Surgical Legacies of Modern Combat: Translating Battlefield Medical Practices into Civilian Trauma Care

Achieving Zero Preventable Deaths Conference
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Disclosures

None

Disclaimer

The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.
War’s Role as a Teacher For Antiquity

“He who would become a surgeon should join an army and follow it for war is the only proper school for a surgeon’..”
History of Battlefield Medical Lessons

World War I
- IV fluids
- Blood transfusions
- Motorized ambulances
- Topical antisepsis

World War II
- Whole blood/plasma available
- Specialty-specific surgical groups
- Antibiotics
- Fixed wing aero-medical evacuation

Korean Conflict
- Improved fluid resuscitation
- Forward availability of definitive surgery
- Helicopters for patient evac/transport
- Primary repair/grafts for vascular injury

Vietnam
- Improved use of helicopters
- Improved laboratory support
- Portable radiology equipment
- Mechanical ventilators in theater

Desert Shield/Storm
- Burn team augmentation of evacuation hospitals to provide theater-wide burn care
- Intercontinental aeromedical transport of burn patients
Contemporary Battlefield Lessons Learned
Joint Trauma System

• Focused empiricism / timely dissemination of knowledge
• Performance Improvement / generation of best practices
• Epidemiology of injury death
• Tactical Combat Casualty Care
• Acute surgical care
  • Damage control resuscitation
  • Forward surgical elements
  • Serial damage control surgery
Genesis of the Military Trauma System Effort

Review of Battlefield Medical Care

Army Trauma Consultant 2003

- Unorganized delivery of trauma care on the battlefield
  - Casualties going to the wrong location
  - Suboptimal staffing and placement of surgical assets
- Medical records are not reliably being delivered with casualties at each level (<40%)
  - Impact on clinical care
  - Documentation directive
- No trauma registry driven by medical input that allows accurate description of injuries or deaths
  - Unable to reliably answer questions and improve outcomes
    - Survivable Injuries and/or deaths
    - Lack of performance improvement measures / research
Battlefield Lesson

Learning Healthcare System
Clinical Practice Guidelines

- Evidence-based
- Best clinical practice
- Tailored to operational battlefield environment
- Open access
- Resource for deploying surgeons and medical providers
Focused Epiricism

Pragmatic approach to process improvement
- Urgency to improve outcomes because of high morbidity and mortality rates
- High-quality data are not available to inform clinical practice changes
- Data collection is possible.

- Principle of focused empiricism is using the best data available in combination with clinical experience to develop clinical practice guidelines through an iterative process

- Successes
  - Damage control resuscitation
  - Whole blood for massive transfusion
  - Tranexamic acid

- Failures
  - Factor VIIa
Average Component Units per Massive Transfusion

- PRBC
- FFP
- Whole Blood
- Platelets

Deployment of 1st JTTS trauma team Aug 2004
Official Massive Transfusion CPG issued Dec 2004
Damage Control Resuscitation Compliance

**Diagram:**
- **X-axis:** Years (2003-2010)
- **Y-axis:** Crude Adherence Rate (%)
- **Legend:**
  - Blue bars: Crude Adherence Rate
  - Red bars: Death Rate

**Data Overview:**
- **IRAQ**
  - 2003: 13.0%
  - 2004: 20.0%
  - 2005: 25.0%
  - 2006: 30.0%
  - 2007: 40.0%
  - 2008: 50.0%
  - 2009: 60.0%
  - 2010: 70.0%

- **AFGHANISTAN**
  - 2008: 30.0%
  - 2009: 40.0%
  - 2010: 50.0%
Battlefield Lesson

Epidemiology of Prehospital Trauma Mortality
Where Can We Save the Most Lives?


What were the Causes of Preventable Death?

