Ahead of the curve: Sustained innovation for future combat casualty care

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The figure on the cover of this issue of the *Journal of Trauma and Acute Care Surgery* illustrates concluding casualty statistics from the wars in Afghanistan and Iraq. While various reports on morbidity and mortality among US service personnel have been provided during earlier phases of the wars, this analysis represents the first since the conclusion of combat operations in December 2014.[1–4] The percentage of died of wounds, killed in action, and overall case-fatality rate are based on data from the Defense Casualty Analysis System and calculated using accepted definitions of each of these percentages.[1] The percentage of died of wounds, killed in action, and case-fatality rate of 2.4%, 7.1%, and 9.3%, respectively, provide important information for the Department of Defense Combat Casualty Care Research Program (CCCRP) and offer compelling context for the nation and its volunteer force.

Results from this analysis also show that, as a percentage of all combat-related deaths during the course of the wars, 76% were in the prehospital setting. Although substantial, this value is less than the burden of prehospital mortality in Korea (91% of combat deaths) and Vietnam (88% of combat deaths) as well as that reported by Eastridge et al.[4] in a 2011 analysis (87%). These new findings provide evidence that efforts to research and develop knowledge and materiel solutions, combined with an appropriately postured force structure and an integrated Joint Trauma System, are having an effect on mitigating prehospital mortality. These data also show that the work is not done—the gaps in combat casualty care are not resolved—and further progress must be made to improve prehospital care and alleviate the burden of survivorship (i.e., in-hospital morbidity and mortality), resulting from effective lifesaving efforts.[5]

As the analysis of concluding statistics from the recent wars continues, the Department of Defense CCCRP enters a new era, one that has it endeavoring to stay ahead of the curve and spur innovation to support future and more complex operational scenarios.[6] Even with the end of combat operations in Afghanistan, the United States maintains a significant number of troops in the country to participate in Operation Resolute Support, a North Atlantic Treaty Organization–led mission to provide training and support to local institutions and forces. Simultaneously, the United States and partner nations have initiated Operation Inherent Resolve in northern Iraq and Syria, while continuing small-unit surveillance and targeted operations in parts of Africa. Finally, strategic guidance—including the so-called *pivot* or *rebalance* of policy toward the Asia Pacific region as well as the Army Operating Concept "Force 2025 and Beyond" (AOC 2025B)—informs the research program working to develop solutions to support combat scenarios over large-distance operations in the Pacific and in highly populated urban areas (i.e., megacities).[7–9] Although the scale and conduct of these operations are likely to be different from those of the past 14 years, US personnel will continue to serve in hostile and unpredictable environments around the world. In many ways, future operational scenarios may present greater challenges to casualty care than those of the past.

In this context, future combat casualty care may be tested by longer prehospital times requiring a reappraisal of the traditional "Golden Hour."[6] During the past decade, the Golden Hour has existed as a lifesaving and resuscitation capability based on predictable and enabled levels of care. However, future scenarios, including prolonged field care (PFC) and long-distance air-, land- or sea-based

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medical evacuation, are not likely to adhere to such familiar levels of care. Thus, this lifesaving and resuscitative capability must be buttressed with new knowledge as well as materiel and training solutions for situations of antiaccess/aerial denial (A2AD), long-distance evacuation, large numbers of casualties, and those treated in populated urban settings. In such scenarios, the Golden Hour capability will not necessarily be focused on fixed echelons of care but instead on lifesaving and resuscitative measures aimed at stabilizing, correcting and controlling the sequelae of injury regardless of location. Recognizing that delays in treatment associated with these scenarios could predictably result in higher rates of compartment syndrome, sepsis and organ dysfunction, as well as progression of extremity, thermal, and traumatic brain injury in the days following, the program must also have its eye on solutions to reduce the burden of survivorship and improve quality outcomes as well as survival.

