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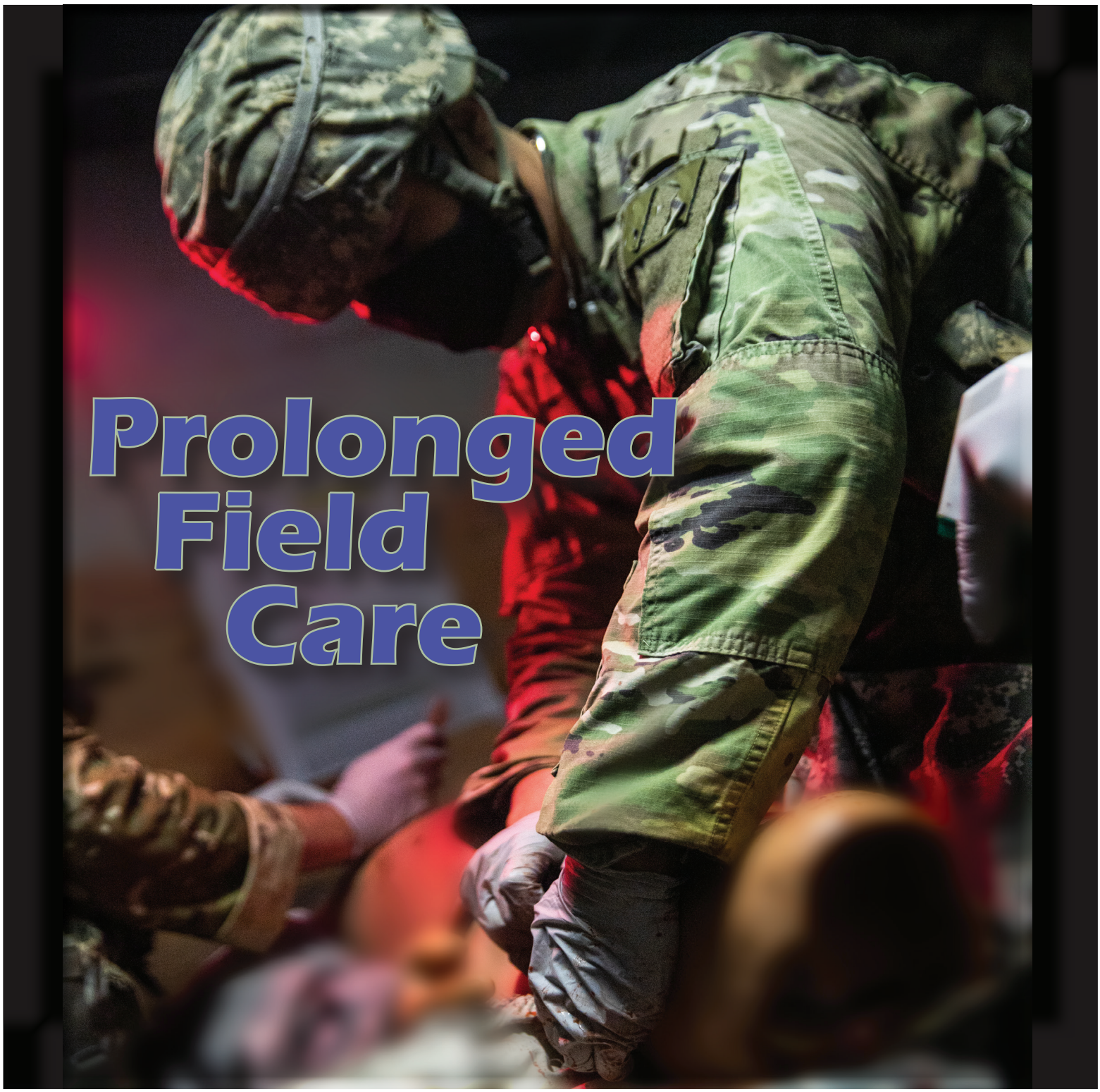

# Prolonged Field Care

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*The Surgeon General*
*Commander*
*US Army Medical Command*

**MG Dennis P. LeMaster**
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*US Army Medical Center of Excellence*

**GEN Paul E. Funk II**
*Commander*
*US Army Training & Doctrine Command*

**Edward A. Lindeke**
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*Borden Institute*

**Lyndon Crippen-Gonzalez**
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# Note from the Editor...

The summer 2022 issue is dedicated to prolonged field care, also referred to as prolonged casualty care. As the battlfield constantly changes, so too must our approach in caring for those service members in austere environments. This issue offers some critical aspects to consider regarding this type of specialty care.

If you or your organization is interested in doing a special topic issue, please contact us at *The Medical Journal* to discuss your ideas and the details involved by emailing usarmy.jbsa.medical-coe.list.amedd-journal@army.mil. We look forward to hearing from you.

*The Medical Journal* accepts submissions year round. Submission guidelines are included in each issue of the journal. To find out more information about the journal and view electronic issues online, log on to our website: https://medcoe.army.mil/the-medical-journal.

The current call for submissions focuses on military veterinary medicine. View the call for submissions on the journal's website, and be sure to share with friends and colleagues. Submission deadline is 31 August, 2022.

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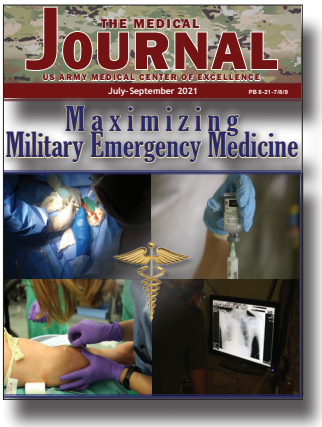
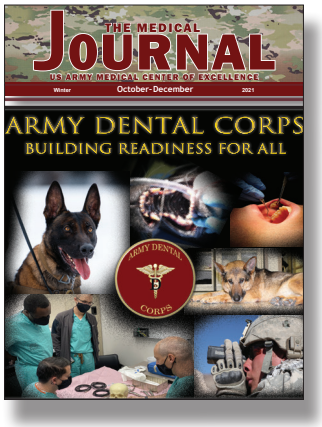



# Descriptive Analysis of Casualties Rapidly Returned to the Fight after Injury: Reverse Triage Implications for Large Scale Combat Operations

MAJ Michael D. April, MD, DPhil, MSc
CPT Rachel E. Bridwell, MD
1LT Jessica Jones, BA
MAJ Joshua Oliver, MD
MAJ Brit Long, MD
MAJ Steven G. Schauer, DO, MS

## Abstract

Background: During large scale combat operations, rising numbers of casualties will likely outstrip in-theater US military medical hospitalization assets. This highlights the importance of identifying those casualties who can return to the fight in order to minimize further medical resource depletion. We describe specific characteristics of casualties returned to duty without requiring evacuation from theater during recent major combat operations.

Materials and Methods: We conducted a secondary analysis of previously published data from the Department of Defense Trauma Registry during 01 January 2007 through 17 March 2020. We included all adult US military casualties. We categorized casualties according to documented disposition, namely, return to duty within 72 hours without evacuation from theater, return to duty greater than 72 hours without evacuation from theater, and all other casualties.

Results: Of 10,182 adult US military casualties, 3,856 (37.9%) returned to duty within 72 hours without evacuation from theater and 220 (2.2%) returned to duty in greater than 72 hours without evacuation from theater. The cohort that rapidly returned to duty had a lower median injury severity score (2) than casualties returning to duty in greater than 72 hours (4) and those evacuated from theater (11). Notably higher proportions of casualties evacuated from theater sustained injuries to the face, thorax, abdomen, and extremities. Modes of transportation were similar across all three groups, though casualties undergoing evacuation from theater were more likely to undergo air transportation during the spectrum of their medical care.

Conclusions: Most combat casualties returning to duty without evacuation from theater did so within 72 hours of hospitalization. Casualties not requiring evacuation from theater were less likely to sustain injuries to the face, thorax, abdomen, and extremities.

*Keywords: combat; trauma; disposition; recovery; return to duty; large scale combat operations; multi-domain operations*

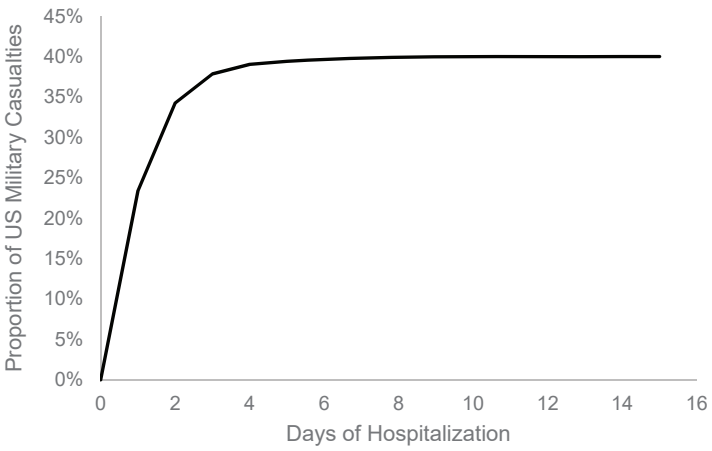
## Background

In recent years, the US Army adopted the multi-domain operations concept.[1] This construct represents a future direction of military combat, combat support, and combat service support systems envisioned by Army leadership, diverging from the counterinsurgency operations which have characterized the last two decades of conflict centered in Iraq and Afghanistan.[2-4] Instead, multi-domain operations (MDO) describes how the Army will battle a near-peer adversary capable of contesting the US in all domains. Large scale combat operations (LSCO) represent the most kinetic manifestation of MDO.[1]

The Army Medical Department, Medical Center of Excellence, and broader Army medical community must now frame the current Army Health System's capability gaps and work to close those gaps in support of the transition to multi-domain operations. Unfortunately, little data exists to clarify the medical challenges associated with multi-domain battle to include LSCO. Notional casualty data from combat training centers for brigade

combat teams[5] and warfighter exercises for maneuver echelons above brigade,[6] currently form the principal lens, through which medical leaders must view the challenges of support operations against near-peer adversaries.

Figure 1. Length of hospitalization for US military casualties returning to duty without evacuation from theater. Vertical axis represents the proportion of all US military casualties. Horizontal axis represents length of hospitalization in days.




Among the challenges is that casualties will almost certainly overwhelm theater hospitalization assets. Warfighter exercises indicate during 8 days of LSCO, a corps (100,000 soldiers) will sustain more than 50,000 casualties. Of these, more than 30,000 typically require hospitalization and evacuation from theater for recovery.[6] Medical brigades represent the medical mission command element generally aligned to a corps. These organizations rarely have enough hospital centers and related theater hospitalization assets assigned to them to offer more than 1,000 hospital beds at any given time. While mass casualty events represented isolated occurrences in Iraq and Afghanistan,[7] these data indicate LSCO will result in daily mass casualty events as a normal course of daily operations. Further compounding this capability gap, these units have very limited mobility, which means they are highly susceptible to destruction from artillery fires. Multi-domain operations will prove devastating to these immobile organizations.

Taken together, the Army's hospitalization capability gap suggests the vital imperative of deliberate approaches to triage during LSCO. Pending significant force design updates expanding and/or augmenting current casualty care capabilities, the Army medical community must consider novel approaches to triage. While much of the previous research has focused on the most acutely injured patients requiring medical intervention,[8] the literature now also requires clarification of those characteristics of patients who can undergo rapid treatment and then return to the fight.

*Goal of the Study:* The goal of this study was to describe, from contemporary combat operations, casualty characteristics and the difference between those who returned to duty within 72 hours versus after 72 hours. We compare the characteristics of casualties not evacuated from theater who returned to duty within 72 hours, versus after 72 hours. We also compare these cohorts to all other casualties.

## Methods

*Study Design and Setting:* We included data from the Department of Defense Trauma Registry (DODTR), formerly known as the Joint Theater Trauma Registry (JTTR), which is the data repository for DoD trauma-related injuries.[9-11] The DODTR includes documentation regarding demographics, injury-producing incidents, diagnoses, treatments, and outcomes of injuries sustained by US/non-US military and US/non-US civilian personnel in wartime and peacetime (including humanitarian) from the point of injury to final disposition. Short-term outcome data are available for non-US casualties. The DODTR comprises all patients admitted to a Role 3 (fixed-facility) or forward resuscitative surgical detachment (FRSD). We defined the prehospital setting as any location prior to reaching a FRSD, field hospital (FH), or a combat support hospital (CSH) to include the Role 1 (point of injury, casualty collection point, battalion aid station) and Role 2 without surgical capabilities (temporary limited-capability forward-positioned hospital inside combat zone).[12-14]

We obtained only de-identified data. Our protocol was submitted to the US Army Institute of Surgical Research (USAISR) regulatory office for review and determined to be exempt from Institutional Review Board oversight.

*Data Collection:* We performed a retrospective review of the prospectively-collected data collected to comprise the DODTR. We queried the DODTR for all encounters that had at least one prehospital assessment or intervention recorded from 01 January 2007 to 17 March 2020 based upon a series of procedural and diagnostic codes. Specifically, we included all casualties with an injury diagnosis using the International Classification of Disease 9th Edition (ICD-9) between 800-959.9, near-drowning/drowning with associated injury (ICD-9 994.1) or inhalational injury (ICD-9 987.9) and trauma occurring within 72 hours from presentation.[11] We excluded non-adult patients and non-US military. This is a secondary analysis of a previously described dataset.[9]

*Outcome Measures:* Our primary outcome measure was patient disposition. We categorized patients according to whether they returned to duty within 72 hours without evacuation from theater, returned to duty in greater than 72 hours without evacuation from theater, or required evacuation from theater. We chose the 72 hour time horizon based upon the doctrinal norm that Role 2 facilities should not hospitalize patients for longer than this period of time.[15] Data used to characterize these populations included demographics, etiology of injury, injury severity scores, and anatomic locations of injuries.

Table 1. Casualty characteristics.

| | | Discharged alive <72 hours, no evacuation from theater n=3856 | Discharged alive >72 hours but no evacuation from theater n=220 | All others n=6106 |
|---|---|---|---|---|
| Demographics | Age | 24 (21-28) | 24 (22-29) | 24 (21-28) |
| | Male | 97% (3755) | 93% (206) | 98% (5990) |
| Injury Type | Battle | 62% (2406) | 52% (115) | 81% (4966) |
| | Non-battle | 37% (1450) | 27% (105) | 18% (1140) |
| Mechanism of Injury | Explosive | 52% (2041) | 40% (90) | 61% (3766) |
| | Fall | 8% (324) | 9% (20) | 4% (236) |
| | Firearm | 11% (458) | 19% (43) | 23% (1415) |
| | MVC | 7% (283) | 9% (20) | 3% (219) |
| | Other | 19% (750) | 21% (47) | 7% (470) |
| Injury Score | Injury Score | 2 (1-5) | 4 (1-5) | 11 (6-20) |
| Any Injury by Body Location | Head/neck | 47% (1832) | 35% (78) | 51% (3109) |
| | Facial | 10% (401) | 16% (37) | 29% (1812) |
| | Thorax | 4% (154) | 7% (16) | 23% (1460) |
| | Abdomen | 5% (199) | 5% (11) | 28% (1747) |
| | Extremities | 23% (895) | 30% (67) | 70% (4281) |
| | Skin | 62% (2399) | 60% (134) | 85% (5196) |
| Outcome | Survival | 100% (3856) | 100% (220) | 96% (5875) |

*Motor vehicle collision: MVC*

*Data Analysis:* We determined the proportions of patients returning to duty as a function of time from hospitalization. Next, we utilized descriptive statistics to characterize our three patient populations. We present continuous variables as means with 95% confidence intervals (CI); non-parametric continuous variables and ordinal variables as medians with interquartile ranges (IQR); and nominal variables as percentages and numbers. We analyzed these data under the assumption of accurate documentation of all care rendered. We performed all statistical analysis using standard statistical software.

## Results

Within the DODTR from 01 January 2007 to 17 March 2020 there were 28,950 encounters with documentation of prehospital activity. There were 10,182 (35.2%) adult US military casualties. Of these, 4,076 (40.0%) returned to duty without evacuation from theater, the majority of which within 72 hours (Figure 1). Specifically, 3,856 (94.6%) returned to duty within 72 hours and 220 (5.4%) returned to duty in greater than 72 hours.

Casualties returning to duty within 72 hours without evacuation from theater had broadly comparable characteristics to those returning to duty in greater than 72 hours without evacuation from theater (Table 1). The former cohort had a lower median injury severity score (2) than casualties returning to duty in greater than 72 hours without evacuation from theater (4) or casualties requiring evacuation from theater (11). Casualties requiring evacuation from theater were distinct from other casualties in that they experienced a higher proportion of injuries due to explosives (61%) or firearms (23%). Casualties undergoing evacuation from theater also experienced a higher proportion of wounds due to battle injuries (81%). We noted no marked differences in anatomic locations of injuries between casualties returned to duty without evacuation from theater within 72 hours versus greater than 72 hours. Notably higher proportions of casualties evacuated from theater sustained injuries to the face (29%), thorax (23%), abdomen (28%), and extremities (70%). Modes of transportation were similar across all three groups, though casualties undergoing evacuation from theater were more likely to undergo air transportation at some point during their care (Table 2).

Table 2. Modes of transportation during treatment in theater.

| | Discharged alive <72 hours, no evacuation from theater n=3856 | Discharged alive >72 hours but no evacuation from theater n=220 | All others n=6106 |
|---|---|---|---|
| BAS | 6% (228) | 7% (17) | 3% (176) |
| Medic | 25% (994) | 25% (56) | 26% (1618) |
| Ground | 8% (339) | 16% (36) | 8% (522) |
| Air | 76% (2960) | 72% (159) | 91% (5556) |

*Battalion aid station: BAS*

## Discussion

Historically, triage systems generally identify patients as expectant, immediate, delayed, or minimal.[16,17] While these systems formed the basis for triage in Iraq and Afghanistan, these settings comprised a relatively resource-sufficient environment during smaller scale counter-insurgency operations; thus, medical providers could perform heroic measures for gravely injured individuals.[18] Similarly, prior DODTR analyses have thought to identify historical and examination findings prognostic of poor outcomes under a similar premise of the importance of identifying casualties requiring prioritization for medical care and resources.[8] However, in the context of MDO and LSCO, a reverse process of triage focusing on identifying specific casualties able to rapidly return to duty without evacuation from theater may need to be the future focus of the military healthcare enterprise. The reasons for this new focus are twofold in that, future large scale combat operations will face two major operational constraints, timely and adequate force reinforcement and force replacements. Thus, optimizing the numbers of casualties returned to duty will be key to continuing combat operations.