Hemorrhage Focus (n=888)

- 39% Cervical (max AIS 1)
- 61% Axilla and Groin (max AIS 5)
- 36% Thoracic (max AIS 3)
- 64% Abdominopelvic (max AIS 4/5)
Eliminating Preventable Death on the Battlefield

- **US Military**
  - Preventable Prehospital Deaths = 25%
- **US Rangers**
  - Preventable Deaths = 3%

**Ranger success attribution:**
- Leadership
  - Command-directed casualty response program
- Training
  - All Rangers and Docs trained in TCCC

Multi-Disciplinary Multi-Institutional Mortality Investigation in the Civilian Prehospital Environment (MIMIC)

- Develop a methodology for evaluating the causes and pathophysiology of pre-hospital deaths (optimal & in context)
- Network of experts to apply the methodology to identify the causes of pre-hospital deaths due to trauma and estimate the potential for survivability.
  - Trauma surgery
  - Neurosurgery
  - Orthopedic surgery
  - Forensic pathology
  - Emergency medicine
  - Emergency medical services
Multi-Disciplinary Multi-Institutional Mortality Investigation in the Civilian Prehospital Environment (MIMIC)

- Define the causes and pathophysiologic mechanisms of 3,000 pre-hospital deaths occurring in six regions of the country representative of the population.
- Describe the epidemiology of pre-hospital mortality in the context of trauma system development and estimate human and fiscal impact on society.
- Develop a blueprint for a sustained public health / injury mitigation strategies in the pre-hospital environment, identifying high priority areas for trauma systems performance improvement.
Battlefield Lesson

Pre-Hospital Care
Tactical Combat Casualty Care

Set of trauma management guidelines customized for the battlefield that focus on the most common causes of preventable deaths on the battlefield:

- Hemorrhage
  - Noncompressible
  - Junctional
  - Peripheral
- Airway obstruction
- Tension pneumothorax

Pre-Hospital
Translation of Lessons Learned

Tactical Combat Casualty Care

Hartford Consensus

- Threat suppression
- Hemorrhage control
- Rapid Extrication to safety
- Assessment by medical providers
- Transport to definitive care

• Need integrated response
  Fire, EMS, Law Enforcement, Medical
The Hartford Consensus

- American College of Surgeons
- FBI
- White House – Medical Policy
- White House Medical
- Asst Secretary of Defense - Health Affairs
- Asst Secretary of Homeland Security – Health Affairs
- Medical Section – Major Chiefs of Police
- ACS Committee on Trauma
- DoD Committee on TCCC

Improving Survival from Active Shooter Events: The Hartford Consensus
Active Shooter and Intentional Mass-Casualty Events: The Hartford Consensus II
The Hartford Consensus III: Implementation of Bleeding Control
The Hartford Consensus IV: A Call for Increased National Resilience
Pre-Hospital Translation Initiatives

LEFR-TCC
Law Enforcement
First Responder
Tactical Casualty Care

NAEMT
Hemorrhage Control: Tourniquets

Kragh, et al – Tourniquet Study

- Ibn Sina Hospital, Baghdad, 2006
- Tourniquets are saving lives on the battlefield
- 31 lives saved in 6 months by use of prehospital tourniquets

“[The fate of the wounded lays with those who apply the first dressing.]”
- Col. Nicholas Senn, 1844-1908
Impact of Tourniquets on the Battlefield

![Bar chart showing the impact of tourniquets on isolated extremity deaths/year during different time periods: Pre-Tourniquet (Pre 2006), Transition (2006-2007), Post-Tourniquet (Post 2007). The chart indicates a significant decrease in deaths after the implementation of tourniquets.]
Civilian Tourniquet Consensus

- Data strongly suggests that tourniquet use saves lives.

- Adverse side effects associated with tourniquets appear to be manageable and do not appear to outweigh the benefits of tourniquet use.
Battlefield Lesson

Resuscitation
Hemostatic Resuscitation

Fig. 1. Percentage mortality associated with low, medium, and high plasma to RBC ratios transfused at admission. Ratios are median ratios per group and include units of fresh whole blood counted as plasma and RBCs.
Civilian Trial
Pragmatic Randomized Optimal Platelet and Plasma Ratio Trial (PROPPR)

Holcomb et al. JAMA 2015;313:471–482
Whole Blood Resuscitation in Combat

Fresh whole blood use by forward surgical teams in Afghanistan is associated with improved survival compared to component therapy without platelets. 

