Changing Patterns of In-Hospital Deaths Following Implementation of Damage Control Resuscitation Practices in US Forward Military Treatment Facilities

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IMPORTANCE  Analysis of combat deaths provides invaluable epidemiologic and quality-improvement data for trauma centers and is particularly important under rapidly evolving battlefield conditions.

OBJECTIVE  To analyze the evolution of injury patterns, early care, and resuscitation among patients who subsequently died in the hospital, before and after implementation of damage control resuscitation (DCR) policies.

DESIGN, SETTING, AND PARTICIPANTS  In a review of the Joint Theater Trauma Registry (2002-2011) of US forward combat hospitals, cohorts of patients with vital signs at presentation and subsequent in-hospital death were grouped into 2 time periods: pre-DCR (before 2006) and DCR (2006-2011).

MAIN OUTCOMES AND MEASURES  Injury types and Injury Severity Scores (ISSs), timing and location of death, and initial (24-hour) and total volume of blood products and fluid administered.

RESULTS  Of 57,179 soldiers admitted to a forward combat hospital, 2,565 (4.5%) subsequently died in the hospital. The majority of patients (74%) were severely injured (ISS > 15), and 80% died within 24 hours of admission. Damage control resuscitation policies were widely implemented by 2006 and resulted in a decrease in mean 24-hour crystalloid infusion volume (6.1-3.2 L) and increased fresh frozen plasma use (3.2-10.1 U) (both P < .05) in this population. The mean packed red blood cells to fresh frozen plasma ratio changed from 2.6:1 during the pre-DCR period to 1.4:1 during the DCR period (P < .01). There was a significant increase in mean ISS between cohorts (pre-DCR ISS = 23 vs DCR ISS = 27; P < .05) and a marked shift in injury patterns favoring more severe head trauma in the DCR cohort.

CONCLUSIONS AND RELEVANCE  There has been a significant shift in resuscitation practices in forward combat hospitals indicating widespread military adoption of DCR. Patients who died in a hospital during the DCR period were more likely to be severely injured and have a severe brain injury, consistent with a decrease in deaths among potentially salvageable patients.
Data for our study were obtained from the JTTR, which is maintained by the Joint Theater Trauma System under the US Army Institute of Surgical Research, Fort Sam Houston, Texas. Established in 2003, the JTTR is the largest and most comprehensive database of wartime wounded and injured patients ever assembled. This prospectively collected trauma registry includes data from all patients evaluated and cared for at forward US MTFs during combat operations in Iraq (OIF) and Afghanistan (OEF), and, as of August 2013, it contains more than 77,000 patients’ medical records. Our study protocol was reviewed and approved by the institutional review boards at Madigan Army Medical Center in Tacoma, Washington, and the Joint Theater Trauma System. The aggregate data were de-identified.

The JTTR was queried to identify all OIF and OEF deaths that occurred at MTFs from 2002 to 2011. Only those who presented to an MTF with recorded vital signs (blood pressure and heart rate) and subsequently died were included in our study, and in accordance with standard combat mortality definitions, these patients were considered to have “died of wounds” (DOW). All patients arriving without vital signs were considered dead on arrival (DOA). Primary data included basic demographics, prehospital assessments and interventions, presenting vital signs and laboratory values, emergency department and operative interventions, initial (24-hour) and total blood products and fluid administered, injuries and diagnoses, Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS), and time from admission to death (in days). Severe injury in each body region was defined as an AIS score of 3 or higher, and severely injured patients were defined as those with an ISS of higher than 15.

To provide both numerator and denominator data for comparison of DOW rates and other population-based ratio data, the total number of patients captured in the JTTR per year was obtained. In addition, summary data documenting the overall and theater-specific (OIF vs OEF) numbers and percentages of patients defined as killed in action (KIA) and the case-fatality rate (CFR) were obtained from review of the monthly the Joint Theater Trauma System Theater Director Reports. These reports provide summary data from the JTTR and continuously track the cumulative rolling monthly averages for the KIA rate and the CFR. The KIA rate reflects the percentage of deaths prior to reaching an MTF among all significantly wounded patients, and the CFR represents all deaths as a percentage of all wounded patients. Thus, the KIA rate is primarily a reflection of the lethality of injuries and the effectiveness of prehospital care, whereas the CFR reflects the overall lethality in a battlefield environment.