To conserve the fighting strength, triage systems will

require a paradigm shift in thinking amongst military healthcare providers. In particular, it will require rethinking of and replacing the current unidirectional casualty flow model from the battlefield into the healthcare system. Instead, healthcare personnel must conceptualize the bi-directional blow of casualties in and out of the healthcare system. To the extent that casualties may flow out of the healthcare system and back to the forward line of troops, which may bolster maneuver formations and prevent further casualties by allowing those formations to rapidly close with and destroy the enemy.

Our analysis of return to duty as a function of hospitalization time offers command surgeons a tool to project the implications of alternative hospitalization thresholds based upon their specific operational scenarios. Most combat casualties returning to duty without evacuation from theater did so within 72 hours of hospitalization. Indeed, we observed an asymptote in the rise of proportions of casualties returning to duty at the 72-hour mark. This is significant in that it provides some validation of the doctrinal 72 hours used as a hospitalization threshold beyond which casualties undergo evacuation out of theater. Only 5.4% of casualties returned to duty beyond this time horizon without undergoing evacuation from theater. This 5.4% represents a cohort for which clinical judgment might play a role in trying to return casualties to the fight. Given this low number, we believe casualties requiring hospitalization for longer than 72 hours should undergo evacuation from theater under most circumstances.

The premise of our analysis that a requirement may exist in future combat operations for a reverse, or bi-directional triage is certain to be controversial. Reverse triage carries with it significant moral and ethical implications for the practice of medicine in that it entails treating as expectant casualties who may otherwise be able to survive. Under the MDO and LSCO scenarios we envision, a reverse triage will be necessary based upon the philosophical doctrine of consequentialism and utilitarianism in order to do the most good for the most casualties.[19,20] However, the extent to which reverse triage will optimize outcomes may not always be apparent looking strictly through the lens of health service support. Part of the justification of reverse triage lies in the idea of conserving and restoring the fighting strength. To the extent that casualties enjoy rapid return to duty, they may be able to reinforce the forward line of troops, who, in turn, may mitigate further casualties by preventing effective enemy fires and maneuver. While these decisions ultimately fall on the shoulder of the senior maneuver commanders, it is imperative that command surgeons expand the apertures of their thought processes so they can provide the best possible advice, not only to bring our wounded home alive but also to win on the future battlefield. This will undoubtedly introduce tension between the professions of arms and medicine, to which all military healthcare providers belong.[21]

Any course of action to avoid requirements for LSCO would require significant financial outlays and restrict the military's operational healthcare assets. Warfighter exercises provide some insight into the current capability gaps. These exercises simulate MDO and LSCO for corps-sized formations (approximately 100,000 personnel). Historically, these formations have sustained on order of 50,000 notional casualties over the course of 8 days of LSCO, including approximately 10,000 killed in action, 10,000 casualties able to return to duty rapidly, and 30,000 requiring evacuation from theater.[6] Yet, the basis of allocation for operational hospitalization assets are such that inadequate bed space will exist even to hospitalize each of the casualties able to return to duty. This projection highlights the importance of being able to identify accurately those casualties able to return to fight rather than expending limited hospitalization resources on casualties requiring prolonged care.

Our data provides some insights into the characteristics of those casualties who did not require evacuation from theater. These casualties were less likely to sustain injuries from explosives or firearms and were also less likely to sustain battle injuries. Casualties not requiring evacuation from theater further had a lower likelihood of injuries sustained to the face, thorax, abdomen, and extremities. These casualties were less likely to have undergone transportation in theater via air; the generalizability of this finding in particular to LSCO during which air superiority is likely dubious. Distinctions demarcating casualties undergoing return to duty within 72 hours versus greater than 72 hours were less clear. The only marked distinction between these cohorts who did not evacuate from theater was a correlation between lower injury severity scores and rapid return to duty.

Unfortunately, while we conducted this analysis to inform casualty care strategies for MDO and LSCO, the generalizability of our findings to these scenarios is questionable. These data all arise from combat casualties treated in the counterinsurgency environments characterized by the wars in Iraq and Afghanistan.[12,13,22] The US military enjoyed marked overmatch against its adversaries during these conflicts and relatively few casualties compared to the numbers suggested by the aforementioned warfighter exercises. It is all but certain the injuries patterns, casualty numbers, and patient dispositions will be markedly different in a MDO setting. In the absence of contemporary LSCO, these data likely represent the best we will have available to inform health service support against a near peer adversary. This is particularly true given that data spanning back to World War II and before are dated and unlikely to be applicable

at this time. Future work might also consider looking at data from the Korean or Vietnam Wars, though again, the generalizability to the contemporary era is uncertain. Another potential alternative would be analysis of notional casualties from training events, though such data will also be of questionable generalizability to the real world setting.[5,6,23]

Another limitation of the study is a lack of granular data related to specific injury patterns. While we were able to abstract injury severity scores and anatomic locations, we have little granular data regarding specific injuries sustained, which speaks to the significant documentation limitations of the DODTR.[11] A related limitation is the retrospective and observational nature of our analysis, rendering the study susceptible to recall bias. Even in the absence of data errors, our data can establish only causation and not correlation.[24] Finally, our data cannot speak to the functionality of casualties who returned to duty. While we presume they were able to perform all aspects of their duties prior to their injuries, this may not be true. It is possible some of them returned to the line with various profiles precluding all pre-injury activities.

This analysis seeks to build upon a growing medical literature exploring the implications of health service support in the context of the military's new multi-domain operations concept. Complex interventions for critically injured patients such as airway management may require less emphasis in future treatment and triage protocols.[2,25-26] To continue the example of airway management, alternative management strategies may require less invasive and resource intensive interventions such as methods to achieve non-invasive oxygenation and positive pressure ventilation.[27-29] Equally important to the study of alternative medical management techniques will be recognition and stress of psychological stress imposed upon healthcare providers striving to provide the best possible care in the worst of circumstances.[30]

## Conclusion

Most combat casualties returning to duty without evacuation from theater did so within 72 hours of hospitalization. Casualties not requiring evacuation from theater were less likely to sustain injuries to the face, thorax, abdomen and extremities.

## Acknowledgements

The authors acknowledge the Department of Defense Trauma Registry (DODTR) for providing the data for this study.

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## Authors

Michael D. April is with Uniformed Services University of the Health Sciences, Bethesda, MD; and 40th Forward Resuscitation and Surgical Detachment, 627 Hospital Center, 1st Medical Brigade, Fort Carson, CO.

Rachel E. Bridwell is with Emergency Medicine, Madigan Army Medical Center, Joint Base Lewis

McChord, WA.

Jessica Jones is with 40th Forward Resuscitation and Surgical Detachment, 627 Hospital Center, 1st Medical Brigade, Fort Carson, CO.

Joshua Oliver is with Uniformed Services University of the Health Sciences, Bethesda, MD; and Madigan Army Medical Center, Joint Base Lewis McChord, WA.

Brit Long is with Uniformed Services University of the Health Sciences, Bethesda, MD; and Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

Steven G. Schauer is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX; and US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

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Biomedical Implications of Military Laser Exposure

# Preparing Emergency Physicians for the Next War: Residency Capstone Training in Prolonged Casualty Care

CPT Jessica Eker, MC
CPT Hugh Hiller, MC
LTC (P) Guyon Hill, MC
LTC Dan Brillhart, MC
CPT Vanessa Hannick, MC

## Abstract

As the landscape and resources of combat operations change and become more unpredictable, the ability to provide prolonged combat casualty care in austere environments will become increasingly important. Prolonged casualty care (PCC) (until recently, prolonged field care [PFC]) is an emerging niche of military medicine that requires specific and dedicated training within our military medical education curricula for providers at all levels. That training should incorporate both didactic classroom instruction and high-fidelity, hands-on, full-scale training in order to prepare providers for delivering care beyond the standard doctrinal timelines employed in recent combat operations. A resolute commitment to training providers in the application of the core principles of PCC will improve the combat readiness of providers and decrease the morbidity and mortality of combat casualties. Carl R. Darnall Army Medical Center's Emergency Medicine Residency Training Program Joint Emergency Medicine Training Exercise is an example of high value training in all facets of military medicine, including prolonged casualty care.

## Introduction

The unique and critical role military emergency medicine (EM) physicians serve in the deployed environment requires a distinctive skill set that is not developed during traditional civilian EM residency training. Central to military medical training is the employment of high-fidelity, hands-on experiences that provide essential exposure to this niche of medicine and cannot be obtained within the confines of the hospital. There is no substitute for realistic training under field conditions to prepare medical personnel for the very real requirement to practice in the harshest and most austere conditions imaginable. As the US military's strategic focus shifts to large scale combat operations and combat deployments simultaneously become more infrequent, our newest military medical providers will have fewer opportunities to practice their unique subset of military medical skills in real-world scenarios, which adds even greater importance to conducting high-fidelity training within our training institutions. In keeping with this, Fort Hood's Carl R. Darnall Army Medical Center Emergency Medicine Residency Program conducts a four-day Joint Emergency Medicine Exercise (JEMX) ,which serves as the capstone to residents' military medical education. Graduating residents from both Army and Navy EM programs join select US Army III Corps, US Air Force, and special operations assets for full-scale, hands-on training to build a ready medical force by focusing on individual physician readiness post-residency while simultaneously exploiting opportunities to meet unit training objectives. In 2021, this training included 43 graduating residents training alongside 1,300 additional medical personnel. Training during this multi-day event consists of didactic lectures, simulation training, and full-scale military medical operations (Table 1) taught and led by subject matter experts across multiple specialties of military medical care.

The first portion of the JEMX consists of didactic lectures from experts across the broad scope of military medicine, which serves as a preparatory experience leading into the hands-on portion of training. At the end of the first 2 training days, learners are given the opportunity to participate in the following labs: autologous whole blood transfusion, aid bag packing and organization, airway management, treatment of the military working dog, and the loading and unloading of casualties from military aircraft. In the final 2 days of the JEMX, learners rotate through full-scale tactical combat casualty care scenarios from point of injury to surgical care and ultimately through intertheater evacuation.

Table 1. Key didactic and applied learning topics taught during Joint Emergency Medicine Exercise (JEMX) 2021.

| Key Didactics Topics | Key Applied Learning Scenarios |
|---|---|
| Tactical Combat Casualty Care | Deployed Ventilator Management |
| Damage Control Resuscitation | Autologous Fresh Whole Blood Transfusion Lab |
| Low Titer Fresh Whole Blood | Packing an Aid Bag |
| Battlefield Pain Control | Rapid Trauma Assessment |
| Care for Military Working Dogs | Tactical Combat Casualty Care Lanes |
| Prolonged Casualty Care | Prolonged Casualty Care Lane |
| Critical Care Air Transport Team Capabilities | Theatre Movement Lane |

A key focus of this year's JEMX was to promote joint interoperability while educating future remote providers on prolonged casualty care (PCC) (until recently, prolonged field care [PFC]) through didactics and full-scale simulation training. PCC is defined as field medical care applied beyond 'doctrinal planning timelines' by a special operations combat medic or higher in order to decrease patient morbidity and mortality.[1,2] This concept focuses on medical care sustained in resource-limited environments until the patient arrives at an appropriate level of care. Unlike previous operations in Iraq and Afghanistan where medical and evacuation assets were robust and air superiority was assured, future small scale or near-peer operations will likely present unique challenges requiring medical personnel to care for casualties for hours or even days before evacuation. Potential PCC scenarios also include maritime or arctic environments and even locations with usually robust evacuation chains when it is unavailable due to severe weather.

This additional focus was timely, given the changing battlefield landscape with the reduction of troops and decrease in combat missions in defined theaters with well-established medical capabilities. These changes highlight the need to shift our focus from the "Golden Hour" paradigm of pre-surgical care to prolonged casualty care.[2,3] Once considered a pillar of special operations forces (SOF) medicine, it is increasingly likely the conventional medical force will be required to become experts in PCC as well. Incorporating PCC-specific training into the medical curriculum of military physicians sets the conditions for success in future conflicts.[4]

## Methods

PCC training at the JEMX began with a 1 hour lecture during the didactic portion of the course by a subject matter expert with extensive, real world PCC experience, followed by training scenarios that took place over the last 2 days of the exercise. During the training lanes, treatment teams were created consisting of 2 EM residents and 1-2 68W combat medics. Each group was assigned a highly experienced senior physician to serve as an observer controller/trainer (OC/T). The goal for this training lane was to implement the principles of Tactical Combat Casualty Care (TCCC) at the point of injury, to properly package and transport a patient, and implement the principles of PCC. The training scenario began with moulaged role players to facilitate data collection during initial assessment and treatment. The teams then transitioned to a perfused cadaver model to allow for realistic training on more invasive procedures. The scenario script is summarized below; however, the experienced OC/Ts were given wide latitude to tailor the training to the needs of the learners.

*The team is supporting military operations in Africa with limited Class VIII medical supplies and no stored blood capabilities. They are called to respond to an ATV rollover accident that occurred just outside camp. On arrival at the point of injury, the scene is secure. There is one simulated patient, a 24-year-old male who is conscious, speaking in full sentences, and complaining of right leg (due to fractured tibia and fibula) and right arm pain (due to a penetrating wound). The patient has already rendered self-aid and applied a tourniquet to his right arm.*

*The goal in this stage of the scenario is for residents to understand basic point-of-injury care using the "MARCH" algorithm which focuses on Massive hemorrhage control, Airway evaluation and management, Respiratory assessment and management, Circulatory assessment and management, Hypothermia treatment or prevention. Initial pain control should also be a focus of care. After the initial point-of-injury assessment and care, 5 residents will transport the patient on a litter to a pre-secured and established safe house, which will serve as their*

Table 2. Durable medical equipment available during prolonged field care training lanes.

| Available Medical Equipment |
|---|
| Tactical Transport Ventilator |
| Portable Monitor with Defibrilator |
| Portable Suction Unit |
| In-line End Tidal Capnograph |

*battalion aid station (BAS). The majority of the prolonged casualty care phase will take place in the BAS.*

*Once the simulated patient is transported to the BAS, the scenario will continue with transition into PCC. Residents are provided with an initial supply of medical equipment and supplies and will not have access to Class VIII re-supply.*

*The patient's initial vital signs are as follows: blood pressure 130/78, heart rate 120, respiratory rate 17, and oxygen saturation 99%. The patient's Glasgow Coma Scale is 15. As needed, the OC/T will adjust vital signs on the provided tablet according to the progression of disease pathology and the applied interventions.*

*If asked, the patient denies loss of consciousness, chest pain, shortness of breath, loss of sensation, headache, neck pain, but does endorse right upper quadrant abdominal pain, right upper extremity pain, and right lower extremity pain.*

*The residents are supplied with common expendable TCCC supplies. The durable equipment available to the residents is listed in Table 2. They also have access to telemedicine consultation using the Telehealth in a Bag platform. The resident is expected to conduct an appropriate trauma assessment and provide treatment as they see fit and within the prescribed core tasks of PCC as outlined in Table 3, as there are no available ground or air evacuation platforms for at least four hours. Residents are expected to document their assessments and treatments on a Prolonged Field Care Casualty Card v22.2 (1Dec2020) (Figure 1).*

## Results

Using resources available, the PFC flowsheet and telehealth capabilities, the resident physicians and their medic augmentees provided realistic PCC for up to 6 hours before evacuating patients to the next higher echelon of care. Each scenario was uniquely guided by the OC/T but started from the same foundation previously described.

Immediately after transporting the patient from point-of-injury to the safe house, residents reassessed the patient first using the MARCH algorithm. They were then informed due to secondary to heavy combat nearby, they would not be able to evacuate for at least 4 hours and would not have any additional resources. They were given a laminated copy of the Prolonged Field Care Card (Figure 1) and instructed to document all interventions, injuries, and vital sign reassessments.

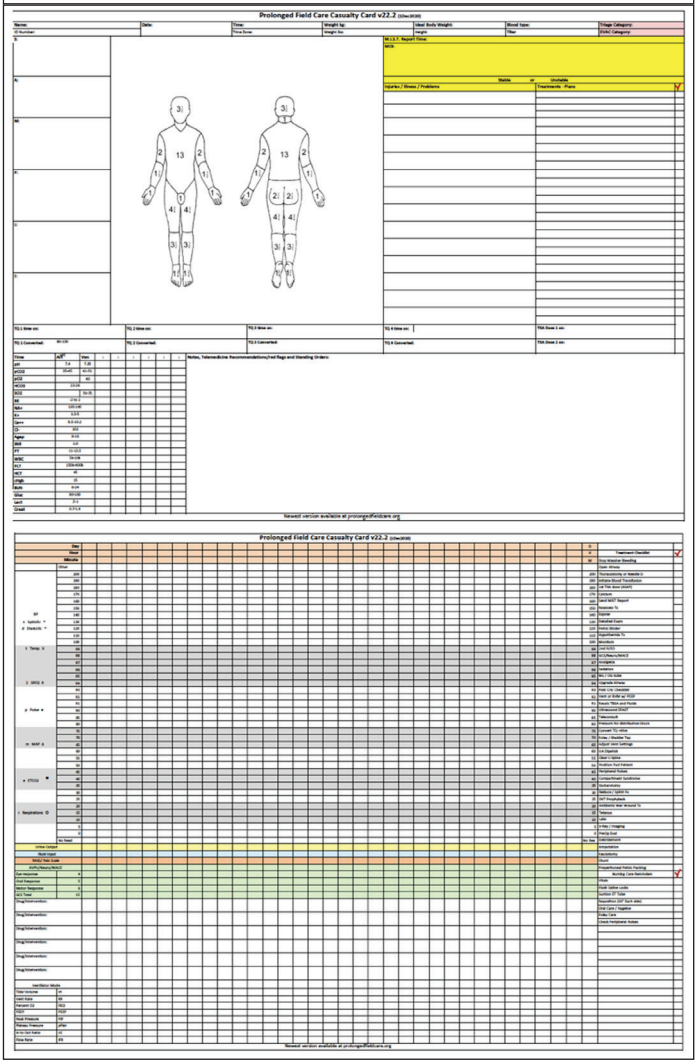
Following initial treatment and stabilization, the teams were guided to reassess the initial tourniquet placed by the patient during self-aid. The learning objective was to identify the need to convert the tourniquet to a pressure dressing, thereby improving the likelihood of

Table 3. Prolonged field care capabilities as identified by the Special Operations Medical Association Prolonged Field Care Working Group (adapted).[16]

| PCC Tasks | Minimum | Better | Best |
|---|---|---|---|
| 1. Monitor the patient to create a useful vital sign trend. | Blood pressure cuff, stethoscope, pulse oximetry, Foley catheter, mental status, and understanding of vital signs interpretation | Add capnometry | Vital signs monitor to provide hands-free vital signs data at regular intervals |
| 2. Resuscitate the patient beyond crystalloid or colloid infusion. | Field fresh whole blood (FWB) transfusion kits | Maintenance crystalloids also prepared for a major burn and/or closed-head injury resuscitation; consider adding lyophilized plasma as available, fluid warmer | Maintain stock of packed red blood cells and fresh frozen plasma; have type-specific donors identified for immediate FWB draw |
| 3. Ventilate/oxygenate the patient. | Provide positive end-expiratory pressure (PEEP) via bag-valve mask (you cannot ventilate a patient in the PFC setting [prolonged ventilation] without PEEP or they may develop acute respiratory distress syndrome) | Supplemental oxygen ($O_2$) via an oxygen concentrator | Portable ventilator with supplemental $O_2$ |
| 4. Gain definitive control of the patient's airway with an inflated cuff in the trachea (and keep the patient comfortable). | Medic is prepared for a ketamine cricothyrotomy | Add ability to provide long-duration sedation | Add a responsible rapid-sequence intubation capability with subsequent airway maintenance skills, in addition to providing long-term sedation |
| 5. Use sedation/pain control to accomplish the above tasks. | Provide opiate analgesics titrated intravenously | Trained to sedate with ketamine (and adjunctive midazolam as needed) | Experienced with and maintains currency in long-term sedation practice using intravenous medications |
| 6. Use physical examination/diagnostic measures to gain awareness of potential problems. | Uses physical examination without advanced diagnostics, maintains awareness of potential unseen injuries (e.g. abdominal bleed, head injury) | Trained to use advanced diagnostics such as ultrasound, point-of-care laboratory testing, etc | Experienced in both |
| 7. Provide nursing, hygiene, and comfort measures. | Ensure patient is clean, warm, dry, padded, and catheterized and provide basic wound care | Elevate head of bed, debride wounds, perform washouts, wet-to-dry dressings, decompress stomach | Experienced in both |
| 8. Perform advanced surgical interventions. | Chest tube, cricothyrotomy | Fasciotomy, wound debridement, amputation, and so forth | Experienced in both |
| 9. Perform telemedicine consult. | Make reliable communications, present patient, relay vital sign trends | Add laboratory findings and ultrasound images | Video teleconference |
| 10. Prepare the patient for flight. | Be familiar with physiologic stressors of flight | Trained in critical care transport | Experienced in critical care transport |
| *Minimum-better-best is a planning tool. Differences between levels may reflect training or experience or available resources.* | | | |

preserving function and avoiding amputation of the extremity. When assessed, the lower extremity was described as neurovascularly intact without any expanding hematoma and without signs of elevated compartment pressure. The OC/Ts attempted to emphasize the appropriate immobilization of unstable fractures in the resource limited environment, where there is no access to the ideal splinting materials available in the hospital.