Transfusion 2013


FWB in austere combat environments safe and independently associated with improved survival when compared with resuscitation with RBCs and FFP alone.
Whole Blood: Back to the Future

• Whole blood historically primary resuscitative solution for hemorrhagic shock.
• Transition to using component therapy occurred without evidence superior efficacy or safety.
• Misconceptions
  – Whole blood must be ABO specific (O low titer 1:256)
  – Whole blood cannot be leukoreduced
  – Cold storage causes loss of platelet function
• Cold whole blood stored for up to 21 days has greater hemostatic capacity than blood components transfused in a 1 : 1 : 1 (in vitro)
  Spinella, Cap: Curr Opin Hematol 2016, 23
Battlefield Lesson

Forward Transitioning
Damage Control Philosophy
Pre-Hospital DCR Concepts

• Stop obvious hemorrhage
  – Hemostatic adjuncts
• Correction of coagulopathy
• Judicious fluid management (permissive hypotension)
• Thermoregulation
• Minimize pre-hospital time ("Golden Hour" is relative)
Golden Hour and the Gates Effect

Figure 1. Case Fatality Rate and Transport Time

Conclusions
A 2009 mandate by Secretary of Defense Gates reduced the time between critical injury and definitive care for combat casualties in Afghanistan. Despite evidence of increased severity and complexity of wounds from explosive devices, the combination of reduced prehospital transport time and increased treatment capability are likely contributors of casualty survival.
Prehospital Time
Noncompressible Torso Hemorrhage (GSW)

Critical nature of prehospital time in patients with non-compressible torso hemorrhage.

Evacuation times < 30 minutes not realistic, particularly in rural or austere environments.

Emphasizes need to develop therapies to increase the window of survival in the prehospital environment.

Military Tactical DCR Forward

- FWB is the best prehospital resuscitation fluid
- 75\textsuperscript{th} Ranger Regiment program
  - Type O – Low Titer Anti-A, Anti-B abs
  - Donors pre-screened for typing, titers, and infectious diseases
  - Use donor pool to transfuse casualties in shock

**Review Articles**

**Tactical Damage Control Resuscitation**

MAJ Andrew D. Fisher, SP USA\textsuperscript{*}; MAJ Ethan A. Miles, MC USA\textsuperscript{†}; LTC Andrew P. Cap, MC USA\textsuperscript{‡}; CDR Geir Strandenes, MC\textsuperscript{‡}; COL Shawn F. Kane, MC USA\textsuperscript{§}

ABSTRACT  Recently the Committee on Tactical Combat Casualty Care changed the guidelines on fluid use in hemorrhagic shock. The current strategy for treating hemorrhagic shock is based on early use of components; Packed Red Blood Cells (PRBCs), Fresh Frozen Plasma (FFP) and platelets in a 1:1:1 ratio. We suggest that lack of components to mimic whole blood functionality favors the use of Fresh Whole Blood in managing hemorrhagic shock on the battlefield. We present a safe and practical approach for its use at the point of injury in the combat environment called Tactical Damage Control Resuscitation. We describe pre-deployment preparation, assessment of hemorrhagic shock, and collection and transfusion of fresh whole blood at the point of injury. By approaching shock with goal-directed therapy, it is possible to extend the period of survivability in combat casualties.
IMPLEMENTATION AND EXECUTION OF CIVILIAN REMOTE DAMAGE CONTROL RESUSCITATION PROGRAMS

Donald Jenkins,1 James Stubbs,1 Steve Williams,1 Kathleen Berns,1,2 Radoslaw Zielinski,3 Geir Stranden,1,2 and Scott Zierold1

1Division of Trauma, Critical Care and Emergency General Surgery, Department of Surgery, Mayo Clinic; 2Mayo Clinic Foundation, Rochester, Minnesota; 3Medic Operations Royal Caribbean Cruises Ltd, Miami, Florida; 4Mayo Clinic Medical Transport, Rochester, Minnesota, and 5Naval Special Operations Command and Department of Immunology and Transfusion Medicine, Maastricht University Hospital, and Institute of Clinical Decision, four, University of Bergen, Bergen, Norway.