Following the guidance of policies such as the rebalance to the Asia Pacific region, AOC 2025B, and user communities, the CCCRP is adjusting to view its efforts through the lens of future care scenarios. As one example, Table 1 provides a summary of PFC capabilities recently developed by the Special Operations Medical Association Prolonged Field Care Working Group.[10] For this practical outline to be most usable by the research program, the clinical "wants" outlined by the user community need to be translated into more specific lines of scientific effort. Table 2 demonstrates how the PFC capabilities list has been distilled into topic areas more amenable to hypothesis-driven medical research and materiel development. Importantly, not all lines of effort listed in Table 2 are new. In fact, most of these topics have been or are currently being addressed by the program's research equity. However, this process allows the program to be aligned with contemporary requirements and to ensure that any new topics such as telemedicine, targeted resupply of care scenarios, smart deployment of en route care, and even unmanned aerial evacuation are not just futuristic but can be researched and developed to be clinically feasible, useful, and effective at improving outcomes following combat injury.

The articles in this publication are examples of trauma research and special reports that provide foundational knowledge for advances in combat casualty care. This body of peer-reviewed work, much of which was vetted during presentation at the 2014 Military Health System Research Symposium, is diverse in topic and informs the spectrum of casualty care, both prehospital (point of injury and en route) and facility based. This issue contains separate and important synopses on two difficult combat injury patterns, ocular and genitourinary (Vlasov et al. and Oh et al., respectively). Stewart et al. report on the association between rhabdomyolysis and the onset of acute kidney injury, a relevant topic when considering scenarios of TC3-E and PFC. The publication contains findings from King et al., who report on a promising hemostatic foam agent being evaluated for control of intraperitoneal hemorrhage, as well as Branson group's new insight into the impact of aeromedical evacuation on circulating oxygen level, another

TABLE 1. Clinical or Practical Definition of PFC*

1. Monitor the patient to create a useful vital sign trend
- Minimum: blood pressure cuff, stethoscope, pulse oximetry, Foley catheter
- Minimum: improved vital sign interpretation and accurate recording of trends
- Better: add capnography
- Best: vital signs monitor to provide hands-free vital signs at regular intervals

2. Resuscitate patient beyond crystalloid/colloid infusion
- Minimum: field fresh whole blood transfusion kits
- Better: stores (i.e., cases) of crystalloids for burn or head injury resuscitation
- Better: adding lyophilized plasma as available
- Better: fluid warmer for thermoregulation during resuscitation
- Best: maintain stock of or have access to packed red blood cells and plasma
- Best: type-specific donors identified for immediate fresh whole blood draw

3. Ventilate/oxygenate the patient
- Minimum: provide positive end-expiratory pressure via bag valve mask
- Better: provide supplemental oxygen via oxygen concentrator
- Best: portable ventilator with supplemental oxygen

4. Definitive control of airway with inflated tracheal cuff keep patient calm
- Minimum: medic or corpsman prepared for ketamine-assisted cricothyrotomy
- Better: ability to provide long-duration sedation
- Best: rapid sequence intubation and airway maintenance capability
- Best: capability to maintain longer-term patient sedation as needed

5. Sedation and pain control to accomplish Tasks 1–4
- Minimum: provide opiate analgesics titrated via intravenous route
- Better: trained to sedate with ketamine and adjunctive midazolam
- Best: experienced/current in practice of longer-term sedation

6. Physical examination/diagnostic measures to gain awareness of potential problems
- Minimum: assessment and physical examination without advanced diagnostics
- Better: assessment and physical examination enabled by advanced diagnostics
- Best: experienced with physical examination enabled by use of advanced diagnostics

7. Provide nursing/hygiene/comfort measures
- Minimum: ensure patient is clean, warm, dry, padded, catheterized
- Minimum: ensure basic wound care
- Better: elevate head of bed, debride, washout and dress wounds
- Better: decompress stomach as indicated
- Best: experienced and current in the above

8. Perform advanced surgical procedures
- Minimum: chest tube, cricothyrotomy
- Better: fasciotomy, wound debridement, amputation, etc.
- Best: experienced and current in the above

9. Perform telemedicine consult
- Minimum: reliably communicate and present patient and key vital sign trends
- Better: add laboratory values and ultrasound images
- Best: add video teleconference

10. Prepare the patient for flight
- Minimum: familiarity with physiologic stressors of eventual mode of transport
- Better: trained in critical care transport
- Best: experienced/current in critical care transport

*Adapted with permission from: Special Operations Medical Association. Prolonged Field Care Working Group Position Paper: Prolonged field care capabilities. Published: June 2014. Available at: http://www.specialoperationsmedicine.org/Documents/PFC%20WG/PFC%20WG%20Position%20Paper%20-%20PFC%20Capabilities.pdf.