Figure 1. Prolonged field care casualty card v22.2 (1Dec2020).[10]




Each team developed its own approach to pain management, but OC/Ts were instructed to explore the full range of analgesic options with the teams to maximize learning potential. Resource management and rationing of essential medications is a very real concern in PCC, and this scenario was guided toward introducing these concerns. Regardless of the pain management strategy employed, the learners were required to mix and administer medications themselves, which was a new challenge for nearly all involved.

As the scenario progressed, the patient continued to complain of left upper quadrant pain and was noted to have a distended abdomen and downtrending hemodynamic parameters. This clinical decline prompted teams to initiate fresh whole blood collection and transfusion.[6] One trainee served as the donor and was, therefore, unavailable to provide patient care during collection; this amplified the perception of the challenges of limited personnel. A single unit of fresh whole blood was drawn from and autotransfused back to the donor to balance real world cost with training value.

During transfusion, the patient developed severe, lower extremity pain. On re-evaluation of the fractured, right lower extremity, residents were informed the patient no longer had distal pulses, and the anterior and lateral compartments were palpably tense. As one resident physician prepared the right lower extremity for fasciotomy, the other resident physician initiated a telemedicine consultation with a surgeon via the Advanced Virtual Support for Operational Forces system (ADVISOR) program. The consulted surgeon assisted by providing step-by-step instructions for a four compartment fasciotomy. During the lateral compartment release, video communications were scripted to fail, leaving only voice communication with the surgeon, simulating the challenges that may be faced with telemedicine consultation and emphasizing the need for adaptability in difficult situations.

Throughout the scenario, tasks were required that are traditionally performed by nurses in the hospital setting, such as Foley catheter placement, intravenous line management, medication administration, and administration of blood products. During these PCC scenarios, a large emphasis was placed on having physicians perform the type of patient care tasks often considered "nursing duties" with the intent of helping resident physicians recognize the limited presence of nurses on the battlefield and the resultant importance of competency in these skills they rarely perform in the hospital setting where the vast majority of their training occurs.

## Discussion

PCC is an extension of the principles of TCCC, but it is a distinct entity which deserves particular attention and training effort. In less than ideal scenarios, where casualty evacuation is delayed, providers must address patient care beyond the initial resuscitation and preparation for transport. Beginning in 2013, the Special Operations Prolonged Field Care Working Group, consisting of

subject matter experts across multiple fields of medicine from across the globe, was formed to discuss medical education and training to better support SOF in medical and operational planning of assessment, treatment, and evacuation of critically injured casualties in austere environments.[7] They recognized the likely challenges military medical providers face in austere environments with respect to rapid and reliable casualty evacuation and the blind spot that existed in our training programs regarding the prolonged care required if a casualty could not be evacuated. They delineated 10 key principles and tasks encountered in this increasingly likely scenario, which are outlined in Table 3.[8]

Due to the uniqueness of PCC and it's severalty from TCCC, it requires a dedicated approach with respect to education and training. Physicians must understand the concepts of PCC beyond the ability to perform them primarily and must also understand them well enough to educate and support the combat medics for whom they are responsible. "Constant training and maintenance of the skill set are required to ensure a medic is sustained and able to safely practice them."[9] The skills asked of austere providers are often thought to be beyond their scope of practice; however, in order to decrease overall morbidity and mortality in remote locations or during LSCO, military physicians must help facilitate the expansion of the skill sets of those who will be delivering care in these exacting circumstances.[2]

During the didactic portion of PCC instruction, learners were presented with case-based education to highlight the 10 essential capabilities emphasized in PCC (Table 2) and the paradigm shifts that have occurred with respect to the development of this unique field of austere medicine.[8] The authors realize this is a rapidly evolving field of military medicine, and the current JEMX curriculum will have to be evaluated and updated constantly to meet the evolving needs of the force. As the PFC working group continues to refine its recommendations and guidelines, the JEMX didactics must follow suit.

During this hands-on phase of PCC instruction, learners were challenged to incorporate all 10 core principles with particular emphasis on five capabilities, to which residents have the least exposure and that highlight the challenges of PCC: The incorporation of telemedicine (Core Principle 9), fresh whole blood transfusion (Core Principle 2), pain control (Core Principle 5), nursing/patient care tasks (Core Principles 1 and 7), lower extremity four compartment fasciotomy (Core Principle 8).

Telemedicine consultation is one of the 10 PCC core capabilities, and is an invaluable asset in austere environments where access to medical subspecialties is otherwise limited. In the deployed setting, and in PCC in particular, medical personnel may be called upon to perform life-saving procedures they are not fully comfortable performing under highly stressful conditions. Utilization of teleconsultation can provide real-time support for austere providers from subject matter experts in these challenging situations. Practical training on telemedicine equipment and its use are required for both the remote provider and consultant to optimize its effective implementation. Ideally, training should take place prior to deployment and providers should develop a primary, alternate, contingency, and emergency (PACE) plan for teleconsultation, with an emphasis on who to call and how to do so.[10,11] During this JEMX, residents implemented teleconsultation within a hard structured safe house utilizing both voice-only and combination voice and video communication using the Telehealth in a Bag device and the ADVISOR program to obtain surgeon consultation. The device provides the technical connectivity for telemedicine in the deployed setting, while the ADVISOR program provides a de facto set of specialists who are "on call" to deployed medical personnel.

The telemedicine consultation allowed residents to perform a surgeon-assisted, lower extremity four-compartment fasciotomy, a procedure within the scope of practice of emergency physicians but seldom performed by them or advanced practice medics. The importance of this procedure cannot be overstated in the combat setting, given the significantly increased morbidity that comes with delayed fasciotomy.[12] In the PCC setting, it is unlikely surgeons will be available to conduct a procedure such as this primarily; therefore, access to telemedicine is of great importance to the austere provider.

Similar to TCCC, the immediate priority of PCC is first to control any massive life-threatening hemorrhage. As described by Eastridge et al, hemorrhage has remained the leading cause of potentially preventable pre-hospital cause of death on the battlefield. While the wide application of tourniquets on the battlefield have significantly improved our ability to control compressible hemorrhage, for the austere military provider, controlling non-compressible hemorrhage remains a unique challenge.[13]

With respect to combat casualty survivability, after effective hemorrhage control, the next most critical intervention is early transfusion of whole blood. According to a study by Shackleford et al, short-term survival of combat casualties is significantly improved when blood products are administered within 34 minutes of injury.[14,15] Whole blood transfusions primarily utilize cold-stored products; however, in far forward locations

the transport of stored blood can be logistically challenging with respect to both volume available, length of safe storage, and the ability to adequately warm cold-stored products. Whether or not stored blood products are available, fresh whole blood transfusion is a critical capability for improving pre-hospital survivability in the setting of massive hemorrhage. Because blood is collected from a pool of pre-screened donors and almost immediately transfused into the recipient, the need for storage and warming are bypassed, thus increasing the volume available and decreasing time to transfusion.[15]

Finally, for any patient care encounter in prolonged field care, competency in tasks typically considered nursing duties, such as the measurement of urine output, is extremely important. Accurate measurement of urine output is particularly useful for guiding resuscitation, but requires Foley catheterization and hourly documentation of output to determine the efficacy of fluid resuscitation. Similarly, the mixing and administration of medications, patient comfort measures, and the trending of vital signs and documentation are seldom performed by physicians and many medics. Despite the lack of emphasis on these skills in traditional medical education curricula, proficiency in these skills is of the utmost importance, as resources and personnel are limited in the austere environment.

## Conclusion

Military medicine is a unique niche of healthcare that requires a thorough understanding of deployment/austere medicine, including point of injury care, medical evacuation, conventional medicine in resource-limited settings, and prolonged casualty care. That understanding is dependent upon creating a military medicine curriculum which includes high-fidelity hands-on learning, as provided in the Carl R. Darnall Medical Center's Joint Emergency Medicine Exercise. PCC has long taken a back seat to the other areas of military medicine because of the nature of combat operations over the last two decades, and most military medical providers get limited exposure to this area of combat casualty care. With the changing nature of current and future combat operations, PCC deserves more emphasis and attention in our military medical curricula as a critical area of education in order to prepare our military medical providers for the challenges of future military conflicts. For many residents, the Carl R. Darnall Army Medical Center JEMX was their first exposure to this critical and evolving subset of austere medicine, and it proved to be a valuable learning experience for residents and medics alike. In particular, it highlighted the unique core principles of PCC, many of which are not emphasized by standard medical education within the hospital.

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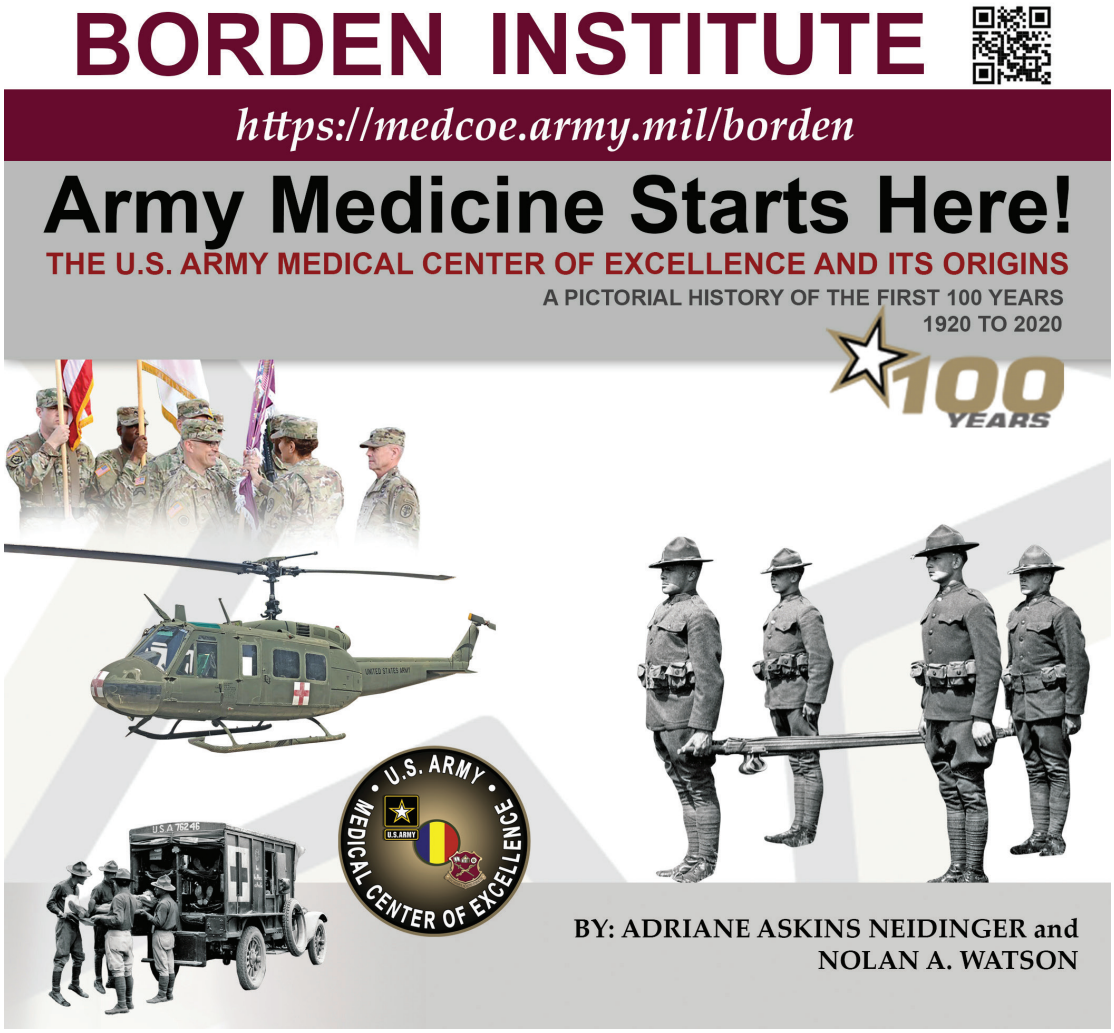
## Authors

CPT Jessica Eker, CPT Hugh Hiller, LTC (P) Guyon Hill, LTC Dan Brillhart, and CPT Vanessa Hannick are all with Carl R. Darnall Army Medical Center, Fort Hood, TX.



# An Analysis of the Incidence of Hypocalcemia in Wartime Trauma Casualties

Mireya A. Escandon, BS
Ashley D. Tapia, BS
MAJ Andrew D. Fisher, MD, MPAS
COL Stacy A. Shackelford, MD
COL Vikhyat S. Bebarta, MD
Franklin L. Wright, MD
Susannah E. Nicholson, MD
MAJ Ronnie Hill, MS
James A. Bynum, PhD
MAJ Steven G. Schauer, DO, MS

## Abstract

Background: Massive transfusion protocols implement the use of blood products to restore homeostasis. Citrated blood products are required for massive transfusions and can induce hypocalcemia, resulting in decreased cardiac contractility. Recent data suggests that major trauma alone is associated with hypocalcemia. This phenomenon remains poorly described. We seek to characterize the incidence and risk factors for early hypocalcemia in the setting of combat trauma.

Materials and Methods: This is a secondary analysis of previously described data from the Department of Defense Trauma Registry from January 2007 to March 2020. In this sub-analysis, we selected only casualties that had at least one ionized calcium measurement. We defined hypocalcemia as an ionized calcium level of <1.2mmol/L.

Results: Within our study database, there were 142 adult casualties that met inclusion with at least one calcium value documented. We found 72 (51%) experienced at least one episode of hypocalcemia. Median composite injury severity score (ISS) was significantly lower in the control cohort compared to those with hypocalcemia (9 versus 15, p=0.010). Survival was similar between the two groups (97% versus 90%, p=0.166). On multivariable analysis when evaluating serious injuries by body region, only serious injuries to the extremities were significantly associated with developing hypocalcemia (odds ratio [OR] 1.48, 95% confidence interval [CI] 1.00-2.21). When comparing prehospital interventions, only intravenous (IV) fluid administration was associated with high proportions experiencing hypocalcemia (25% versus 43%, p=0.029). In the multivariable model adjusted for ISS, mechanism of injury, and patient category, IV fluids were associated with the development of hypocalcemia (OR 2.48, 95% CI 1.03-5.94). When comparing vital signs, only respiratory rates were noted to be higher in the hypocalcemia cohort (18.6 versus 20.4, p=0.048).

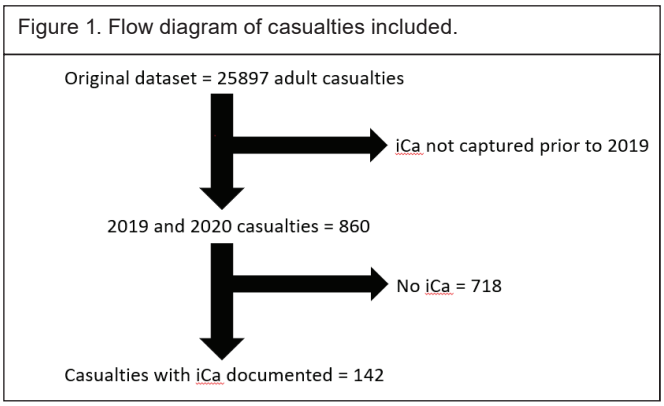
Conclusions: Approximately half of combat casualties with available ionized calcium (iCa) level were hypocalcemic. Prehospital IV fluid use was associated with the development of hypocalcemia. Our study has implications for forward-staged medical teams with limited laboratory analysis capabilities. Additional research is needed to determine whether calcium replacement improves survival from traumatic injury and to identify the specific indications and timing for calcium replacement. This study will help inform a clinical study intended to aid in the development of clinical practice guidelines for deployed medical personnel.