Received 5 Nov 2011; first review completed 2 Dec 2011; accepted in final form 3 Jan 2014.

ABSTRACT—Remote damage control resuscitation is a recently defined term used to describe techniques and strategies to provide hemorrhage resuscitation to injured patients in the prehospital setting. In the civilian setting, unlike the typical military patient, whose needs for resuscitation are defined in the prehospital setting, the typical patient is a civilian, who requires treatment for hemorrhage in all ages with all types of comorbidities and may have bleeding that may be due to injuries sustained in a civil setting. The prehospital setting, addressing the needs of the patient is no less challenging than in the military environment, albeit the caregivers are typically not trying their lives to risk providing effective treatment. Two organizations have been involved in remote damage control resuscitation in the civilian environment: Mayo Clinic and Royal Caribbean Cruises Ltd. The limitations in the medical environment, and the challenges for patients, who have hemorrhage requiring resuscitation, vary. The approach for remote damage control resuscitation in the setting of a non-military environment is focused on the prehospital phase of the emergency environment, which is the most challenging aspect of the emergency environment. The patient would be treated in the emergency department or trauma bay, and protocols that formed in the initial encounter with hemostatic prehospital resuscitation, and then the care is continued in the hospital environment. The emphasis is focused on maintaining the patient’s vital signs and improving the patient’s condition before further treatment. The key to maintaining the patient’s condition is the rapid and efficient care provided in the emergency department or trauma bay.

KEYWORDS—Shock, prehospital, trauma, shipboard, helicopter, whole blood, TXA

INTRODUCTION
Remote damage control resuscitation (RDCR) is essentially defined as the concept of damage control resuscitation applied prehospital. It is very important in austere situations in which, traditionally, blood products and robust resuscitative capability have not existed. This article describes the development and implementation of such RDCR programs in non-military environments; see at Mayo Clinic Trauma Center (inclusive of Mayo Clinic Medical Transport) and the Queen aboard Royal Caribbean Cruises Ltd (RCL) cruise ships.

Identification of the need for a civilian RDCR program
Early and aggressive use of blood components has become the standard of practice for the management of traumatic hemorrhagic shock and the devastating effects of primary and secondary coagulopathy that develops in the majority of severely injured trauma victims. The prehospital resuscitation of the exsanguinating patient with trauma is in time and resource dependent. Rural and maritime hemorrhage care (medical and injury management) and care is complicated because the transportation time to definitive care is increased. The combination of damage control resuscitation with emphasis on early plasma delivery and the location of definitive care centers remote from initial resuscitation in the rural environment or aboard ship have led to the development of RDCR programs in these settings. Austere environment applies just as well in civilian settings as it does in military settings, as does the concept to the shortest prehospital time in most civilian urban trauma centers, the geographic expanse of the rural landscape or the maritime environment leads to delays in obtaining and delivering the care to the hemorrhaging patient. Even in the presence of a mature regional rural trauma system and robust input-to-air via evacuation, the care of a patient in shock is limited by the timing and effectiveness of resuscitation in those remote areas.

Aggressive replacement of coagulation factors with plasma is a crucial hemorrhage resuscitation component of effective massive transfusion protocols (MTP). The necessity to transfuse plasma early and often in the severely injured, the last time associated with the thawing and provision of fresh frozen plasma (FFP) hampers such efforts. Massive transfusion protocols have evolved to rely on the rapid availability of thawed plasma (TXP) for use in hemorrhagic resuscitation (1).

The rural trauma center and shipboard emergency medical services experience in Minnesota
To address the early resuscitation needs and trauma-induced coagulopathy in the exsanguinating patient with trauma, an RDCR strategy was developed that involves prehospital FFP-first transfusion protocol, and the use of tranexamic acid (TXA) was
Prehospital Plasma
PAMPPer Trial