Descriptive statistics for the entire patient cohort were analyzed, and trends for key study variables over time were analyzed by grouping them into calendar years based on the date of injury. The widespread implementation of DCR policies and a DCR-based massive transfusion clinical practice guideline were implemented over the latter half of 2005. Based on this, patients were divided into 2 primary groups by the date of in-
jury and whether this date fell into the pre-DCR (before January 2006) or DCR (2006-2011) time period. The specific categories of data that were compared by year and between the 2 study groups included the initial (24-hour) and the total volume of fluids and blood products administered for the hospital admission. In addition, the ISS and AIS scores, based on body region (head/neck, face, thorax, abdomen, extremities, and external/skin), were analyzed. The Revised Trauma Score was calculated for each patient, as previously described. In addition, the probability of survival for each patient was calculated using the TRISS (Trauma Score and Injury Severity Score) method. The Revised Trauma Score and the probability of survival were calculated using the ICDPIC version 3.0 module in Stata version 12.1 (StataCorp). A statistical comparison of the continuous data was performed with the t test or the Mann-Whitney U test, and the categorical data were analyzed using the χ² test. All statistical analyses were performed using SPSS version 21 (IBM Corporation) with statistical significance set at \( P < .05 \).

### Results

From 2002 to early 2011, a total of 57 179 soldiers were admitted to an MTF for a trauma-related injury, and these admissions were recorded in the JTTR. Of these 57 179 soldiers, 2565 subsequently died in theater MTFs, for an overall DOW rate of 4.5% (Table 1; Figure 1). Of these 2565 soldiers, 902 died during the pre-DCR period, and 1663 died during the DCR period. The majority of those killed in either time period (80% of all deaths) died less than 24 hours after injury (ie, early deaths), and this percentage of early deaths increased significantly from the pre-DCR period (77%) to the DCR period (80%) (\( P = .02 \)). The percentage of intermediate deaths (1-7 days after injury) was unchanged (13% for both periods; \( P = .95 \)), whereas the percentage of late deaths (>7 days after injury) decreased from 10% during the pre-DCR period to 6% during the DCR period (\( P \leq .01 \)). Throughout the entire study period, 74% of soldiers who DOW had an ISS of higher than 15, qualifying them as severely injured. Comparing the pre-DCR and DCR periods (Table 2), we found that both the mean ISS and the percentage of patients with severe injury increased significantly (from a mean ISS of 22.5 to 26.7 and from 63.5% to 79.7%, respectively; \( P < .05 \)). Similarly, the mean Revised Trauma Score was significantly lower (indicating more severe injury) for the DCR cohort (4.76) than for the pre-DCR cohort (5.67) (\( P < .001 \)). The mean probability of survival based on the TRISS method was 77% for the pre-DCR cohort and 64% for the DCR cohort (\( P < .001 \)). Severe injuries to specific body regions (defined as a regional AIS score of >3) were identified in 65% of all patients. The mean AIS score for the head/neck region increased significantly from 3.9 during the pre-DCR period to 4.3 during the DCR period (\( P < .01 \)), whereas the mean score for all other body systems did not change. In addition, the percentage of patients with severe head injuries increased significantly from 57% during the pre-DCR period to 73% during the DCR period (\( P < .05 \)), whereas the percentage of those with severe facial, chest, abdominal, extremity, and external injuries did not change (Figure 2; Table 2). To examine whether the
significant increase in injury severity among soldiers who subsequently died in the hospital was simply a reflection of increasing injury severity among all wounded patients, overall trends from all injured patients in the JTTR were examined. As demonstrated in Figure 3, there was no significant increase in injury severity (by mean ISS) among all injured patients during this time period. Consistent with previous reports, there were significant decreases seen in the percentage of KIA cases and in the CFR.

When examining fluid and blood product use, we found that there was a notable decrease in the amount of crystalloid given in the first 24 hours, from 6.1 L during the pre-DCR period to 3.2 L during the DCR period (P < .05). Colloid volume was not significantly changed (from 695 mL during the pre-DCR period to 857 mL during the DCR period), and there was also no difference in the use of cryoprecipitate (from 8.6 U during the pre-DCR period to 7.8 U during the DCR period; P = .79) or platelets (from 3.1 U during the pre-DCR period to 3.8 U; P = .61) between the 2 study periods. The initial administration of both packed red blood cells (PRBCs) and fresh frozen plasma (FFP) increased significantly between the 2 time periods (the mean volume of PRBCs increased from 8.4 U during the pre-DCR period to 11.4 U during the DCR period, and the mean volume of FFP increased from 3.2 U during the pre-DCR period to 10.1 U during the DCR period) (both P < .05). Platelets given during these 2 time periods were not significantly changed (from 3.1 to 3.8 U), although very few patients received early platelets in the pre-DCR period. There was a marked change in the blood product ratio administered in the first 24 hours between the 2 time periods. The mean PRBC:FFP ratio changed from 2.6:1 during the pre-DCR period to 1.4:1 during the DCR period (P < .01) (Figure 4; Table 3). The ratio of cryoprecipitate to PRBCs (from 1.03:1 to 0.7:1) and the ratio of platelets to PRBCs (from 0.37:1 to 0.33:1) showed no significant differences between the 2 time periods.