*Keywords: prehospital; combat; casualty; battlefield; military; hypocalcemia*

## Introduction

Calcium is essential to maintaining proper metabolic function by modulating muscle function (including cardiac), nerve activity, bone mineralization, and functioning as Factor IV in the coagulation cascade.[1,2] Acute hypocalcemia may be seen in individuals with multisystem trauma.[3] Multisystem trauma is often accompanied by severe hemorrhage and requires resuscitation with massive transfusion protocols.[4] Multisystem trauma and hemorrhagic shock can cause acidosis, coagulopathy and hypothermia, collectively known as the lethal triad. Hypocalcemia is associated with mortality, is a key factor in coagulopathy, and has been described as a component of the "lethal diamond" along with hypothermia, acidosis, and coagulopathy.[5,6] Calcium levels appear to

play a key role in the physiologic and biochemical alterations induced during traumatic injury by affecting cardiac contractility.




The timing and degree of calcium repletion optimal for trauma patients and the effect on survival remain unknown.[4,7-9] Currently, the Tactical Combat Casualty Care (TCCC), Prolonged Field Care/Prolonged Casualty Care (PFC/PCC), and the Damage Control Resuscitation (DCR) Clinical Practice Guideline (CPG) suggest administration of 1 gram of calcium after administering the first unit of blood product, with the DCR CPG recommending additional 1 gram of calcium after every 4 units of blood products.[10-12] The PFC/PCC and DCR CPG suggest monitoring iCa and administering calcium for levels <1.2mmol/L.[10,11] The European guideline on management recommends maintenance of calcium within normal levels but does not state what range would be considered normal.[2] The incidence of hypocalcemia and severe hypocalcemia in trauma patients may vary depending on the specific threshold used in the definition. Giancarelli et al defined hypocalcemia as ionized calcium (iCa), as <1.12 mmol/L, and severe hypocalcemia as <0.90 mmol/L.[7] The limited studies conducted do not help elucidate answers to these problems, and only one study exists relevant to the combat setting. Thus, we sought to describe the incidence of hypocalcemia and outcomes during combat operations, as the unique injury patterns seen in combat trauma may predispose casualties to a higher rate of hypocalcemia.

## METHODS

*Data Acquisition*: This is a secondary analysis of a previously described dataset from the Department of Defense Trauma Registry (DODTR).[13] The primary dataset was based on casualties that had at least one prehospital assessment or intervention recorded from 01 January 2007 to 17 March 2020. The US Army Institute of Surgical Research (USAISR) regulatory office reviewed the protocol and determined it was exempt from Institutional Review Board oversight. In this analysis, we included only casualties which had at least one iCa measurement.

*DODTR Description*: The DODTR, formerly known as the Joint Theater Trauma Registry (JTTR), is the data repository for DoD trauma-related injuries.[9,14] The DODTR incorporates demographics, injury-producing incidents, diagnoses, treatments, and outcomes of injuries sustained by US/non-US military and US/non-US civilian personnel in wartime and peacetime (including humanitarian) from the point of injury to final disposition from the acute care phase. The DODTR includes patients admitted to a Role 3 (fixed-facility) or forward surgical team (FST) with an injury diagnosis using the International Classification of Disease 9th Edition (ICD-9) between 800-959.9, near-drowning/drowning with associated injury (ICD-9 994.1) or inhalational injury (ICD-9 987.9) and trauma occurring within 72 hours from presentation. The registry defines the prehospital setting as any location prior to reaching a surgical capability. Starting 03 September 2019, the DODTR started capturing ionized calcium data when available, which accounts for the overall low numbers.

*Analysis*: Statistical analysis was performed using standard statistical software. Continuous variables are presented as means and 95% confidence intervals (CI), nonparametric continuous variables and ordinal variables as medians and interquartile ranges (IQR), and nominal variables as percentages and numbers. Abbreviated injury scale measurements were converted into binary measurements with serious defined as ≥3 and not serious as <3 as we have done previously.[15,16] Given the limitations with vital signs captured prehospital and lack of time stamps within our dataset for emergency department vital signs, we relied on the "worst" emergency department (ED) vital signs documented.[13,16] For the purposes of this analysis, a threshold of <1.2mmol/L defined hypocalcemia.[17] Shock index and revised trauma scores were calculated using previously published formulas.[18] Multivariable logistic regression models were performed seeking associations and presented as odds ratio (OR) and 95% CI. When the low incidence of some findings within our population (e.g. serious injuries to the face, etc.) resulted in model dissociation, we used a penalized Firth regression model to search for associations in a multivariable model.[19,20]

## RESULTS

Within our dataset there were 860 casualties from 2019 through the partial year 2020 (months not available). Out of these patients, 142 adult casualties had at least one ionized calcium value captured in the DoDTR (Figure 1). We found that 72 (51%) experienced at least one

Table 1. Demographics, injury data, and outcome data.

| | | No hypocalcemia n=70 | Hypocalcemia n=72 | p-value |
|---|---|---|---|---|
| **Demographics** | **Age** | 30 (25-31) | 30 (30-33) | 0.166 |
| | **Male** | 100% (70) | 100% (72) | N/A |
| **Affiliation** | **US military** | 17% (12) | 16% (12) | 0.072 |
| | **NATO military** | 0% (0) | 7% (5) | |
| | **Non-NATO mil** | 52% (12) | 17% (12) | |
| | **Humanitarian** | 30% (21) | 37% (27) | |
| **Mechanism of injury** | **Explosive** | 51% (36) | 45% (33) | 0.473 |
| | **Fall** | 4% (3) | 1% (1) | |
| | **Firearm** | 38% (27) | 44% (32) | |
| | **MVC** | 5% (4) | 5% (4) | |
| | **Other** | 0% (0) | 3% (2) | |
| **Injury Score** | **Composite** | 9 (2-19) | 15 (5-25) | 0.010 |
| **Serious injuries by body region** | **Head/neck** | 15% (11) | 23% (17) | 0.237 |
| | **Face** | 0% (0) | 1% (1) | 0.322 |
| | **Thorax** | 11% (8) | 15% (11) | 0.623 |
| | **Abdomen** | 14% (10) | 23% (17) | 0.200 |
| | **Extremities** | 25% (18) | 37% (27) | 0.131 |
| | **Skin** | 4% (3) | 1% (1) | 0.362 |
| **Outcome** | **Alive** | 97% (68) | 90% (65) | 0.166 |

episode of hypocalcemia. The median age for the control cohort and the hypocalcemia cohort was 30, all were male, and most were injured by explosive. Median composite injury severity score (ISS) was significantly lower in the control cohort (9 versus 15). Survival was similar between the two groups (97% versus 90%) (Table 1). On multivariable analysis for serious injuries by body region, only serious injuries to the extremities were significantly associated with developing hypocalcemia (odds ratio [OR] 1.48) (Table 2). When comparing prehospital interventions, only IV fluid administration was associated with hypocalcemia (25% versus 43%, p=0.029). In the multivariable model adjusted for ISS, mechanism of injury, and patient category, IV fluids were associated with hypocalcemia (OR 2.48) (Table 3). When comparing vital signs only respiratory rate was noted to be higher in the hypocalcemia cohort (18.6 versus 20.4, p=0.048). There were no between-group differences in shock index or revised trauma score (Table 4).

## Discussion

In this study, using the recommendations of the DCR

Table 2. Odds ratios for serious injuries by body region with hypocalcemia as the outcome in a multivariable regression analysis*.

| | |
|---|---|
| Head/neck | 1.40 (0.91-2.19) |
| Face | 1.53 (0.34-18.82) |
| Thorax | 0.93 (0.54-1.61) |
| Abdomen | 1.34 (0.85-2.17) |
| Extremities | 1.48 (1.00-2.21) |
| Skin | 0.50 (0.15-1.33) |

**Firth bias overestimates used due to dissociation of serious injuries to the face from the logistic regression model*

CPGs, we defined hypocalcemia as anything less than 1.2 mmol/L. Within our dataset, a total of 142 individuals had a documented iCa level of which 51% had a reported incident of hypocalcemia. While it is well known hemorrhage that leads to shock may deplete calcium, we found IV fluids were associated with hypocalcemia. Of the recorded vital signs, only respiratory rates were different between the hypocalcemic and non-hypocalcemic groups. However, our sample size is relatively small, and this may account for trends between the two groups that did not reach significance.

The association of prehospital IV fluids and hypocalcemia may be due to iatrogenic dilution,[3] although an earlier study on hypocalcemia failed to demonstrate an association between the amount of crystalloid and hypocalcemia.[21] In a more recent study, the use of IV fluids did not correlate with hypocalcemia. Moore et al reported no correlation between the amount of fluid administered prehospital and calcium levels on admission (normocalcemic patients receives a mean of 250 ml versus 400 ml for hypocalcemic patients, p=0.43).[22] Giancarelli had similar findings.[7] Interestingly, there was no other association with hypocalcemia noted in this study. Furthermore, there was no difference in mortality. A systematic review by Vasudeva et al demonstrated increased mortality in hypocalcemic patients within the three studies reviewed.[3]

A study conducted by Giancarelli et al reviewed 156

Table 3. Prehospital interventions comparison and multivariable model adjusted for injury severity score, mechanism of injury, and patient category between hypocalcemia and normocalcemia patients.

| | No hypocalcemia | Hypocalcemia | p-value | Odds Ratio* |
|---|---|---|---|---|
| Whole Blood | 10% (7) | 18% (13) | 0.228 | 1.25 (0.32-4.84) |
| Packed red cells | 5% (4) | 3% (2) | 0.438 | 0.16 (0.01-2.30) |
| Fresh frozen plasma | 1% (1) | 3% (2) | 1.000 | 3.02 (0.10-90.08) |
| Wound dressing | 37% (26) | 33% (24) | 0.634 | 1.18 (0.44-3.12) |
| Warming | 54% (38) | 47% (34) | 0.399 | 1.33 (0.45-3.91) |
| Limb tourniquet | 28% (20) | 34% (25) | 0.430 | 1.94 (0.55-6.80) |
| Intubation | 3% (2) | 4% (3) | 1.000 | 1.45 (0.18-11.60) |
| IO access | 8% (6) | 4% (3) | 0.322 | 0.25 (0.03-2.06) |
| IV fluids | 25% (18) | 43% (31) | 0.029 | 2.48 (1.03-5.94) |
| Tranexamic acid | 11% (8) | 23% (17) | 0.056 | 2.27 (0.63-8.12) |
| Calcium | 3% (2) | 1.3% (1) | 0.617 | 0.30 (0.00-10.71) |

**Multivariable logistic regression model used*

Table 4. Comparison of select vital signs and scores.

| | No hypocalcemia | Hypocalcemia | p-value |
|---|---|---|---|
| Systolic pressure* | 120.5 (115.8-125.2) | 121.1 (116.6-125.6) | 0.858 |
| Diastolic pressure* | 75.7 (71.7-79.7) | 75.5 (72.2-78.7) | 0.933 |
| Heart rate* | 100.5 (94.3-106.7) | 102.5 (97.0-107.9) | 0.632 |
| Pulse oximetry# | 97 (96-99) | 97 (94-100) | 0.395 |
| Respiratory rate* | 18.6 (17.7-19.6) | 20.4 (18.9-21.9) | 0.048 |
| Temperature* | 97.8 (97.4-98.2) | 97.9 (97.5-98.4) | 0.731 |
| Glasgow Coma Scale# | 15 (3-15) | 15 (3-15) | 0.639 |
| Shock index* | 1.03 (0.96-1.10) | 1.07 (1.02-1.13) | 0.323 |
| Revised Trauma Score* | 6.5 (6.1-7.0) | 6.3 (5.9-6.7) | 0.386 |

**Presented as means, confidence of intervals, and t-test*
*#Presented as median, interquartile range, and Wilcoxon test*

civilian cases with documented massive transfusion.[7] This case study defined hypocalcemia as iCa <1.12 mmol/L, and severe hypocalcemia as less than 0.90 mmol/L. Cases that fell within these categories were compared, and 97% of patients had documented hypocalcemia, with 71% documented as severe hypocalcemia. This current study demonstrated 51% of patients with iCa measurement available had hypocalcemia on hospital admission (<1.2mmol/L). Also noted, none of the patients with iCa value available received massive transfusion. A smaller study by McKay et al evaluated 41 patients who received massive transfusion (≥10 units of packed red cells). Hypocalcemia was present in 35 (85%) patients and hypercalcemia in 9 (22%).[9] Using the Youden index, they identified optimal iCa limits at 0.84 mmol/L and 1.3 mmol/L.[9] A 2011 study from Australia evaluated patients undergoing massive transfusion, defining severe hypocalcemia as iCa < 0.8 mmol/L.[8] The mean iCa for the 352 patients was 0.8 (IQR 0.7 to 0.9) with severe hypocalcemia in 52% of the cohort. They noted a linear relationship between hypocalcemia and mortality, with acidosis and fresh frozen plasma transfusion volume as the most significant risk factors. Within the military, a prospective study conducted by Connor et al assessed the initial iCa levels in military casualties.[4] In this study, they defined hypocalcemia as iCa <1.2 mmol/L and found that 55.5% of casualties with multisystem trauma had a higher prevalence of hypocalcemia upon arrival to a forward surgical team (FST). The mean iCa level found within this study was 1.16 mmol/L.

As with any retrospective analysis, several limitations exist in this study. First, our data depends on proper documentation. Previous studies have highlighted documentation limitations for combat casualties.[16,23] Additionally, with only 142 patients in our dataset, a larger dataset is needed for more reliable validation. Our sample size limits the ability to draw further conclusions. Of note, the DoDTR only recently started collecting calcium data so the data capture remains immature.

## Conclusion

Approximately half of combat casualties with available iCa level were hypocalcemic. Prehospital intravenous fluid use was associated with the development of hypocalcemia. Our study has implications for forward-staged medical teams with limited laboratory analysis capabilities. Additional research is needed to determine whether calcium replacement improves survival from traumatic injury and to identify the specific indications and timing for calcium replacement. This study will help inform a clinical study intended to aid in the development of clinical practice guidelines for deployed medical personnel.

## Acknowledgements

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## Authors

Mireya A. Escandon is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Ashley D. Tapia is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Andrew D. Fisher is with Texas Army National Guard, Austin, TX; and University of New Mexico School of Medicine, Albuquerque, NM.

COL Stacy A. Shackelford is with Joint Trauma System, JBSA Fort Sam Houston, TX.

Vikhyat S. Bebarta is with Center for COMBAT Research, University of Colorado Anschutz Medical Campus, Aurora, CO; and 59th Medical Wing, JBSA Lackland, TX.

Franklin L. Wright is with Center for COMBAT Research, University of Colorado Anschutz Medical Campus, Aurora, CO.

Susannah E. Nicholson is with University Hospital at University of Texas Health San Antonio, San Antonio, TX.

Ronnie Hill is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

James A. Bynum is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

MAJ Steven G. Schauer is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; Brooke Army Medical Center, JBSA Fort Sam Houston, TX; and Uniformed Services University of the Health Sciences, Bethesda, MD.

# Simulation-Based Assessment of the Novel, Disposable i-view Video Laryngoscope by Emergency Medicine Physicians

CPT Matthew R. Figlewicz, DO
CPT Krishna Constantino, MD
Jessica Mendez, BS
Mireya A. Escandon, BS
Nguvan Uhaa, BS, LPN
LTC Joseph K. Maddry, MD
MAJ Steven G. Schauer, DO, MS

## Abstract

Introduction: Airway obstruction is the second leading cause of potentially preventable death on the battlefield. Previous studies demonstrate the most frequent airway intervention is intubation. Currently, the US Army has advanced video laryngoscopy (VL) in its sets, kits, and outfits (SKOs) at a cost of approximately $12,000 and generally only deploys them to the forward resuscitative surgical detachments and field hospitals. The i-view is a disposable video laryngoscope that costs approximately $120. The purpose of this study was to assess operator performance with this device and survey user opinions.

Methods: We conducted a prospective, observational study with emergency medicine residents and attending physicians using a synthetic cadaver model. Placement success, time-to-cannulation, number of attempts, and number and type of complications were recorded, followed by surveys.

Results: We enrolled 31 participants. One was missing data and was excluded, leaving 30 for analysis. The median age was 29, most (66%) were male, most were Air Force (57%), in-training residents (77%) with few reporting previous deployment experience (13%). Almost all had real patient experience with both direct (93%) and video laryngoscopy (90%). Most (90%) were able to get a grade 1 view with all achieving airway cannulation on first-pass attempt. The median time to cannulation was 11.6 seconds. On the post-procedure survey, most strongly agreed they would use this in the deployed setting (77%). Most reported they found it easy to use (77%).

Conclusion: Our simulation-based study demonstrates the device has strong potential use for the clinical setting with all achieving rapid first-pass success for intubation. This study lays the foundation for validation of this device in the clinical setting.

*Keywords: i-view; airway; video; laryngoscopy; emergency*

## Introduction

Airway obstruction is the second leading cause of preventable death on the battlefield.[1] Management of these airways is frequently required due to traumatic disruption of the anatomical structures, complicating both oxygenation and ventilation by the casualty. It also complicates attempts at advanced airway placement with either a supraglottic airway (SGA), cricothyrotomy, or endotracheal intubation (ETI).[1,2] Tactical Combat Care Casualty (TCCC) guidelines recommend nasopharyngeal airway (NPA) placement followed by cricothyrotomy in the prehospital combat setting while delaying ETI until a more controlled setting can be obtained or a more skilled airway operator is available.[3] In the deployed setting, evacuation may be delayed secondary to location or contact with a hostile force, which may prolong care under fire, resulting in possible decompensation of a previously stable patient. This forces airway intervention by a less skilled operator.

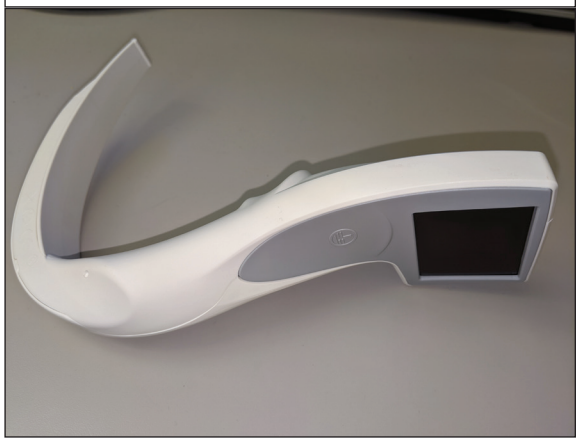
Previous studies have demonstrated the most frequent airway intervention in a combat casualty setting is ETI.[2,4-7]

ETI is commonly obtained through video laryngoscopy (VL) and ETI is most frequently performed by trained medical personnel. Specific to VL, currently the US Army has advanced VL in sets, kits, and outfits (SKOs) at a cost of approximately $12,000 and are almost exclusively deployed to forward resuscitative surgical detachments (FRSD) and field hospitals.