**Original Contributions**

**Taking the Blood Bank to the Field: The Design and Rationale of the Prehospital Air Medical Plasma (PAMPPer) Trial**

Joshua B. Brown, MD, Francis X. Guyette, MD, MPH, Matthew D. Neal, MD, Jeffrey A. Claridge, MD, Brian J. Daley, MD, Brian G. Harbrecht, MD, Richard S. Miller, MD, Herb A. Phelan, MD, Peter W. Adams, BS, Barbara J. Early, BSN, Andrew B. Peitzman, MD, Timothy R. Billiar, MD, Jason L. Sperry, MD, MPH

**Table 1. Specific aims of the PAMPPer trial**

<table>
<thead>
<tr>
<th>Primary aim</th>
<th>Determine whether prehospital transfusion of 2 units of AB plasma compared to standard air medical care reduces 30-day mortality in trauma patients at risk for hemorrhagic shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary aim 1</td>
<td>Determine whether prehospital transfusion of 2 units of AB plasma compared to standard air medical care results in lower 24-hour RBC transfusion requirement, incidence of MOF, NI, ALI, and TRALI.</td>
</tr>
<tr>
<td>Secondary aim 2</td>
<td>Determine whether transfusion of 2 units of AB plasma compared to standard air medical care results in a lower 24-hour plasma, platelet, crystalloid, colloid, and vasopressor requirement.</td>
</tr>
<tr>
<td>Secondary aim 3</td>
<td>Determine whether transfusion of 2 units of AB plasma compared to standard air medical care results in improved INR, PT/PTT, and TEG measures of coagulopathy.</td>
</tr>
<tr>
<td>Secondary aim 4</td>
<td>Determine whether transfusion of 2 units of AB plasma compared to standard air medical care modulates the early immune response.</td>
</tr>
</tbody>
</table>
Prehospital Blood Outcomes

Pre-Trauma Center Red Blood Cell Transfusion Is Associated with Improved Early Outcomes in Air Medical Trauma Patients

Joshua B Brown, MD, Jason L Sperry, MD, MPH, FACS, Anisleidy Fombona, B5, Timothy R Billiar, MD, FACS, Andrew B Peitzman, MD, FACS, Francis X Guyette, MD, MPH

Prehospital blood transfusion in the en route management of severe combat trauma: A matched cohort study

David J. O'Reilly, FRCS, Jonathan J. Morrison, MRCS, Jan O. Jansen, FRCS, FFICM, Amy N. Apodaca, PhD, Todd E. Rasmussen, MD, and Mark J. Midlands, MD, FRCS, Birmingham, United Kingdom

<table>
<thead>
<tr>
<th>AOR for PTC RBC</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All HEMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-h survival</td>
<td>4.91</td>
<td>1.51–16.04</td>
</tr>
<tr>
<td>Shock on admission</td>
<td>0.28</td>
<td>0.09–0.85</td>
</tr>
<tr>
<td>TIC</td>
<td>1.39</td>
<td>0.87–2.24</td>
</tr>
<tr>
<td>In-hospital survival</td>
<td>1.06</td>
<td>0.42–2.61</td>
</tr>
<tr>
<td>Scene HEMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-h survival</td>
<td>6.31</td>
<td>1.88–21.14</td>
</tr>
<tr>
<td>Shock on admission</td>
<td>0.24</td>
<td>0.07–0.80</td>
</tr>
<tr>
<td>TIC</td>
<td>2.02</td>
<td>0.53–7.71</td>
</tr>
<tr>
<td>In-hospital survival</td>
<td>4.32</td>
<td>0.76–24.72</td>
</tr>
</tbody>
</table>

AOR, adjusted odds ratio; HEMS, helicopter emergency medical services; PTC, pre-trauma center; TIC, trauma-induced coagulopathy.