### Discussion

Combat fatalities are an unfortunate but inevitable consequence of war. The high volume and the increased severity of injured patients seen during combat operations throughout history has resulted in major advancements in trauma care. The recent conflicts in Iraq and Afghanistan have been no exception, with real-time data collection and timely analyses providing information that has been used to implement immediate improvements in care. Despite the progress in frontline battlefield care and the implementation of improved military-wide processes,27,28 as many as 87% of

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**Table 2. Demographics and Injury Data for Pre-DCR and DCR Study Cohorts**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Years</td>
<td>2001-2005</td>
<td>2006-2011</td>
<td></td>
</tr>
<tr>
<td>Patients, No.</td>
<td>902</td>
<td>1663</td>
<td></td>
</tr>
<tr>
<td>Deaths, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early (0-24 h)</td>
<td>77</td>
<td>80</td>
<td>.02</td>
</tr>
<tr>
<td>Intermediate (1-7 d)</td>
<td>13</td>
<td>13</td>
<td>.95</td>
</tr>
<tr>
<td>Late (&gt;7 d)</td>
<td>13</td>
<td>6</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Mean ISS</td>
<td>22.5</td>
<td>26.7</td>
<td>.03</td>
</tr>
<tr>
<td>ISS &gt; 15, %</td>
<td>63.5</td>
<td>79.7</td>
<td>&lt;.01</td>
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<td>Any AIS score &gt;3, %</td>
<td>55.6</td>
<td>69.9</td>
<td>&lt;.01</td>
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<tr>
<td>AIS score, %</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>3.9</td>
<td>4.3</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Face</td>
<td>1.71</td>
<td>1.78</td>
<td>.39</td>
</tr>
<tr>
<td>Chest</td>
<td>3.26</td>
<td>3.19</td>
<td>.67</td>
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<tr>
<td>Abdomen</td>
<td>2.93</td>
<td>3.09</td>
<td>.24</td>
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<tr>
<td>Extremities</td>
<td>2.82</td>
<td>2.95</td>
<td>.57</td>
</tr>
<tr>
<td>External (skin)</td>
<td>2.07</td>
<td>2.11</td>
<td>.81</td>
</tr>
<tr>
<td>Revised Trauma Score, %</td>
<td>5.67</td>
<td>4.76</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>TRISS probability of survival, %</td>
<td>0.77</td>
<td>0.64</td>
<td>&lt;.01</td>
</tr>
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</table>

Abbreviations: AIS, Abbreviated Injury Scale; DCR, damage control resuscitation; ISS, Injury Severity Score; TRISS, Trauma Score and Injury Severity Score.

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**Figure 2. Percentages of Soldiers With Severe Injury, Stratified by Study Cohort and Type of Injury**

Statistical significance was determined by use of the χ² test. AIS indicates Abbreviated Injury Scale; DCR, damage control resuscitation; and ISS, Injury Severity Score.
battlefield deaths still occur in the pre-MTF setting.\textsuperscript{29} This is nearly unchanged from the oft-cited 90% prehospital mortality rate of previous conflicts.\textsuperscript{30,31} However, even though the proportion of deaths that occur in the pre-MTF phase of care remains high, there has been a significant improvement in overall survival during the last 70 years. Case fatality rates have decreased to approximately 10% in OIF and OEF,\textsuperscript{32} a significant decrease from the 30% seen during World War II and the 24% seen during the Vietnam and Persian Gulf conflicts.\textsuperscript{33}