Studies have demonstrated VL has an increased first pass success rate of ETI in the hands of both the skilled and less skilled operator.[8-10] This has been demonstrated both in the hospital setting and prehospital setting.[11-13] With multiple studies and meta-analysis demonstrating improved first pass success of ETI in both the prehospital and hospital setting, having the option for both DL and VL in either setting represents an opportunity to improve patient outcomes.

The novel i-view VL device (Figure 1) is disposable and costs approximately $120—both of which make it a desirable option for forward staging and prolonged field care or delayed evacuation situations. The single use also results in the device being considered a supply rather than durable equipment which would eliminate the need for routine equipment checks and tracking requirements. The goal of this study was to assess whether the i-view demonstrated the potential to provide VL technology to forward staged locations.

Figure 1. Example of the i-view video laryngoscope used in the study.

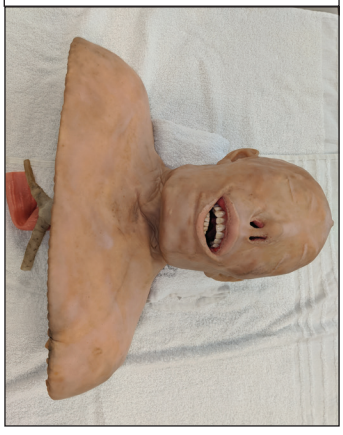


## Methods

*Ethics*: The US Army Institute of Surgical Research regulatory office reviewed the protocol and determined it was exempt from institutional review board oversight. Participants were briefed about the study and were provided an information sheet. Participation was voluntary. All data collection was anonymous.

*Subjects & Setting*: The study took place during the routine residency and staff meetings at the Brooke Army Medical Center (BAMC). The department has a 3-year, American Council of Graduate Medical Education (ACGME) Emergency Medicine residency. Each year, the program has 8 Army and 8 Air Force residents rotating through the program. BAMC is the largest hospital in the Department of Defense and the only military hospital designated as a level 1 trauma center. The facility admits public trauma and serves as one of two regional trauma receiving centers.

Figure 2. Image of the synthetic airway trainer used in the study.



*Data Collection*: Potential participants were recruited from routinely occurring events prior to the COVID-19 pandemic onset, such as grand rounds and staff meetings. Volunteers were provided information about the study, the goals of the study, and an information sheet. They were provided an opportunity to ask questions prior to agreeing to participate. Once they agreed to participate, they were provided a demographic form. Participants could handle the device and evaluate it; however, they were not allowed to perform practice intubations. They could set up the intubation equipment using a method of their choosing. In addition to the endotracheal tube, there were provided a bougie, a malleable stylet, and a rigid stylet. The choice of which of these available adjuncts to use was left to the participants. No physical standardization (i.e., participants with hands down, no equipment) of timer starting. There may be a range of when participants state they are ready (e.g., one participant may be ready to open the mouth, i-view in hand versus i-view on the table). Once participants stated they were ready, a study team member would start the timer. The time would stop when the participant was satisfied the tube was in the trachea. Once the timer was stopped, a study team member would examine through visualization and bag-valve-mask evaluation for air flow through the lung tract. Every insertion and removal of the device from the oral cavity was considered an attempt. Complications, such as esophageal intubation, displaced tube, or damage to the manikin such as dental injury were recorded. A synthetic

Table 1. Demographics and experience.

| | | |
|---|---|---|
| Demographics | Age | 29 (27-32) |
| | Male | 66% (20) |
| Service | Air Force | 57% (17) |
| | Army | 43% (13) |
| Training Status | Resident | 77% (23) |
| | Staff | 23% (7) |
| Deployment Experience | Previously deployed | 13% (4) |
| | Months deployed | 7 (1-11) |
| Intubation Experience | Estimated intubations | 12 (3-49) |
| | Previous real patient direct laryngoscopy | 93% (28) |
| | Previous real patient video laryngoscopy | 90% (27) |
| View | Grade 1 | 90% (27) |
| | Grade 2 | 10% (3) |
| | Grade 3 | 0% (0) |
| | Grade 4 | 0% (0) |

airway trainer was used because (1) the study team has previous experience with this platform, (2) it is routinely used by the advanced training programs at the US Army Medical Center of Excellence, and (3) we felt it is the best available airway trainer with regards to texture and anatomical accuracy (Figure 2).[14]

*Data Analysis*: We performed all statistical analysis using standard statistical software. We present continuous variables as means and 95% confidence intervals, nonparametric continuous variables and ordinal variables as medians and interquartile ranges, and nominal variables as percentages and numbers.

## Results

The study took place from February 2020 to January 2021, with intermittent stoppages secondary to the COVID-19 pandemic and restrictions on human subject research. During this time, 31 participants were enrolled, with one missing data that was excluded, leaving 30 for analysis. The median age was 29, most (66%) were male, most were Air Force (57%), in-training residents (77%) with few reporting previous deployment experience (13%) (Table 1). Almost all had real patient experience with both direct (93%) and video laryngoscopy (90%). Most (90%) were able to get a grade 1 view with all achieving airway cannulation on first-pass attempt (Table 2). The median time to cannulation was 11.6 seconds. On the post-procedure survey (Table 3), most participants strongly agreed they would use this in the deployed setting (77%). Most reported they found it easy to use (77%).

Table 2. Outcomes.

| | | |
|---|---|---|
| Outcome | Successful cannulation | 100% (30) |
| | First-pass cannulation | 100% (30) |
| | Time to intubation | 11.6 seconds (7.6-15.0) |

Table 3. Feedback from survey.

| | | |
|---|---|---|
| I would use this in the deployed setting | Strongly agree | 77% (23) |
| | Agree | 20% (6) |
| | Neutral | 0% (0) |
| | Disagree | 3% (1) |
| | Strongly disagree | 0% (0) |
| I found this easy to use | Strongly agree | 77% (23) |
| | Agree | 23% (7) |
| | Neutral | 0% (0) |
| | Disagree | 0% (0) |
| | Strongly disagree | 0% (0) |

## Discussion

The data from the pilot study demonstrated all operators were able to obtain a grade one view of the glottic opening using the Cormack-Lehane scoring system. All participants in this study were able to achieve first-pass success ETI, and did so in less than 12 seconds on average, with a majority finding the device easy to use and agreeing they would use it in a deployed setting. The findings from our study are consistent with the civilian literature supporting reliable views of the glottic opening with VL.[8,12] The addition of VL to civilian prehospital systems with low prehospital ETI success by nonphysicians has improved first past intubation success, with a range of 12.6% to 26.8% improvement.[11,13] These findings are also consistent with current military literature regarding prehospital success and outcomes of ETI; although, this does vary from the TCCC guidelines.[2,4,6,7]

The second most common cause of potentially preventable death on the battlefield is airway compromise. To mitigate preventable battlefield deaths, extensive research has demonstrated that 87.3% of all mortality occurred prior to military treatment facility (MTF) arrival.[1] Even though TCCC guidelines do not recommend ETI as an initial airway intervention, previous studies have demonstrated ETI is the most common advanced airway intervention taken by operators pre-MTF and has demonstrated the best mortality outcomes.[2,6]

In the setting of a possible delayed evacuation for casualties, combat medics may be the only qualified medical provider available. While ETI has been shown to be the most common airway intervention performed pre-MTF, TCCC guidelines recommend early cricothyrotomy over SGA, and cricothyrotomy is the only definitive airway procedure for which medics receive training and equipment.[2,3,15] In the setting of combat, pre-hospital ETI has similar success to that of civilian medics.[16] With similar success rates and the possibility of delayed evacuation increasing over the next decade due to potential loss of air superiority, a VL option for ETI may improve a combat medic's ability to manage a decompensating, non-traumatic airway. As stated previously, VL

improves ETI success and improves outcomes and with the literature supporting this information, the i-view could represent another tool to assist with decreasing combat related mortality.[11]

Given the multiple studies regarding the difficult airway and the evidence demonstrating increased ETI success with VL, it is reasonable to suggest combat care in the deployed setting, to include delayed evacuation or prolonged care under fire, would benefit from the addition of VL as an option in forward-staged SKOs to include the Role 1 areas, such as battalion aid stations or forward operating bases. Research should continue to evaluate the benefits of VL in the deployed setting, as the current literature suggests benefit and improved outcomes with the use of VL. With the i-view not only being affordable at $120 in comparison to the current advanced VL at a cost of $12,000, but the i-view is also small, portable, and does not require a power source, allowing it to easily be included in all military SKOs. Research should continue to evaluate the efficacy of this device in a clinical setting and not just simulated.

There were multiple limitations to this study. This was a small, single center study performed at a level 1 trauma center, which limits the ability to generalize this to other populations. Operators assessed in this study were all emergency medicine physicians and residents, considered to be experienced operators in terms of airway management. There was also no physical standardization as listed above regarding when operators began the study, possibly affecting the primary outcome of time to cannulation. As this study is evaluating a device for use in a deployed, prehospital setting, it is reasonable to assume most operators will not have the experience skill level of the emergency physician. There is the possibility sporadic enrollment secondary to COVID-19 introduced bias, as participants had more time in the clinical setting to develop their intubation skills. We must also consider the inherent bias that comes from survey data, in this case, considering the Dunning-Kruger Curve in how individuals view their own abilities and knowledge. Lastly, this study was non-blinded. Given it would be impossible to blind operators to the device they are physically using and there was no comparison device in this study, this does create bias.

## Conclusion

Our simulation-based study demonstrates the device has strong potential use for the clinical setting with all achieving rapid first-pass success for intubation. This study lays the foundation for validation of the device in the clinical setting, not just a controlled simulation environment. As all performers were physicians, clinical validation in this cohort should direct further research into evaluation for field protocols for use by 68 Whiskeys and Rangers.

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## Authors

CPT Matthew R. Figlewicz is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

CPT Krishna Constantino is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

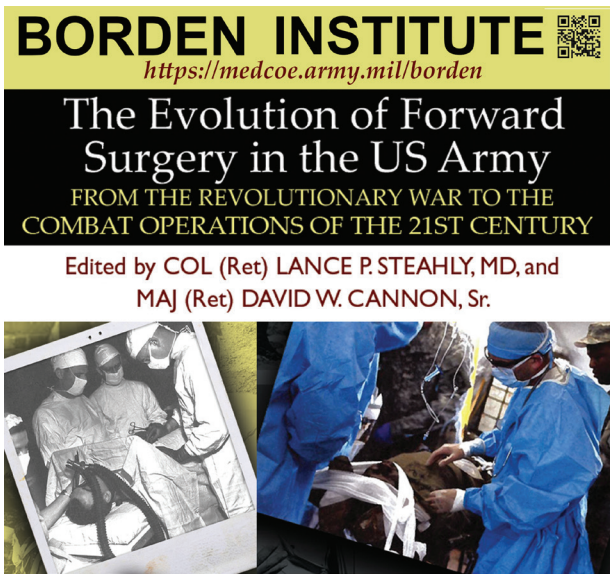
Jessica Mendez is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Mireya A. Escandon is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Nguvan Uhaa is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

LTC Joseph K. Maddry is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX; US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; Uniformed Services University of the Health Sciences, Bethesda, MD; and 59th Medical Wing, JBSA Lackland, TX.

MAJ Steven G. Schauer is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX; US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; and Uniformed Services University of the Health Sciences, Bethesda, MD.



# Unconventional Warfare Medicine Is the Ultimate Prolonged Field Care

Nedas Jasinskas, MD
LTC Regan Lyon, MD
COL Jay Baker, MD

## Abstract

While conventional military forces have long been the focus of modern warfare, unconventional warfare (UW) will be waged behind enemy lines by US, allied, partner special operations forces (SOF), and civilian resistance movements. Prolonged field care (PFC) will be a forced necessity in the UW environment with unique challenges to mobility and security. Recorded experiences from World War II of allied surgeons and others reveal insights about how to prepare for this unique set of special warfare in the future, including in the areas of manning, training, planning, operations, and equipping. Countries at potential seams of conflict, like the Baltic States, possess significant UW experience. Lithuanian SOF medical leaders have developed a guerilla medicine course that increases readiness to provide PFC and austere resuscitative surgical care in UW. US military medical forces can benefit from partners like Lithuania and others by sharing knowledge, experiences, and adapting best practices to our tactics, techniques, and procedures.

## Introduction

From the time of Alexander the Great to present day, great armies have clashed violently in open combat while unconventional warfare (UW) has been waged in the shadows.[1,2] For the last 20 years of conflict, most battlefield trauma care has been delivered within well-developed trauma systems. Relatively small numbers of daily casualties received near-immediate first response, expedient evacuation from the point of injury, and rapid stabilization by robust surgical teams within the "golden hour."[3] Unfortunately, recent experiences from the Global War on Terror are likely to be irrelevant in future conflicts. The next war may involve violent crashes of huge ground forces against each other, massive long-range artillery strikes, and/or over-the-horizon naval battles with thousands of daily projected casualties. In these unconventional conflicts, military combat hospitals will be the primary effort to handle such casualty numbers. Like great wars in the past, critical UW operations waged by allied and partner special operations and partisan forces in critical supporting actions will produce many more casualties in the shadows.[4]

Unconventional warfare occurs as an existential struggle by a nation's citizenry seeking independence from an oppressive government or occupation by an overwhelming adversary.[5] When this occurs, usual medical systems cannot be relied upon for medical care of friendly forces. In violation of Geneva conventions, unscrupulous adversaries target existing medical systems in early stages of conflict to multiply damage for friendly combatants and the civilians supporting them.[6] An adversary's area air denial systems and counterinsurgency ground forces aim to disrupt medical evacuation and prolong care in the field indefinitely.[7] Delivery of medical support is extremely challenged when both conventional military and civilian urban medical systems are tightly controlled or completely disrupted by occupant forces of a stronger enemy. When traditional conventional medical pathways are ruled out, medical support to resistance efforts may be forced to rely exclusively on medical auxiliary networks. In the emerging era of Great Power Competition (GPC), potential national resistance movements have a unique opportunity to plan and practice operating in a back to iron sight environment before conflict occurs.

Figure 1. Books featuring prolonged field care and austere surgical care in UW environments.


Prolonged field care (PFC) in future UW environments will be severely challenged as a forced necessity. Restricted freedom of movement will prolong time between injury and evacuation and limit the positioning and availability of surgical teams. Additionally, targeting by the adversary demands special tactics and clandestine training to effectively maneuver and prevent compromise both to force and mission. Historical examples during and following World War II (WWII), including a prolonged national resistance against Soviet occupation in Lithuania, contain valuable lessons about guerrilla medicine practices in these challenging environments. This article has two objectives:

- Briefly review lessons learned from historical PFC experiences in UW settings;
- Propose a course of training based on established partner nation training that incorporates these lessons to enable successful PFC in UW settings.

## Historical Guerilla Medicine Experience

Geoffrey Parker, Lindsay Rogers and Colin Dafoe provided courageous medical leadership and support to Nazi resistors behind enemy lines in France and Yugoslavia as general surgeons during World War II (Figure 1).[8-13] They were brave, adventurous individuals who were driven to provide the highest possible quality care in extremely challenging and dangerous environments. Their training, experience, mental resilience, and high states of physical fitness were critical to their selection for this mission. Often alone and with just a ruck on their backs, they infiltrated Nazi frontlines via nighttime parachute insertions to establish initial medical operations. These guerilla physicians innovated out of necessity to establish and provide medical support in extremely austere environments, sometimes building hospitals and operating suites out of parachute canopies, as described by the book *The Parachute Ward*.[10] Resupply was severely limited, and they adapted in the face of incredible austerity, such as creating suture material by unraveling parachutes' silk fibers. They lived and operated with the forces they supported, fought and fled under the most dangerous circumstances, defended the patients they cared for against direct enemy threat, and were forced to abandon the underground hospitals and operating theaters they built themselves. The closer Dr. Rogers positioned his Yugoslavian partisan hospitals to the point of conflict with German Nazis, medical intervention success increased but with an increased risk of hospital compromise.[9,13] These men were regarded as heroes for the medical care they provided and improved morale of the forces they served, enabling them to overcome a brutal and ruthless enemy.

After cessation of active hostilities in 1945, The Soviet Union occupied the Baltic Nations, including Lithuania. Lithuanian freedom fighters called the "Forest Brothers" ran an active guerrilla warfare campaign against their occupier from 1944 until at least 1953.[14] More than 30,000 men and women lived in dense forests and organized a national resistance movement with one goal: restore Lithuanian independence. Over time, the majority of Forest Brothers were caught, tortured, executed, or sent to Siberian gulags. One of the toughest challenges was to provide medical care for Lithuanian freedom fighters without being discovered. A limited number of surviving witnesses, documents, and letters from this post-WWII period describe the heroic behavior of medical personnel, including nurses, surgeons, physicians and pharmacists. Many actively participated in resistance activities, often under cover of night, placing their careers and lives at risk. The lessons learned from this resistance movement, called the "war after the war" by Lithuanians, has inspired evaluation of different resistance scenarios and possible medical care pathways in austere environment. These analyses seeded creation of a guerrilla medicine training module to prepare for modern day UW conflict.

The following vignette illustrates the danger to combatants in receiving medical care in usual facilities and demonstrates unconventional evacuation contrary to standard medical doctrine:

> *When, during a skirmish with the enkavedisti, the leg of the partisan Erelis was broken above the knee, it was essential to take him to a hospital to save his life. He was provided with fictitious documents and the bone breakage was officially explained as the kick of a horse. After several weeks of treatment it was still not possible to put his leg in a cast, and*

*the enkavedisti had already begun to suspect that a partisan was being treated in the hospital. Nastė (nurse), who knew the case, could have done nothing and avoided all danger. Instead, she determined to do what she could to save Erelis from death. Without knowing to what detachment he belonged, she smuggled him out of the hospital at night, took him to his native district and then transferred him to a local partisan detachment, providing him with the necessary medicines. After placing Erelis in safe hands, Nastė summoned a surgeon from Kaunas, who set his leg.*[14]

These experiences and a handful of other sources, including decades-old UW medical doctrine, provide principles for successful conduct of prolonged field care and higher levels of medical care in UW scenarios (Table 1).