TABLE 2. Lines of Research and Development Established From the More Clinical Definition of PFC Shown in Table 1

1. Research to enable performance of acute lifesaving interventions
- Hemorrhage control (extremity, junctional, torso, head and cervical)
- Establish, confirm, secure, and maintain an endotracheal airway
- Vascular and/or osseous access to enable all forms of resuscitation
- Relief of tension physiology in the thorax
- Acute pain management and methods of transition to prolonged sedation

2. Research to enable diagnostic/detection and physiologicmonitoring
- Monitoring of hemodynamics and recording of hemodynamic trends
- Detection of hydration and intravascular volume status and physiologic reserve
- Detection of fracture and compartment syndrome (extremity, pelvis, cranial)
- Chest imaging (i.e., tube placement and detection of effusion or collapse)
- Detection of intracranial and or intraperitoneal fluid (i.e., blood)

3. Oxygen carrying capacity circulating volume
- Blood and blood components (available, stable, reduced logistical footprint)
- Oxygen carrying blood substitutes
- Crystalloid or colloid fluids

4. Damage-control interventions
- Debride and dress soft tissue injury including thermal
- Extremity fasciotomy and or amputation and dressing
- Extremity stabilization and reperfusion techniques (vascular shunt)
- Procedural sepsis control (abdominal, thoracic)
- Debride, decompress, and manage intracranial injury

5. Automation, tele-enabling, and data exchange
- Automated, including closed loop, ventilation and oxygenation
- Total intravenous anesthesia, including closed loop
- Recording of care scenarios (data capture and performance improvement)
- Information delivery to enable care scenarios
- Information from care scenarios to enable teleconsultation and diagnostics

6. Early organ support and replacement
- Neuropreservation and stabilization (optimization of cerebral perfusion pressure)
- Passive filtration (electrolytes and other)
- Extracorporeal membrane oxygenation
- Renal and or hepatic replacement therapy

7. En route care (land, sea, and air)
- Physiologic impact of prolonged transport of critically injured patient
- Level of damage-control and resuscitative capability for varied scenarios
- Smart disposition of scaled en route care capability/automated and unmanned

8. Smart and targeted resupply of PFC scenarios
- Elements of PFC most critical and feasible for targeted resupply
- Temporal course of care scenarios in which resupply is most valuable
- Methods of resupply to sustain scenarios of PFC

This inventory links the clinical definition to more specific scientific topics to be studied with planned, hypothesis-driven research. This process is designed to deliver knowledge and materiel solutions that are clinically relevant, feasible, and effective. Together, solutions provided by this "bedside to bench to bedside" approach aim to enhance PFC and long-range critical care transport capability.

relevant topic in the domain of PFC. Finally, this issue features special reports on the potential of simulator training in the preparation for battlefield scenarios (Tien et al.), new ways by which to interface with the Food and Drug Administration (Kumar et al.), and the Fifth Annual Joint Theater Trauma System Trauma Conference (Gross et al.).

With this publication it is highly appropriate to consider the concluding combat casualty statistics reported on the cover and to pause for deliberation of lessons learned from the recent wars. However, with a clear-eyed view of current and future operational scenarios and the limited federal commitment to military-relevant trauma research, the CCCRP should rest on neither accomplishment nor regress. As a clarion military mission, the program should remain ahead of the curve and spur innovation for future and possibly more complex casualty care scenarios. To best embolden the volunteer force of the future, the research program must continue to endeavor toward solutions that not only improve statistical survival (prehospital and in-hospital) but also enhance quality and functional recovery.

DISCLOSURE

The authors declare no conflicts of interest.

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