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, interfability 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.

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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**SUMMARY OF FINDINGS:**
This study evaluated the military trauma system practices related to damage-control resuscitation. The findings indicate that the current system practices are effective in reducing mortality and morbidity in severely injured patients. The study also identifies areas for improvement in the reimbursement of resources and the coordination of efforts among various military medical facilities.

**SUGGESTIONS FOR FUTURE RESEARCH:**
Future research should focus on the integration of advanced technology and the development of standardized protocols to improve the effectiveness of damage-control resuscitation. Additionally, more research is needed to understand the long-term outcomes of patients treated with damage-control resuscitation.

**LIMITATION OF ABSTRACT**
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massive transfusions. This CPG describes a balanced resusci-
tation strategy in which fluids, blood products, and other
adjunctive methods are used to reverse or prevent coagulo-
pathy and aid in the management of ongoing hemorrhage.
damage-control surgery is not a new concept, but combining
it with hemostatic resuscitation to prevent uncontrolled coa-
gulopathic hemorrhage has been an important advance during
the course of the Iraq and Afghanistan wars.

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. Although all blood components may not
be available at many far-forward locations, the availability of
blood components at hospital-level care and fairly equitable
effectiveness to whole-blood transfusion make blood compo-
nent transfusion the current method of choice in the military
trauma system.

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 compli-
ance 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 com-
pliance 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 manage-
ment of trauma patients. Several physiologic processes impor-
tant to trauma care are significantly affected by hypothermia.
Spontaneous hypothermia, as opposed to induced hypo-

thermia, creates several problems in addition to the under-
lying injury, including cold diuresis, impaired drug clearance,
decreased cerebral blood flow, pulmonary edema, and multi-
gan dysfunction. Perhaps most important is the contribu-
tion to coagulopathy. Hypothermia can strongly inhibit
the coagulation cascade, affecting both enzyme and PLT
function. 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. It has
previously been identified as an independent predictor of mortality in trauma patients, but more re-
cently, it was found to be predictive as it relates to severity and
couagulopathy.

Hypothermia was identified early in the Afghanistan and
Iraq wars as having a significant impact on combat trauma care. 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 con-
tinued on regular rotations since, growing to its current size of 17 personnel. In 2006, the JTTS published a CPG for hypo-
thermia prevention, monitoring, and management across all echelons of the military trauma system. This was associated
with a significant decrease in the incidence of hypother-

mia a year after the implementation across the trauma sys-
tem. 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.

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 Data-
base, maintained at the US Army Institute of Surgical Re-
search, 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 trans-
fusion 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
analyzed 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 χ² 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 mas-
size transfusion patient was trended over time for individual
components by year using basic univariate analysis techni-
ques. 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 ag-
gregate 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. 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 non-hypothermic, 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 JTTTS 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

Figure 1. Average component units per massive transfusion.

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

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.
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, 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. 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
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.

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

<table>
<thead>
<tr>
<th>Initial Temperature</th>
<th>Total Population (n = 19,970)</th>
<th>No Coagulopathy (n = 19,718)</th>
<th>Coagulopathy (n = 252)</th>
<th>p</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;36°C</td>
<td>252 (1.26)</td>
<td>197 (1)</td>
<td>55 (21.8)</td>
<td>0.0001</td>
<td>4.9438</td>
<td>3.6432 6.7088</td>
</tr>
</tbody>
</table>

**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**


**DISCLOSURE**

The authors declare no conflicts of interest.

**REFERENCES**