Table 1. Summary of key lessons learned in unconventional warfare medicine.[7-13, 18-22]

| | |
|---|---|
| **Manning** | • 1-3 pax teams |
| **Training** | • Emphasis on physical fitness and mental toughness |
| **Planning** | • Assist guerilla forces<br>• Long duration<br>• Air limited<br>• Tactical evacuation<br>• Minimally equipped<br>• Minimal support |
| **Operations** | • Self-evacuation<br>• No flyovers<br>• Debridement, immobilization, delayed primary closure<br>• Sick and wounded dispersed in "guerilla hospitals"<br>• "Convalescent camps" |
| **Equipping** | • "Bare minimum"<br>• "Carry on my own back"<br>• Dressing, essential drugs, nursing items for patient comfort<br>• Resupply extremely challenged—required local improvisation, enemy sources, outside resupply by parachute |

The extreme challenge of UW medicine in the GPC problem set has been a growing area concern for the US Special Operations Forces (SOF) community since at least 2017, when retired US Army Colonel Dr. Warner "Rocky" Farr published *The Death of the Golden Hour and the Return of the Future Guerilla Hospital*.[7] Special Operations Command—Europe (SOCEUR) conducts an annual Trojan Footprint exercise focused on testing US, allied, and partner SOF in the UW operating environment. This exercise provides a unique laboratory for US, allied, and partner SOF to develop and assess techniques to practice PFC and austere resuscitative and surgical care (ARSC) in the most challenging setting possible.[15,16] Lessons learned from Trojan Footprint in 2018 revealed that US medical forces, as currently structured and trained, would not be able to provide unilateral, unsupported medical care for severely injured US SOF in UW.[17] Potential future scenarios in UW necessitate the use of the indigenous forces fighting for their independence and very existence. Countries at risk for occupation like Lithuania possess significant UW experience and are already preparing for potential future resistance movements. US military medical forces can benefit from partners like these by learning from their knowledge, experience, and adapting to our own tactics, techniques, and procedures for PFC.

## Lithuanian SOF Training for UW Medicine

Lithuanian SOF medical leaders have developed a training program to provide PFC, ARSC and general medical support in a UW environment and is referred to as the Guerilla Medicine (GM) course.

*Personnel Requirements*: All Lithuanian SOF personnel including medics are required to pass basic selection and complete a basic SOF training program. This enables all personnel to be on the same page—whether one is a logistics sergeant, staff officer, medic, surgeon or operator in a tactical unit.

*Training Requirements*: A resistance preparation and organization course is included in the basic SOF training program. Participants are trained to organize the medical system pragmatically, wisely utilize human and material resources, and organize improvised medical care in an austere, dynamic, denied environment. All participants receive orientation to UW medicine principles during a dedicated module as a prerequisite for a follow-on 5-day GM course.

The GM course is designed for education, training, proper planning, and field testing of UW medicine skills. The main objectives of the GM course are as follows:

- Prepare to provide medical support in denied or semi-permissive urban environments;
- Learn elements of existing health care system and how to capitalize on utilizing their weaknesses as strengths;
- Solve common medical conundrums with improvised equipment and drugs;
- Build robust medical cache and casualty care systems;
- Test practical skills in simulated casualty situations.

During the course, participants live in a denied society full of enemy sympathizers and develop cover stories to provide validation of survival in this environment. Course attendees learn the main principles of how to build a robust underground medical network. Standards

for medical care eligibility, receiving casualties, treating trauma injuries, and disposition should be established well in advance. Triage is taught according to the Pareto principle with the goal to take care of roughly 80% of medical problems with 20% of total resources. Without a sound plan and flexible system, one could waste all the resources at once and lose the fight in the very beginning.

The use of an auxiliary network of local supporters to help the medical network is critical in these environments. Course participants conduct link-ups with these assets, role-played by SOF cadre, to learn how to clarify an asset's intent and motives, identify an asset's strengths and weaknesses, and properly integrate different medical personnel into their resistance medical network based on these factors. It is crucial for medical planners to grade an asset's motivation to define his or her proper role and position in the medical auxiliary network. If this assessment is incorrect, casualties will become the most vulnerable to compromise when treated by medical providers working in an auxiliary network.

*Casualty Care & Evacuation*: By understanding the principles of casualty flow in a denied environment, participants learn shortcuts for organizing covert "guerilla hospitals," covert ambulances, medical personnel rotations or house calls, and telemedicine consults. Course participants are taught how to utilize unoccupied veterinary, rehabilitation, dentistry, and mental health clinics to increase their resource capacity. Participants are taught to establish working medical facilities in opportunistic shelters and develop local escape, evasion, conspiracy, and logistics protocols. They must determine available communication lines, potential compromise vulnerabilities, and a communications plan for the system. Seeing the larger picture and understanding how the system is functioning facilitates creativity in overcoming unique challenges in these environments.

*Equipping & Logistics*: Medical equipment and supplies are one of the most important parts of any viable medical network. Participants of the GM course are taught about key medical equipment and supplies for treating the most common injuries and medical problems and how to improvise using this standard set of equipment. They are also taught how to create and maintain medical caches, decide on a cache's content, and establish a logistical supply chain for the cache. By understanding the critical nature and limitations of these caches, participants understand how to better utilize resources efficiently. The final module of the GM course is dedicated to synthesizing all lessons into a whole-of-system approach to guerilla medicine and a variety of medical training boot camps.

*Utilization & Sustainment*: After completing the basic SOF training program and guerilla medicine course, graduates are ready to join their new teams and begin developing auxiliary networks. Effectiveness of this training is subsequently tested during the annual Lithuanian international SOF exercise, Flaming Sword, which is often run concurrently as a partner exercise with Special Operations Command—Europe's (SOCEUR) Trojan Footprint. These exercises challenge SOF units, medics, and surgical teams to work and conduct operations in a simulated denied environment. Medical simulations are conducted with role players, realistic training platforms, and improvised underground medical facilities across the full spectrum of UW challenges.

## Conclusion

While US and Western European SOF might consider Eastern Europe a future deployment, preparing to resist occupation through organized national resistance is a persistent, existential problem set for our Eastern allies. "Hope is a primary driver of resistance movements, and the best way to keep hope alive in a resistance movement is to keep people alive."[17] Effective, persistent training in UW medicine develops readiness to keep both people and hope alive.

Practicing PFC for friendly combatants will be extremely challenging in an unconventional warfare environment. Like other high risk special operations, medical support for guerrilla movements is extremely challenging to build after conflict has already started. Relatively low cost investments now will pay dividends in minimizing future battlefield mortality rates. While the last couple of decades have provided extensive combat medicine advancements, they are limited in their applicability to denied environments that will rely on PFC more heavily. Current medical doctrine, education, and training fall short in these scenarios and demand innovation in our preparation for future conflicts. Proactive planning, education, training, and testing through field exercises and assessments are keys for success, and we can benefit from our partners' experiences in UW medicine to help guide our efforts.

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## Authors


Nedas Jasinskas, is with Emergency Department, Hospital of Lithuanian University of Health Sciences, Kaunas, Lithuania.

LTC Regan Lyon, is with Naval Postgraduate School, Monterrey, CA.

COL Jay Baker, is with US Army, Special Operations Command Europe (SOCEUR), Stuttgart, Germany.

# Development of Data-Driven Triage Systems for Identifying Mortally Wounded Casualties—Implications for Future Large-Scale Combat Operations

Sarah Johnson
Ryann S. Lauby
MAJ Michael D. April, MD, DPhil
MAJ Andrew D. Fisher, MD, MPAS
LTC Joseph K. Maddry, MD
LTC Luke Hofmann, DO
LTC Kevin Gillespie, DMD
Jose Salinas, PhD
MAJ Steven G. Schauer, DO, MS

## Abstract

Background: Uncontested air movement and advances for medical care of combat casualties have resulted in a decreased case fatality rate. However, in future large-scale combat operations, the military has established a plan for multidomain operations to defeat near-peer adversaries. Prolonged casualty care and mass casualty scenarios will become more prevalent. Prehospital friendly scoring systems such as the shock index (SI) and revised trauma score (RTS) may provide useful triage data. Development of accurate, data-driven, triage systems will be key to optimize management of resources, care, and transport of combat casualties.

Methods: We included data from the Department of Defense Trauma Registry between 01 January 2007 to 17 March 2020. Data comprised of adult US military or coalition service members for analysis as the baseline cohort, and those who died within 24 hours were included in the early death cohort. We performed statistical analysis on demographics and injury data, SI and RTS to measure the receiver operating characteristics (ROC) of each value to predict early death.

Results: The early death cohort had a significantly higher injury severity score (25 vs. 5) and a higher percentage of serious injuries in every body region than the baseline cohort. The early death cohort sustained serious injuries to the head and neck at a rate five times that of the baseline cohort (43.4% vs 8.1%) with odds ratio (OR) of death 8.0 (95% confidence interval 5.7-11.1) followed by skin (13.6% versus 1.9%) with an OR of 6.3 (95% CI 3.8-10.3). The mean SI was 1.21 versus 0.80. The revised trauma score (RTS) was 4.18 versus 7.34. The RTS had a higher area under the receiver operating characteristic (0.896 versus 0.716 for SI).

Conclusions: Serious injuries to the head and skin were most strongly associated with death within the first 24 hours. The RTS appears to be a more accurate tool than SI alone for assessing injury mortality. Military medical personnel should consider these factors when triaging casualties during future conflicts in resource limited settings with delayed evacuation.

*Keywords: prehospital; transport; early; death; mortal; wounded*

## Introduction

*Background*: The battlefield has changed dramatically during recent conflicts. Characterized by advanced technologies, recent conflicts have increased the importance of high precision weapons and electronic warfare.[1] Technological advances have also enabled improved casualty evacuation times from the point of injury (POI) to surgical care.[2] Improved body armor has led to an increased proportion of extremity injuries, brain injuries and burns.[2,3] The recent conflicts in Afghanistan, Iraq, and Syria have had the lowest US case-fatality rates (CFR) in history, with rates progressively falling over the last century.[4] CFR describes the overall lethality of the battlefield and often excludes those immediately returned to duty (RTD).[5] Out of the 52,937 casualties as

of December 2014, Operation Enduring Freedom (OEF) in Afghanistan had a CFR of 15.1%, excluding return to duty (RTD), and Operation Iraqi Freedom (OIF) had a CFR of 21.4%.[6] In comparison, Vietnam had a CFR ,excluding RTD, of 23.2%, continuing the trend of large scale combat operations (LSCO) as the Korean War and World War II had CFRs of 26.4% and 33.8% respectively.[7] The decrease in CFR is attributable, in large part, to medical advances and decreased transport times.[4,6]

Between September 11, 2001, and March 31, 2014, more than 90% of US casualties underwent transport via medical evacuation, meaning transportation on a medically equipped platform.[8,9] Rapid transportation to surgical-capable medical treatment facilities (MTF) and "increased treatment capability are likely contributors of casualty survival."[9] The remote, austere locations of combat medical care capable of damage control resuscitation (DCR) has been pushed forward while improving evacuation methods.[10,11] Shorter transport time improves casualty outcomes;[9] however, many factors involved with LSCO against peer and near-peer adversaries will prohibit quick transport times. These include the massive numbers of casualties encountered in LSCO; the freedom to evacuate at-will likely will not be present. We will have limited windows of air superiority in which multiple casualties must undergo evacuation together. Conversely, casualties may have to be evacuated using unmanned vehicles or undergo prolonged ground transport via motor vehicles and train.[12]

Set for 2025 to 2050, multidomain operation (MDO) between all military branches fluidly maneuvers to confront opposing countries in all aspects including land, air, sea, cyberspace and information, and space.[13-15] In addition to increased transport times, notional casualty numbers from combat training center rotations suggest numbers will rapidly overwhelm operational healthcare resources.[16] All casualties will need to undergo triage to provide the most effective use of resources under the circumstances.[17,18] The use of triage assists in achieving the ultimate goals of military medicine: preservation of life, limb and eyesight and returning combatants to the fight.[18]

Current triage methods for prehospital mass casualty incidents generally rely on some variation of the sort, assess, lifesaving interventions, treatment and/or transport (SALT) and Simple Triage and Rapid Treatment (START) triage systems.[17,19,20] Both systems rely on provider experience and estimations, neither of which is particularly data-driven or useful for inexperienced medical personnel. Given the subjectivity of much of it, neither of these systems lend themselves well to clinical decision support tools. In assessing scoring systems, we sought out measurement tools that use data points and are readily available to prehospital personnel (e.g. physical exam findings, vital signs, etc.). While other systems may provide improved accuracy, the need for advanced data points, such as laboratory testing or radiologic imaging, are not feasible in the prehospital setting. A review of the literature led to the shock index (SI) and revised trauma score (RTS). Shock index, a measure of heart rate divided by systolic blood pressure (SBP), is used to predict outcomes for trauma patients, often secondary to internal hemorrhage.[21] Previous research has found casualties with a shock index over 0.9 have higher mortality rates.[21] RTS is a standard physiological scoring tool based on physiologic variables of systolic blood pressure, respiratory rate, and the Glasgow coma scale (GCS).[22] Both of these scores can be calculated in the prehospital setting without any advanced tools. Moreover, their simplicity lends them to be easily embedded in decision support tools.

Casualties who have a higher chance of a survival should be prioritized when mass triaging. The use of effective triage helps allocate the best resources to the largest number of casualties. Despite the longstanding use of triaging, in the recent conflicts we have not had to triage large numbers of US military casualties to expectant management.[23] As such, while some methods for triaging are taught to medical personnel, these are not data-driven methods to determine which casualties may survive transport but will likely die after consuming large volumes of scarce resources.

*Goal of this Study*: We analyzed data on casualties who died within 24 hours of admission to a deployed military treatment facility for prediction of mortality with potential implications for future triage during MDO/LSCO.

## Methods

*Data Acquisition*: This is a secondary analysis of previously published de-identified data from the Department of Defense Trauma Registry (DODTR) which is previously described.[24] This study was determined to be exempt by the US Army Institute of Surgical Research regulatory office.

*DODTR Description*: The DODTR, is the data repository for DoD trauma-related injuries.[25,26] The DODTR includes documentation regarding demographics, injury-producing incidents, diagnoses, treatments, and outcomes of injuries sustained by US/non-US military and US/non-US civilian personnel in wartime and peacetime (including humanitarian) from the point of injury to final disposition. Short-term outcome data are available for non-US casualties. The DODTR comprises all

patients admitted to a Role 3 (fixed-facility) or forward resuscitative surgical detachment (FRSD) with an injury diagnosis using the International Classification of Disease 9th Edition (ICD-9) between 800-959.9, near-drowning/drowning with associated injury (ICD-9 994.1) or inhalational injury (ICD-9 987.9) and trauma occurring within 72 hours from presentation. The registry defines the prehospital setting as any location prior to reaching a FRSD, field hospital (FH), or a combat support hospital (CSH) to include the Role 1 (point of injury, casualty collection point, battalion aid station) and Role 2 without surgical capabilities (temporary limited-capability forward-positioned hospital inside combat zone).[27,28]

Table 1. Demographics and injury data.

| | | Baseline | Early Deaths | p-Value |
|---|---|---|---|---|
| Demographics | Age | 24 (21-29) | 23 (21-27) | 0.031 |
| | Male | 97.8% (11,841) | 97.6% (164) | 0.0830 |
| Affiliation | US Military | 83.1% (10,055) | 75.6% (127) | 0.010 |
| | NATO Military | 16.9% (2,045) | 24.4% (41) | |
| Mechanism of injury | Explosive | 58.7% (7,106) | 59.5% (100) | <0.001 |
| | Fall | 5.6% (679) | 0% (0) | |
| | Firearm | 19.1% (2,312) | 35.7% (60) | |
| | MVC | 4.7% (572) | 2.9% (5) | |
| | Other | 11.8% (1,431) | 1.7% (3) | |
| Injury Severity | Composite | 5 (2-13) | 25 (17-33) | <0.001 |
| Serious injuries by body region | Head/neck | 8.1% (982) | 43.4% (73) | <0.001 |
| | Face | 0.2% (35) | 1.7% (3) | <0.001 |
| | Thorax | 8.7% (1,054) | 17.2% (29) | <0.001 |
| | Abdomen | 5.9% (720) | 20.8% (35) | <0.001 |
| | Extremities | 23.9% (2893) | 39.2% (66) | <0.001 |
| | Skin | 1.9% (237) | 13.6% (23) | <0.001 |
| Outcome | Death | 0.9% (168) | 100% | N/A |

*NATO = North Atlantic Treaty Organization*
*MVC = Motor vehicle crash*

*Analysis*: We performed all statistical analysis using standard commercial software packages. The baseline cohort was comprised of all adult US military or coalition personnel with documented prehospital activity in the DODTR. The early death cohort was comprised of the casualties within the baseline cohort who died within the first 24 hours. We present binomial variables using percentages, frequencies, and chi square tests; normally distributed continuous variables using means, confidence intervals, and student's t-test; ordinal variables and non-normally distributed continuous variables using median, interquartile ranges, and Wilcoxon rank sum test. Multivariable regression models were used to describe associations and interactions between variables. Receiver Operating Characteristic (ROC) curves were generated to assess for regression model fit to assess fit via the area under the ROC (AUROC). Youden's Index was used to optimal thresholds for sensitivity and specificity. We analyzed the data under the assumption of accurate documentation of all care rendered and interventions/measurements were documented accordingly.

The abbreviated injury scale (AIS) and the composite injury severity scale (ISS) are based on estimated mortality from the totality of injuries to each of six body regions (head/neck, face, thorax, abdomen, extremities, skin/superficial).[29-31] The scale ranges from 0 (minor injuries, 0% estimated risk of death) to 6 (maximal injuries, non-survivable injury). An example of an AIS of 0 would be a superficial abrasion or minor laceration or less. An example of an AIS of 6 would be a complete transection of the aorta. The composite score—the ISS—represents the three most severely injury body regions, squaring each score, and then summing the three squared numbers (ISS=A2+B2+C2).[32] An ISS of >15 is considered major polytrauma. Given the right-skewing of AIS scores and to give the reader a better sense of those seriously injured (estimated mortality >10% from injuries to the body region) versus those not seriously injured, we converted the AIS metrics into a binary variable of serious (≥3) versus not serious (<3) as we have done in previous studies.[27,28,33] The scoring of the AIS is performed by trained personnel within the Joint Trauma System.

## Results

Within the DODTR from 01 January 2007 to 17 March 2020 there were 28,950 encounters with documentation of prehospital activity, of which 12,268 were adult US military or North Atlantic Treaty Organization (NATO) service members and met inclusion for this analysis. Within that cohort, 278 died within the initial hospitalization, of whom 168 died within the first 24 hours. Of those within the baseline cohort, 11,990 survived to hospital discharge.

Of the 168 casualties who died within the first 24 hours, the "early death" cohort, the median age was 23 years and 97.6% were male (Table 1). The majority were US military members (75.6%). Explosives were the most common mechanisms of injury in both the early death cohort and the baseline cohort (59.5% and 58.7% respectively), followed by firearms (35.7% and 19.1%). The early death cohort had a significantly higher injury severity score (25 versus 5). Furthermore, the early death cohort had higher percentage of serious injuries (AIS of 3 or greater) in every body region than the baseline cohort.

