possible that some of the recent increase in hypothermia might be from better documentation of initial temperatures. It is also important to note that these are generally not core body temperatures. Most of the temperatures recorded would be the initial oral, axillary, or tympanic route temperatures. If low, a core body temperature would be indicated, but that subsequent temperature is unlikely to be recorded in the trauma registry. Many patients, particularly in Afghanistan, will have had initial resuscitation and damage-control surgery at a field site before arriving to hospital-level care. Data from that earlier level of care have been unreliably collected during the 10-year period, so entry into hospital level care was the most consistent data point to use as the first temperature. Finally, the Iraq and Afghanistan conflicts have different operational characteristics, and trends that might be diluted in a broad, systemic evaluation.

CONCLUSION

The military trauma system in its ability to affect CPG and performance improvement substantially affected resuscitation practice, including hypothermia prevention, for massive transfusion trauma patients. This change in practice was associated with improved mortality outcomes for massive transfusion trauma patients.

AUTHORSHIP

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DISCLOSURE

The authors declare no conflicts of interest.

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