Although overall battlefield mortality is now at a historic low, the number of in-hospital deaths has increased significantly but has received relatively little focused analysis. This historically high DOW rate is likely a reflection of improved prehospital care and decreased transport times, resulting in more severely injured patients surviving to reach a medical facility. Although this data set did not provide accurate times from injury to admission, there has been a well-described continuous improvement in transport times, with the average transport time decreasing from approximately 2 hours in the early years of OEF and OIF to approximately 45 minutes in more recent years. The analysis of in-hospital deaths has long been a key component of process- and quality-improvement efforts in civilian trauma centers, and it has been associated with decreased morbidity and mortality. We believe that analysis of this patient population is of equal or even greater importance in the combat setting and can provide invaluable data for evidence-based decision making. In addition, we felt that dynamic analysis of this patient population for significant changes over time would be important for both epidemiologic and clinical reasons.
In the prehospital combat setting, Eastridge et al²⁹ have shown that 24.3% of deaths were due to potentially survivable injuries, with hemorrhage accounting for the vast majority. As such, much of the military-relevant trauma research has focused on decreasing bleeding in the early postinjury period, with tourniquets³⁴-³⁶ and hemostatic dressings³⁷,³⁸ receiving special attention. While the body of literature on pre-MTF deaths continues to grow, there is relatively little data regarding in-hospital combat deaths. However, given that only 24% of pre-MTF combat deaths are due to potentially survivable injuries²⁹ and that 51% of in-hospital deaths were due to wounds that were labeled as potentially survivable,³⁹ it would seem prudent to shift more focus on those patients who DOW after presentation. Of the aforementioned patients, potentially survivable wounds were predominantly due to hemorrhage (80%), whereas nonsurvivable wounds were most often due to head injuries (83%). Other studies support these findings, confirming that head injury and hemorrhage are the most significant causes of in-hospital mortality.²³,⁴⁰ with most deaths occurring shortly after admission.²³,⁴¹ Thus, there appears to be a significant potential for salvage in up to 50% of patients who die of wounds at an MTF.

Head injuries have been identified as one of the most significant causes of death in all combat environments. Our data support this finding and show that head injuries are associated with the highest mean AIS score in DOW patients, have demonstrated an increase in average severity, and represent an increasing percentage of the DOW population. This also implies that head injuries contribute disproportionately to the increase in overall injury severity that we observed in this data set. This injury pattern can be attributed to 2 unique features of our current conflicts: the evolution of enemy armaments and the widespread implementation of improved body armor. The use of improvised explosive devices has also increased dramatically during these conflicts²⁷-²⁹ and is evidenced by a significantly increased percentage of blast injuries.⁴⁴,⁴⁵ The increased incidence and severity of these blast injuries, combined with the increased use of protective gear that shields the torso, has caused damage to be shunted away from the trunk and toward the head and extremities.⁴⁶-⁴⁸ This is consistent with the data presented by many other researchers.⁴⁴,⁴⁹-⁵³ Focused efforts for both the prevention and treatment of major head/brain injury warrant significant attention from combat trauma researchers, and our results indicate that this is becoming an increasingly important cause of in-hospital mortality.⁴⁵-⁵⁸ Significant initiatives aimed at prevention or minimization of traumatic brain injuries, including improved personal protective equipment, vehicles, and wearable helmet blast sensors, have been implemented, but further research efforts are indicated.⁴⁶,⁵⁹,⁶⁰

Severe hemorrhage has clearly been identified as the most common cause of preventable battlefield death. However, only about one-third of hemorrhagic deaths are from wounds amenable to a tourniquet, whereas two-thirds are attributed to juxta-axilla/groin or truncal hemorrhage. Among this patient population, the manner and method of resuscitation and correction of coagulopathy have been essential to improving outcomes. Emerging from the early years of our current conflicts,²²,²³ the foundation of DCR practice rests on the theory that the coagulopathy of trauma is worsened when the physiologic balance of whole blood is disrupted.⁶¹,⁶² Several studies²⁷,²⁸,²⁹,³⁰,³³,³⁴ have shown improvements in early and overall survival and functional outcomes when DCR practices are applied in the wartime setting. Similarly, civilian studies⁶³-⁶⁵,⁶⁶ have suggested survival benefits for trauma patients, particularly those who receive a massive transfusion. It should be noted that although DCR strategies are generally accepted as beneficial,⁶⁸ several studies have shown no mortality benefit,⁶⁹,⁷⁰ whereas others have challenged whether the 1:1 ratio of PRBCs to plasma is truly optimal.⁷¹ Furthermore, no randomized controlled trials have evaluated DCR strategies, and many of the available observational studies are significantly limited by observer and time bias.⁷² Even with these problems, the amount of literature favoring the early transfusion of balanced blood products has led to widespread adoption of these resuscitative techniques in both the military and civilian settings⁶⁹,⁷³ and has powered the general belief that DCR is one of the most important medical breakthroughs of our current conflicts.