Table 2. Multivariable regression analysis with serious injuries by body region in association with 24-hour mortality.

| | |
|---|---|
| Head/neck | 8.0 (5.7-11.1) |
| Face | 1.5 (0.4-5.2) |
| Thorax | 0.8 (0.5-1.3) |
| Abdomen | 2.6 (1.7-4.1) |
| Extremities | 1.5 (1.0-2.1) |
| Skin | 6.3 (3.8-10.3) |

The body region most associated with death was the head/neck region (odds 8.0 with a 95% confidence interval of

Table 3. Shock index and revised trauma score for early deaths versus baseline.

| | Baseline | Early Deaths |
|---|---|---|
| Shock Index | 0.80 (0.79-0.81) | 1.21 (1.09-1.34) |
| Revised Trauma Score | 7.34 (7.32-7.36) | 4.18 (3.43-4.94) |

5.7-11.1) (Table 2). The body region next most associated with death was the skin (odds 6.3 with a 95% confidence interval of 3.8-10.3).

The mean shock index was 0.80 for the baseline cohort versus 1.21 for the early deaths with a Youden's index of 0.912 and AUROC of 0.716 (Table 3, Figure 1). The revised trauma score was 7.34 versus 4.18 for early deaths with a Youden's index of 6.81 and AUROC of 0.896 (Table 3, Figure 2).

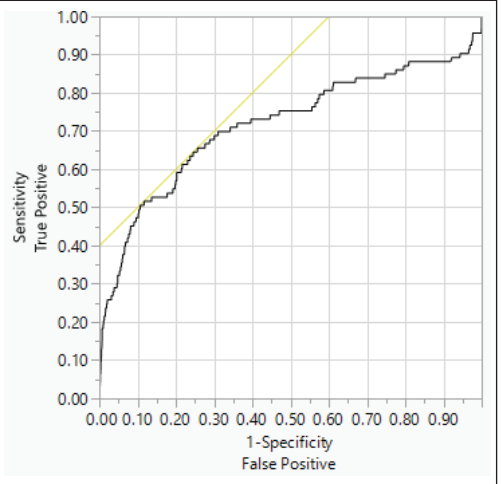
## Discussion

Possible future conflicts against a near-peer adversary require the use of better triage tools to provide the best level of care to the largest number of casualties and most effectively allocate resources. Previous research found casualties who received a massive transfusion also had lower rates of survival in addition to consuming large amounts of resources.[34] In this study, 12,268 casualties comprised the baseline cohort, and 168 casualties comprised the early death cohort (died within 24 hours).

Both cohorts had similar percentages of injury due to explosives. There was a substantial difference of injury due to gunshot wounds (GSWs) between the baseline cohort (19.1%) and the early death cohort (35.7%). The nature of GSWs leads to penetrating injuries with ischemic, devitalized tissue around the wound channel, which places the casualty at high mortality risk.[35] When triaging casualties, special consideration should be used with gunshot wounds (GSW). Eastridge's study of casualties who died of wounds found 25% of mechanisms of injury were GSWs and 72% were explosives.[36] Another study done by Shackelford et al found prehospital deaths incurred a higher percentage of GSW (34% versus 23%) and explosives (56% versus 42%) than those who survived more than 4 hours of prehospital care.[37] A recent evaluation of mortality within the US Special Operations Command found catastrophic tissue destruction as the leading mechanisms of death (73.7%; 272 of 369).[38] The leading cause of death was blast injury, with the majority classified as killed in action (KIA) and in the prehospital setting, (89.2%; 143 of 166). Additionally, the study noted cause of death from GSW was 40%, higher than previous studies. While mechanism of injury (MOI) is relatively easy to identify, the use of it as a sole predictor of death must be taken into consideration with the other data points presented herein.

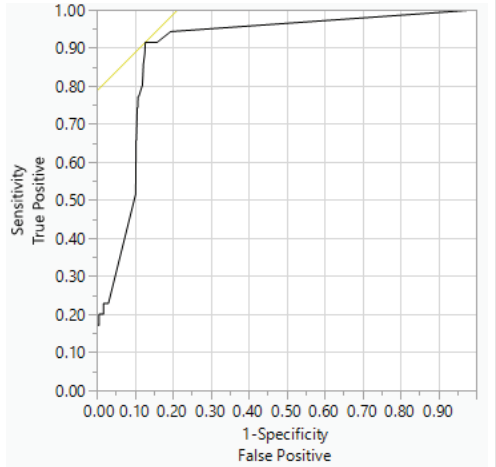
Organizing serious injuries by body region revealed major differences in the early death and baseline cohort. A higher percentage of serious injuries in each body region led to the higher injury severity score (ISS) in the early death cohort (25 versus 5). Twenty-five is considered a very severe trauma.[39] Almost half of the early death cohort incurred injuries to the head and neck region (43.4%). This was more than five times the percent of the baseline cohort who incurred serious injuries to the head and neck region (43.4% versus 8.1%). Similarly, the head and neck region incurred markedly higher odds of death (8.0). A study by April et al found the majority of deaths in their dataset sustained a serious

Figure 1. Receiver operating characteristic for shock index.




*AUROC 0.716; Youden's index 0.912; Sensitivity 0.645; 1-specificity 0.245*

Figure 2. Receiver operating characteristic for revised trauma score.




*AUROC 0.896; Youden's index 6.8174; Sensitivity 0.9143; 1-specificity 0.128*

injury to the head/neck as well.[40] The odds of death due to serious skin injuries was 6.3. This might be due to extensive burns and tissue destruction that may accompany explosions, a possible indicator of impending death when triaging casualties. While not as high as the head/neck and skin regions, the abdomen also incurred very high odds of death (2.6). Historically, blast injuries to the abdomen resulted in fatal outcomes, but advancements in body armor, prehospital care, and damage control surgery have led to improved outcomes.[41] While the early death cohort sustained more than double the percent of thoracic injuries (17.2% versus 8.7%), this region incurred no increased odds of death, while many papers indicate thoracic injuries often result in high mortality.[6,42] This likely demonstrates many thoracic injuries can be temporarily remedied with non-operative measures such as a chest tube.[43] Preventative measures such as advancing body armor development may reduce injuries altogether.[3] While the AIS relies on a complex standardized system for scoring, the use of a serious/not serious assessment may be feasible in the prehospital setting using some physical exam findings given we dichotomized them as serious versus not serious.

In assessing the shock index, the entire shock index confidence interval is higher than 0.9 (1.09-1.34), which typically relates to high mortality.[21] In addition, the Youden's Index predicted the cut-off value to be only slightly higher: 0.912. The receiver operating characteristic for shock index found an AUROC to be 0.716 with a low sensitivity (0.645) and high false positive (0.245). The results of shock index failed to demonstrate it as a reliable and accurate predictor of early death, but it retains some value when combined with other data points.

The RTS was much lower in the early death cohort (4.18) than in the baseline cohort (7.34). The AUROC for the RTS was 0.896, indicating the RTS has a stronger fit for association with early mortality. The sensitivity was 0.914 (specificity 0.872), so those with a low RTS often died within 24 hours. In addition, the false positive rate was 0.128, signifying a low RTS rarely correspond to no mortality within 24 hours. The Youden's Index found the RTS value simultaneously optimizing sensitivity and specificity for predicting 24-hour mortality to be 6.81. Therefore, in a LSCO scenario, it may be reasonable to adopt expectant management for casualties with an RTS less than 6.8. The GCS is heavily weighted in the RTS to account for head injuries with limited other multisystem injuries.[44] A study by Shackelford et al found almost all prehospital deaths had a GCS of 8 or less (98%), while only 18% of casualties who survived more than 4 hours of prehospital care had a GCS of 8 or less.[37] Given 43.4% of early death casualties incurred a severe injury to the head and neck region with a high odds of death in this region (8.0), a triage system that weighs heavily on head injuries would likely have a high predictive value for casualty outcomes. The GCS is not without controversy. It may be challenging to accurately score in a stressful situation and interoperator reliability is moderate.[45] Other criticisms of the system take issue with suitability in acute trauma care. However, the RTS has been shown to be an effective means of predicting death.[46,47] A more unfortunate aspect of the RTS and current approach to prehospital trauma care is the lack of consistent blood pressure measurements.[27,48] Because the Tactical Combat Casualty Care guidelines use radial pulse as a surrogate, the blood pressure cuff is left out of the aid bag for most personnel.[49,50] A recent study was able to provide further evidence of the lack of relationship between a radial pulse and blood pressure.[51] Therefore, increase use and availability of a blood pressure cuff could improve triaging of patients.

There are limitations to our study. By the nature of a retrospective review, all our data is dependent on previously entered records. The detail and accuracy of these records are up to the personnel entering them, and we cannot determine details which were excluded.[48,52] Second, for a patient to be entered into the DODTR, casualties must arrive at a location with surgical capabilities (Role 3 or forward resuscitative surgical detachment, etc.) alive or with on-going life-sustaining procedures. We are unable to assess any casualties who did not survive long enough to arrive at a location with surgical capabilities, all of whom should either be categorized as either already dead or expectant. Third, as this is a retrospective review, we can only assess for associations. Fourth, we have no way to compare our data to how a medic or forward staged medical officer would triage casualties in the setting of limited resources. In other words, we have no way to quantify medical personnel gestalt when assessing survivability. Lastly, we do not have any operational or tactical data to feed into the triage system which much also be accounted for.

## Conclusion

Serious injuries to the head and skin were most strongly associated with death within the first 24 hours. The RTS appears to be a more reliable tool for assessing injury mortality. Military medical personnel should consider these factors when triaging casualties during future conflicts in resource limited settings with delayed evacuation.

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## Authors

Sara Johnson is with 59th Medical Wing, JBSA Lackland, TX.

Ryann S. Lauby is with 59th Medical Wing, JBSA Lackland, TX.

MAJ Michael D. April is with 40th Forward Resuscitation and Surgical Detachment, 627 Hospital Center, 1st Medical Brigade, Fort Carson, CO; and Uniformed Services University of the Health Sciences, Bethesda, MD.

MAJ Andrew D. Fisher is with University of New Mexico Hospital, Albuquerque, NM; and Texas National Guard, Arlington, TX.

LTC Joseph K. Maddry is with 59th Medical Wing, JBSA Lackland, TX; Uniformed Services University of the Health Sciences, Bethesda, MD; US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; and Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

LTC Luke Hofmann is with Uniformed Services University of the Health Sciences, Bethesda, MD; and Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

LTC Kevin Gillespie is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Jose Salinas is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

MAJ Steven G. Schauer is with Uniformed Services University of the Health Sciences, Bethesda, MD; US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; and Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

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# Incidence of Expired Blood Product Use in the US Central Command Theater of Operations

Ryann S. Lauby
Sarah A. Johnson
MAJ Andrew D. Fisher, MD
MAJ Michael D. April, MD, DPhil
MAJ Ronnie Hill, MS
Michael A. Meledeo, PhD
Kristin M. Reddoch-Cardenas, PhD
James Bynum, PhD
COL Jason Corley, MS
MAJ Steven G. Schauer, DO, MS

## Abstract

Introduction: During multi-domain combat operations, logistical constraints may compel forward medical personnel to decide whether to use expired blood products. The incidence of expired blood product usage in recent conflicts is unknown.

Methods: We queried the Armed Services Blood Program (ASBP) database of all blood administered in theater from 2002-2019. We categorized any administration of blood product with a transfusion date of 1-30 days after the expiration date for this analysis. We excluded any documented transfusions more than 30 days after the expiration date as likely represents clerical error based on study team experience.

Results: There were 1,491 (0.4% of the total transfusion dataset) units that met inclusion for this analysis. Of the 1,491, 86% (n=1,278 transfusions) will occur within 1-3 days post-expiration. These 1,491 units were transfused into 741 patients. The majority of expired blood product recipients were male (87%). Afghans were most frequent (46%), followed by US forces (22%) with most occurring during Operation Enduring Freedom (64%). Trauma was the most common mechanism of injury for these patients (70%). The most common blood type transfused to recipients was O positive (28%). The most frequently transfused expired unit was red blood cells (n=899), followed by platelets (n=299), followed by whole blood (n=152).

Conclusions: Expired red blood cell and platelet use suggests a need for better methods for extending the lifespan of whole blood and further development of longer stability cold-stored platelets to meet the needs of our end-users. Our data arises from mature theaters during counterinsurgency operations. The incidence of transfusion of expired blood products may increase in future multi-domain operations where medical personnel are likely to operate under more resource constrained settings.

*Keywords: expired; blood; administration; deployed; military; combat*

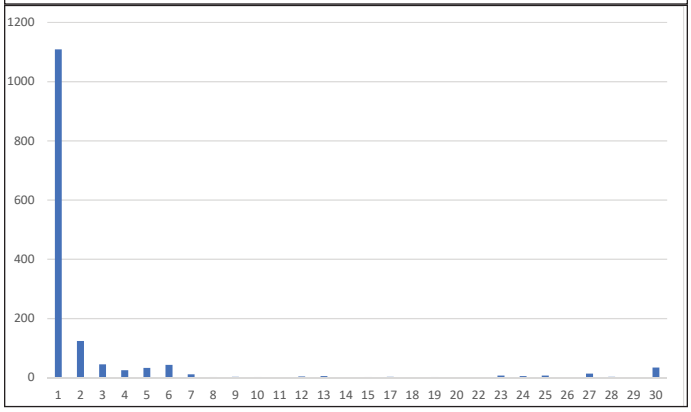
## Introduction

*Background*: Hemorrhage is the leading cause of potentially survivable death on the battlefield.[1] Blood transfusions are necessary to treat patients with severe hemorrhage. The use of blood products over crystalloids has improved mortality.[2-8] Therefore, military medical planners have pushed blood products forward to the point of injury to establish early hemostatic resuscitation.[9] The battlespaces within US Central Command are large, and the current distribution system of blood products across the theatre faces significant challenges in delivering blood to far forward areas prior to its expiration date. Multidomain operations (MDO) and, in particular, large scale combat operations (LSCO) will compound these difficulties given lack of freedom of movement.

The average age of red blood cells (RBCs) transfused in theater was 33 days in Operation Enduring Freedom (OEF).[10] Conversely, the average age of RBCs administered in the US civilian setting is 21 days.[10] When blood arrives at the combat support hospitals, the mean storage age is 27 days (± 5.2 days).[10] However, newer unpublished data suggests this has improved to 7 days (± 3

days) from arrival at the US Air Force Blood Transhipment Center (email communication, LTC Ronnie Hill, MS, Armed Services Blood Program, July 2021). Hence, blood reaching the theater was already 15-35 days away from expiration upon arrival. With the expansion of military operations into Africa, blood expiration is an increasing concern.[11,12] The US Africa Command (AFRICOM) covers an area five times the size of the continental US with limited innate medical logistical support and must rely on services available at US installations in Europe.[11]

Figure 1. Volume of expired blood by days expired.




There is much research on the ill effects of transfusion of aged blood but limited knowledge with expired blood. Older blood has a linear relationship to increased levels of potassium with time which disrupts electrolyte concentrations in the body.[13] A meta-analysis study performed by Wang et al determined the safety of transfusing older blood as compared to newer blood, concluding (1) transfusing older stored blood is associated with higher mortality; (2) associations exist between expired blood and increased risk of complications including multiple organ dysfunction syndrome and pneumonia; and (3) there are increased risks of renal dysfunction, sepsis, intubated ventilation for >72 hours and deep venous thrombosis following administration of blood products close to expiring.[14] Another study by Ho et al examined the time-dependent effects of storage on RBCs, including reduction in deformability and altered adhesiveness and aggregability; they also found evidence of storage lesion leading to reduced tissue oxygen availability and influences on morbidity and mortality.[15] However, others have pointed towards aged blood retaining value as a transfusion product.[16-18] Platelet products pose a high risk of outdating and wastage due mostly to the short shelf life—5-7 days when stored at room temperature.[19] During this time, platelets undergo a pronounced storage lesion resulting in loss of hemostatic function, mitochondrial function, and platelet aggregation response.[19-22]

In the civilian setting, new blood can readily replace old blood with rotational cycles, ensuring minimal waste due to expiration. Due to the nature of the military setting, long shipping distances inhibit quick replacement times; therefore, occasionally only expired blood is available after exhaustion of unexpired products. This may be of particular risk during MDO/LSCO. Clinicians in this setting must then rely on risk/benefit analysis in real time to determine whether to administer the expired blood to the patients.

*Goal of this Study*: While anecdotal reports of expired blood use exist, the incidence of transfusion of expired blood in theater remains unclear. We sought to determine the incidence of such events.

## Methods

*Data Acquisition*: The US Army Institute of Surgical Research Regulatory Compliance Division reviewed and approved this protocol along with HIPAA waiver.

The Armed Services Blood Program (ASBP) acquired the data. As part of routine operations, the ASBP maintains a log of all blood products transfused within US Central Command (CENTCOM), which includes recipients, blood product(s) transfused, blood type, date of blood product acquisition, date of expiration, and transfusion date. We included any units transfused within 1-30 days post-expiration. Based on study team subject matter expertise, we excluded from our analysis any units transfused >30 days after product expiration given the likelihood these dates represented clerical errors.

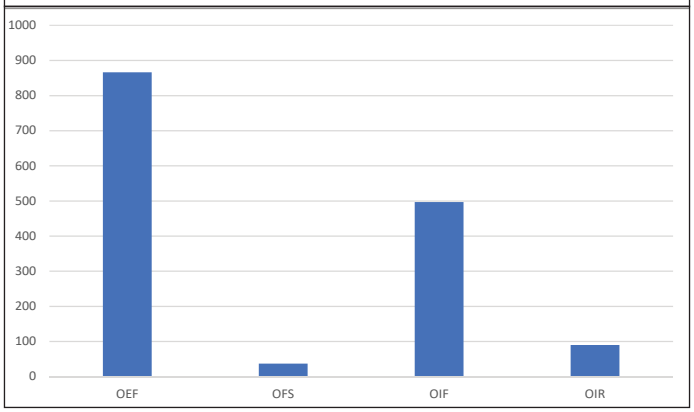
*Data Analysis*: All statistical analysis was performed using standard statistical software. We present continuous variables as means and 95% confidence intervals, nonparametric continuous variables and ordinal variables as medians and interquartile ranges, and nominal variables as percentages and numbers.

## Results

Within the ASBP dataset, there were 358,605 total blood product units transfused. Of these, 1,897 were transfused after the date of expiration. Within that subset, there were 1,491 (0.4%) units for which transfusion occurred 1-30 days post-expiration, meeting the inclusion criteria for this analysis. Of the 1,491, 86% (n=1278) were transfused in 1-3 days post-expiration into 741 patients (Figure 1). The majority of expired blood product recipients were male (87%). Afghans were most frequent recipients (46%) followed by US forces (22%), with most

transfusions occurring during OEF (64%, Figure 2). Trauma was the most common mechanism of injury for these patients (70%). The most common blood type of the products transfused to recipients was O positive (28%) (Table 1). Most of the expired blood transfusions occurred during the first decade of conflict (Figure 3). The most frequently transfused expired unit was red blood cells (n=899), followed by platelets (n=299), followed by whole blood (n=152) (Figure 4).