### Prehospital Interventions

<table>
<thead>
<tr>
<th>Recipients</th>
<th>Nonrecipients</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intravenous access</td>
<td>14 (14.4)</td>
<td>16 (16.5)</td>
</tr>
<tr>
<td>Advanced airway</td>
<td>19 (19.6)</td>
<td>9 (9.3)</td>
</tr>
<tr>
<td>Chest decompression</td>
<td>19 (19.6)</td>
<td>22 (22.6)</td>
</tr>
<tr>
<td>Prehospital time, min</td>
<td>68 (50–100)</td>
<td>109.5 (70–171)</td>
</tr>
<tr>
<td>Admission observations</td>
<td>7 (7.2)</td>
<td>9 (9.3)</td>
</tr>
<tr>
<td>Cardiac arrest</td>
<td>132 (111–145)</td>
<td>121 (114–150)</td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td>19 (15–24)</td>
<td>20 (16–26)</td>
</tr>
<tr>
<td>Respiratory rate</td>
<td>92 (74–115)</td>
<td>105 (82–128)</td>
</tr>
<tr>
<td>Heart rate</td>
<td>22 (22.6)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Transfusion acid</td>
<td>2 (2)</td>
<td>10 (10.3)</td>
</tr>
<tr>
<td>Recombinant activated factor VII</td>
<td>1 (1–2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Prehospital transfusion</td>
<td>2 (1–2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Total PRBC</td>
<td>1 (1–2)</td>
<td>N/A</td>
</tr>
<tr>
<td>FFP</td>
<td>2 (1–2)</td>
<td>N/A</td>
</tr>
<tr>
<td>PRBC</td>
<td>5 (1–8.5)</td>
<td>N/A</td>
</tr>
<tr>
<td>FFP</td>
<td>2 (0–7.5)</td>
<td>N/A</td>
</tr>
<tr>
<td>Cryoprecipitate</td>
<td>0 (0–0)</td>
<td>N/A</td>
</tr>
<tr>
<td>Platelets</td>
<td>0 (0–0)</td>
<td>N/A</td>
</tr>
<tr>
<td>Total FFP</td>
<td>4 (2–10)</td>
<td>N/A</td>
</tr>
<tr>
<td>Total PRBC</td>
<td>2 (2–9)</td>
<td>N/A</td>
</tr>
<tr>
<td>Any in-hospital PRBC transfusion</td>
<td>75 (77)</td>
<td>38 (39)</td>
</tr>
<tr>
<td>Massive transfusion</td>
<td>12 (12)</td>
<td>8 (8)</td>
</tr>
<tr>
<td>FFP:PRBC ratio</td>
<td>1 (0.83–1.23)</td>
<td>0.46 (0.67–0.72)</td>
</tr>
<tr>
<td>Mortality</td>
<td>8 (8.2)</td>
<td>19 (19.6)</td>
</tr>
</tbody>
</table>

*Categorical data are shown as n (%) and compared using McNemar test.
*Non-categorical data are shown as median (IQR) with range added where relevant and compared using the Wilcoxon signed-rank test. Significant results shown in bold.
U/T, untestable because of the limitations of McNemar test (because of zero value).
N/A, not applicable; U/T untestable due to zero value.
Prehospital Whole Blood

• Program development /proof of concept in process at several institutions
  – Mayo Clinic
  – University of Pittsburgh
  – University of Texas Health San Antonio / San Antonio Military Medical Center
DCR Forward

vs.

• Scoop and Run or Stay and Play?
• Advanced providers?
• Critical care capabilities
• Blood products
• Surgical capability enroute
UK MERT

Observed Mortality vs Expected Mortality

ISS 1-9: Observed 2.3, Expected 8.9
ISS 10-19: Observed 3.4, Expected 15.2
ISS > 20: Observed 7, Expected 37.5

Battlefield Continuum of Care
Proof of Concept Forward Surgery
Route from Injury to Definitive Care

CASEVAC 1 Hour
TACTICAL EVAC 24 Hours
STRATEGIC EVAC 48-72 Hours

BAS Level 1
Forward Surgical teams Level 2
Combat Support Hospital, EMEDS, Fleet Hospital Level 3
Definitive Care Level 4

Surgical Capability
The Vision: A National Trauma Care System

A national strategy and joint military–civilian approach for improving trauma care is lacking. **A unified effort is needed** to ensure the delivery of optimal trauma care to **save the lives of Americans** injured within the United States and on the battlefield.

A national learning trauma care system would **ensure continuous improvement of trauma care best practices** in military and civilian sectors.

“Military and civilian trauma care will be optimized together, or not at all.”

*The National Academies of Sciences • Engineering • Medicine*