Our data confirm findings from other studies showing that the military has actively implemented DCR policies, particularly among the most severely injured patients. We found that the average resuscitation ratio of red blood cell products to FFP decreased significantly between the 2 time periods and approached the “gold standard” of a 1:1 resuscitation ratio in the later years of our study. This reflects both the implementation of DCR protocols and the widespread acceptance of the concept of DCR among military trauma surgeons. Although our analysis primarily focused on red blood cells and FFP, we also noted that select patients received additional products, including cryoprecipitate and platelets, but that there was no significant difference between the 2 time periods with respect to these products. Several previous series⁷⁴,⁷⁵ have demonstrated a potential survival benefit associated with the use of cryoprecipitate or platelets when given in balanced ratios to red blood cells. However, it is difficult to sort out the independent contribution of these products to improved outcomes be-

### Table 3. Data on Fluids and Blood Products Administered in 24 Hours for the 2 Study Cohorts

<table>
<thead>
<tr>
<th>Fluids or Blood Products</th>
<th>Mean Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-DCR</td>
<td>DCR</td>
</tr>
<tr>
<td>Volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crystalloid, L</td>
<td>6.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Colloid, mL</td>
<td>695</td>
<td>857</td>
</tr>
<tr>
<td>PRBCs, U</td>
<td>8.4</td>
<td>11.4</td>
</tr>
<tr>
<td>FFP, U</td>
<td>3.2</td>
<td>10.1</td>
</tr>
<tr>
<td>Platelets, U</td>
<td>3.1</td>
<td>3.8</td>
</tr>
<tr>
<td>Cryoprecipitate, U</td>
<td>8.6</td>
<td>7.8</td>
</tr>
<tr>
<td>Whole blood, U</td>
<td>4.1</td>
<td>6.8</td>
</tr>
<tr>
<td>PRBC:FFP ratio</td>
<td>2.6:1</td>
<td>1.4:1</td>
</tr>
</tbody>
</table>

Abbreviations: DCR, damage control resuscitation; FFP, fresh frozen plasma; ISS, Injury Severity Score; PRBCs, packed red blood cells.
cause they are highly associated with FFP administration and may just represent another surrogate for a balanced product resuscitation.

Along with the change in the resuscitation approach, we noted a significant change in the epidemiology of the DOW population in terms of injury severity and patterns of injury. The overall ISS increased significantly between the 2 study periods, and the anatomic distribution demonstrated an increase in wounds, such as severe brain injury, that typically have been classified as “nonsurvivable.” These findings are additionally confirmed by the comparison of the Revised Trauma Score and TRISS survival probabilities between cohorts, with both demonstrating a greater injury burden and a significantly lower probability of survival in the DCR cohort. We believe that this represents a logical second-order effect of improved early care and resuscitation (namely, that there is improved salvage of less severely injured patients and a decreased number of deaths among those with potentially survivable injuries). In addition to representing an interesting epidemiologic phenomenon and confirmation of improved survival data, this has important implications for the utility and focus of combat death analysis. One could argue that this indicates that analysis of in-hospital deaths may represent an area of diminishing returns because the proportion of patients with truly nonsurvivable injuries increases while the opportunities for improvement correspondingly decrease. It could also support the assertion that a shift to other areas of potential improvement or patient salvage is indicated, such as deployed neurotrauma critical care and head-injury preventative measures. Finally, such data may be important for the design and selection of outcome measures in future studies of this patient population.

Our study has several limitations that are important to discuss. The data used for this analysis come from a combat trauma registry and may be subject to data entry and coding errors. The analysis was done retrospectively and, therefore, is subject to inherent limitations and potential bias or confounding. The potential for observer bias, misclassification, interobserver variability, confounding variables, and differing clinical judgment may have affected the treatment of patients in our study. Although data were included on anatomic areas of injury and injury scores, there was no reliable data on the exact cause of death or the exact timing from injury to death (or transport times). Our study also compares 2 groups in a before-and-after design over an 8-year period, and there were undoubtedly multiple systemic factors that evolved and improved during this time that could have contributed to the outcome measures. We primarily analyzed the ratio of FFP to PRBCs, and there may have been interactions with other products such as cryoprecipitate or platelets that are not accounted for. Finally, only in-hospital deaths were analyzed, and the classification and treatment of prehospital deaths and survivors cannot be inferred.

Conclusions

There has been a significant shift in resuscitation practices in forward combat hospitals, indicating the widespread military adoption of DCR. Patients who died in the hospital during the DCR period were more likely to have been severely injured and to have had severe brain injury, consistent with a decrease in the number of deaths among potentially salvageable patients. Our study provides a valuable adjunct to the currently available DCR literature in that it removes survivor bias and confirms that severely injured patients who DOW are receiving more balanced transfusion ratios and less crystalloid. The widely reported reductions in mortality associated with the adoption of DCR policies appears to also be reflected by an epidemiologic shift in in-hospital deaths toward increased overall injury severity and an increased percentage of soldiers with nonhemorrhagic causes of death, such as severe brain injury.

ARTICLE INFORMATION

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Study concept and design: All authors.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Langan, Eckert.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: All authors.
Study supervision: Martin

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REFERENCES