Figure 2. Volume of expired blood by days expired.




## Discussion

From 2002 to 2019, casualties underwent transfusion of 1,491 units of expired blood products. The number of US casualties in Iraq between the years 2004-2007 increased, with the highest number of annual casualties taking place during the first decade of war. There was a surge in the use of expired blood in 2006, even though the death toll was lower. The troop surge in 2007 could have caused increased burden on logistical and medical systems leading to more availability of medical personnel and blood products decreasing the reliance on expired blood products. Alternatively, it may be related to changes in practice patterns as more data guiding resuscitation was published.[23] Another surge of expired blood products occurred in 2010, when the number of casualties in Afghanistan increased. Increased casualty numbers secondary to the surge without maturing the distribution and logistics systems could have contributed to a lack of availability of age appropriate blood.[24,25]

One study performed by Matot et al studied the use of aged blood in bleeding rats to determine the effects on their liver. They concluded the administration of aged blood exacerbates liver injury following acute hemorrhage, and it results in decreased improvement for hyperoxia and hypercapnia.[9] The meta-analysis by Wang et al found higher mortality in patients receiving aged blood as well.[14] Since we are not aware of any clinical research on transfusing expired blood, the data on near-expired blood may estimate the effects of expired blood. These studies indicate older blood may result in negative consequences in patients. Therefore, expired blood may carry additional risks, but outcome data is lacking. The ability to link data such as this to robust outcome metrics is a major limitation as highlighted in previous publications on deployed documentation. It is important to determine the actual effects of expired blood to drive recommendations for the extreme situations that may occur in future LSCO/MDO conflicts. Moreover, we must highlight that knowingly using expired products creates ethical dilemmas for medical personnel as they must make a risk/benefit decision without any data to truly guide their risk assessment. The lack of qualified blood donors is a major problem in the civilian setting with spillover into the military setting since the ASBP relies on blood donation within the US-based donation centers. Blood banks continue to experience a steady decline in donors secondary to increasing stringent regulations.[26]

Table 1. Patient characteristics.

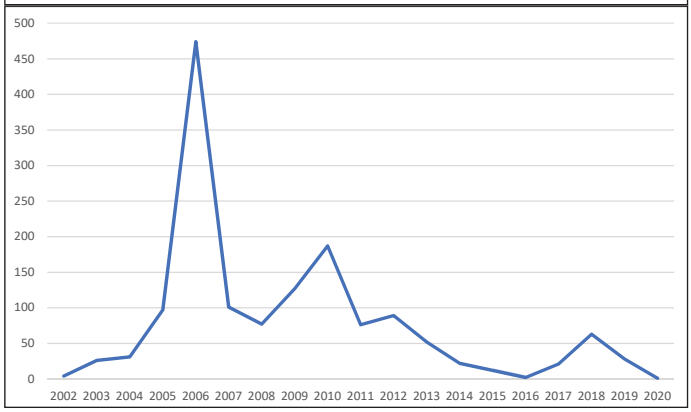
| | | |
|---|---|---|
| Gender | Male | 87% (647) |
| | Female/Unknown | 12% (94) |
| Affiliation | US | 22% (164) |
| | Coalition/Allies | 8% (57) |
| | Afghan | 46% (343) |
| | Iraqi | 17% (128) |
| | Unknown | 6% (49) |
| Indication | Trauma | 70% (519) |
| | DNBI | 13% (98) |
| | Unknown | 17% (127) |
| Military Operation | OEF | 64% (478) |
| | OIF | 27% (206) |
| | OFS | 3% (20) |
| | OIR | 5% (37) |
| Blood Type | A negative | 4% (28) |
| | A positive | 22% (167) |
| | AB negative | <1% (4) |
| | AB positive | 6% (42) |
| | B negative | 2% (42) |
| | B positive | 19% (146) |
| | O negative | 4% (33) |
| | O positive | 28% (211) |
| | Unknown | 13% (100) |

*DNBI: Disease and nonbattle injury; OEF: Operation Enduring Freedom; OIF: Operation Iraqi Freedom; OFS: Operation Freedoms Sentinel ;OIR: Operation Inherent Resolve*

As revealed by our study, approximately 0.4% of blood transfused in a military combat setting was expired. This indicates further research is necessary to determine the effects of expired blood. More importantly, the use of the expired blood indicates medical personnel were likely in situations in which they had to make real-time risk/benefit decisions with use of expired blood versus no blood at all. As a point of reference, approximately 13,000-21,000 units of packed red cells were destroyed per year from 2008 to 2019, with expiration as the most common reason (email communication, COL Jason Corley, MS, Armed Services Blood Program, July 2021). To mitigate

this risk, the Department of Defense (DoD) should continue to invest in four areas that will yield high impact during future operations. First, the development of promising science to extend the use of blood products, such as cold-stored platelets, is necessary across all blood products—especially LTOWB.[27,28] Research from several groups has suggested the feasibility of 21-day cold storage of platelets using in vitro assays, and a phase III, multicenter, clinical trial (CHIlled Platelet Study "CHIPS") is currently underway to evaluate the efficacy of 21-day cold-stored platelets in patients undergoing complex cardiac surgery, in hopes to achieve full US Food and Drug Administration (FDA) licensure.[29-31] This one-week extension in shelf life will undoubtedly assist in enhancing platelet inventories for both the military and civilian sectors and may subsequently provide insight as to whether shelf life can be further extended. Second, more robust methods for disseminating blood around theaters with contested airspace are needed through drones or even underground technology under development for other purposes. A study by Mesar et al tested the use of unmanned drone delivery of medical supplies, including blood products, to remote areas. They concluded this method of transport to be a success which could be very beneficial for transporting blood products within their time of viability.[32] Third, support further advancement to bring synthetic or semisynthetic hemoglobin-based oxygen carriers and other therapies to full fruition.[33,34] Finally, development of a more robust emergency blood program, such as walking blood banks for the collection and transfusion of warm, fresh whole blood, could greatly improve the amount of viable blood available in a combat setting. Implementing a program where all service members who meet criteria of a walking donor could be easily accessed by unit providers could greatly contribute to this concept. At this time, the DoD programs have specific criteria for access and are only available for units that seek to build a program. Of course, another related area for research focus is ongoing study of modalities to prevent hemorrhage such as tourniquets and hemostatic agents.[35-40]

Figure 3. Volume of expired blood transfused per year.

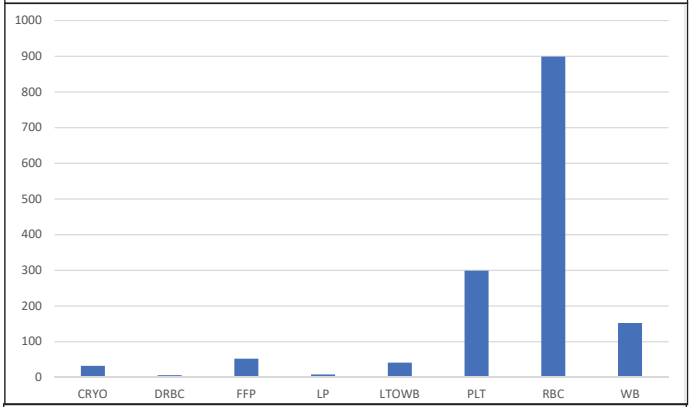



There are several limitations to this study. First, the data we presented here is observational and descriptive, thus we are unable to assess the effects of blood administration on outcomes. As previously stated, the lack of a robust method to link such events to outcome data hinders effective performance improvement.[41,42] Next, these data arise from counterinsurgency combat operations and may not extrapolate to the expired blood product administration patterns seen during LSCO.[43] Third and as previously mentioned, data entry in the current blood program system of record in combat environments is subject to data entry errors for various reasons. Lastly, we do not have information as to the reason for using expired blood or the conditions surrounding the events. Better performance improvement systems would enhance research capabilities.

## Conclusion

Expired red blood cell and platelet use suggests a need for better methods for extending the lifespan of whole blood and further development of longer stability cold-stored platelets to meet the needs of end-users. Our data arises from mature theaters during counterinsurgency operations; the incidence of transfusion of expired blood products may increase in future multi-domain operations where medical personnel are likely to operate under more resource constrained settings.

Figure 4. Volume of expired blood transfused by product type (n=1490).




*n=1 unknown product was removed;*
*CRYO: Cryoprecipitate; DRBC: Double red blood cell; FFP: Fresh frozen plasma; LP: Liquid plasma; LTOWB: Low titer O whole blood; PLT: Platelets; RBC: Red blood cells WB: Whole blood*

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## Authors

Ryann S. Lauby is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Sarah A. Johnson is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

MAJ Andrew D. Fisher is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX; and Uniformed Services University of the Health Sciences, Bethesda, MD.

MAJ Michael D. April is with Department of

Surgery, University of New Mexico School of Medicine, Albuquerque, NM; and Medical Command, Texas Army National Guard, Austin, TX.

MAJ Ronnie Hill is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Michael A. Meledeo is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Kristin M. Reddoch-Cardenas is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

James Bynum is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

COL Jason Corley is with Army Blood Program, US Army Medical Command, JBSA Fort Sam Houston, TX.

MAJ Steven G. Schauer is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; Medical Command, Texas Army National Guard, Austin, TX; and Army Blood Program, US Army Medical Command, JBSA Fort Sam Houston, TX.

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# A Scoping Review of Promising Alternative Blood Products for Prolonged Field Care

Ryann S. Lauby
Sarah A. Johnson
Michael A. Meledeo, PhD
James Bynum, PhD
MAJ Steven G. Schauer, DO, MSCR

## Abstract

Hemorrhage is the leading cause of potentially preventable death on the battlefield. Blood transfusions are used as treatment to restore circulating volume until the hemorrhage can be surgically controlled. Research has shown earlier transfusion of blood products has better casualty outcomes, so blood products have been pushed forward to the point of injury. Currently, there is a mixed use of blood components and whole blood in the prehospital setting—both of which have challenging supply chain requirements. Alternative blood products offer several potential advantages, as they are easier to mass produce, obviating the need for donor recruitment. They also have improved shelf-life stability, potentially remove cold-chain storage, and even cross-matching requirements. In this limited review, we sought to provide a narrative review of current promising developments including hemoglobin-based oxygen carriers, polyhemoglobin, platelet like cells, dried plasma, liquid plasma, fibrinogen concentrates, enzyme concentrates, nanoparticles, and perfluorocarbon-based artificial oxygen carriers.

*Keywords: hemoglobin; oxygen; carrier; military; combat; trauma*

## Background

Hemorrhage is the leading cause of potentially preventable death on the battlefield. A study completed by Eastridge et al analyzed battlefield death and its main causes in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). They found 87.3% of all injury mortality occurred in the prehospital setting. Of these, 24.3% were determined to be potentially survivable with the most common cause of injury being hemorrhage (90.9%). They concluded in order to improve the outcome of combat casualties with potentially survivable hemorrhage, methods for reducing the time from injury to when a casualty receives blood products are needed.[1]

Advances in battlefield medicine during the conflicts of Iraq and Afghanistan included universal availability of interventions such as tourniquets and hemostatic dressings.[2-5] These practices have increased the survival rate of injuries, particularly for hemorrhaging casualties. However, non-compressible torso hemorrhage and junctional hemorrhage are 2 common causes of preventable death, neither of which can be treated with the aforementioned standard methods of control.[2] Therefore, blood transfusions are used as treatment to restore circulating volume until the hemorrhage can be surgically controlled. Research has shown earlier transfusion of blood products has better casualty outcomes, so blood products have been pushed forward to the point of injury (POI).[6]

Evidence has shown the superiority of blood products over crystalloids for hemostatic resuscitation pertaining to traumatic hemorrhage patients. Furthermore, balanced resuscitation using a near equal amount of packed

red cells, plasma, and platelets is optimal when whole blood is not available.[7-12] Whole blood represents the optimal transfusion ratios; thus, the military has made advancements to early resuscitation programs such as low titer group O whole blood (LTOWB).[13] Moreover, whole blood has less dilution and less anticoagulants in solution. Even though these programs exist, blood product availability prehospital is limited in both civilian and combat settings, often due to the limited shelf-life stability and cold-chain storage requirements.[14] The viability of red blood cells (RBCs) after storage differs for every donor with viabilities at the end of the storage ranging from <60% to >95%.[15] Storage of blood components also causes significant damage to the product such as reducing functional capacity and survival time of the cells.[16] RBCs are the most common type of blood product transfused. However, during storage, RBCs undergo structural and functional changes, reducing function and viability. This can lead to the development of storage lesions, which are biochemical and biomechanical changes that reduce RBC survival and function.[17] Storage lesions can also have negative effects in platelets. Platelet storage lesions (PSL) caused by multiple biochemical processes and sometimes bacterial contamination cause deleterious changes to structure and function. PSL limit platelets to a 5-day room-temperature shelf life.[18] Despite the advances in blood component storage technology, there is no single method to eliminate all risks associated with storage.

Table 1. Summary of reviewed products.

| Category | Developing Product | Summary |
|---|---|---|
| Hemoglobin-based oxygen carriers | Human-derived Hemolink MP4OX Polyheme Hemopure ErythroMer OxyBridge | These use hemoglobin, a natural oxygen-carrying molecule, to carry oxygen throughout the body. They act as oxygen bridges to complement or replace biological blood products. |
| Perfluorocarbon-based artificial oxygen carriers | Perfluoro decalin | Perfluorocarbon-based artificial oxygen carriers use fully synthetic, perfluorocarbon materials to transport gases throughout the body. |
| Polyhemoglobin | PolyHb-Tempol | Polyhemoglobin is a blood substitute that is an oxygen carrier with platelet-like activity. It is formed from cross-linking fibrinogen to hemoglobin to form polyhemoglobin-fibrinogen (polyHb-Fg). |
| Platelet mimics | SynthoPlate Platelet-like cells PlateletBio | Often albumin-based nanoparticles that mimics hemostatic activity by way of adhesion and aggregation. |
| Dried plasmas | FrontlineODP | Spray-dried plasmas are either human-derived or synthetic products that provide the coagulation factors found in plasma. |
| Liquid plasma | No specified model | Similar to the spray-dried plasma but they remain in liquid form and is never frozen unlike fresh frozen plasma. |
| Fibrinogen concentrates | No specified model | Human-derived concentrates use for the prevention/treatment of fibrinogen-based bleeding disorders by repleting functioning fibrinogen. |
| Enzyme concentrates | Prothrombin complex concentrate | Prothrombin complex concentrate provides the specific coagulation products needed without the need for whole plasma. This reduces pathogen risk and remove need for ABO matching. |
| Nanoparticles | No specified model | Nanotechnology focused on bioengineering synthetic blood substitutes and semi- |

Each blood product has different logistical challenges for administration in the pre-hospital setting. Platelets do not express Rh antigens; however, they do contain small amounts of RBCs. Though minor, this can result in alloimmunization to the RhD antigen. Although the risks are minor, incompatibility and platelets' short shelf life can result in low availability.[19] Plasma is used to correct clotting factor deficiencies. However, fresh frozen plasma (FFP) is typically needed at the point of injury which poses challenges for administration due to the need to maintain freezing conditions until usage and then control thawing. Freeze dried plasma (FDP) sourced from the French military is in use by the US Special Operations Command under an emergency use authorization, but no Food and Drug Administration- (FDA) approved FDP currently exists in the US.[20] The recent battlespaces of Iraq, Afghanistan, and Syria are large, and distribution has faced significant logistic difficulties when transporting blood products across the theater. Due to these challenges, an alternative blood product would be beneficial for the military, particularly in multi-domain operations (MDO). With alternative products, the challenges associated with storage, transportation, and viability could be overcome in the prehospital setting until more advanced treatment facilities can be reached.

The Defense Advanced Research Projects Agency (DARPA) developed a program, Fieldable Solutions for Hemorrhage with Bio-Artificial Resuscitation Products (FSHARP), with an aim to develop technical advances to create blood product alternatives. The goal of FSHARP is to create a substitute that approximates WB since it is the preferred resuscitation fluid in combat casualty care.[21] This program is a 4-year effort with two 24-month phases, during which 2 technical areas will be addressed: blood substitute development and manufacturing/stabilization. Kickoff is anticipated in 2022.

Participants in this program are tasked with creating blood products with the following characteristics: perform the therapeutic functions of blood components needed for resuscitation, can be co-administered to perform the functions of WB with no adverse effects, have a 6-month shelf life without a cold-chain requirement,

and have a quick, scalable, cost-effective, and consistent manufacturing process.[21] This program could create alternative blood products to address many of the current problems faced when administering blood in a combat and prehospital setting.

There are currently several different blood product alternatives being researched. Even though alternative blood products are made as substitutes for different kinds of blood components, the goal for each product is similar: long-term stability, compatibility with all blood types, and availability. In this limited review, we sought to present some promising alternative blood product candidates which may represent viable options for future prolonged field care (PFC) events during MDO.

Products were primarily identified through existing relationships with military scientists, PubMed, and search engines seeking products in advanced stages of development. We also searched through references of relevant publications and reference libraries from some of the authors on this paper. The overall concepts discussed in this paper are outlined in Table 1.

*Hemoglobin-Based Oxygen Carriers (HBOCs)*: HBOCs use hemoglobin (Hb), a natural oxygen-carrying molecule, to carry oxygen throughout the body.[22] HBOCs act as oxygen bridges to complement or replace biological blood products in life-threatening trauma situations in austere environments.[23] There are no FDA-approved HBOC products for the human population in the US, though some are used under special conditions from the FDA. According to the FDA, concerns exist since Hb is not contained within the red blood cell, potentially accumulating to toxic levels in the blood. Cell-free Hb can also cause high blood pressure and escape from blood vessels which can damage kidneys and the other organs.[24] In animal models, haptoglobin has been found to bind to Hb and prevent Hb toxicity. If haptoglobin is applicable to human HBOCs, it may be an answer to designing safer HBOCs.[22]

In a study completed by Jansman et al, they designed an HBOC that incorporated a nanozyme (nanomaterial with enzyme-like characteristics).[25] They prepared an HBOC using the layer-by-layer technique, and the resulting as-prepared Hb-oxygen-based nanocarriers were hemo- and bio-compatible. Their potential was further revealed by the HBOC's superoxide radical- and peroxide-scavenging abilities, which were maintained over many cycles. These results demonstrated the nanocarriers have potential to be successful oxygen delivery systems with prolonged activity against reactive oxygen species.[23]

Many clinical trials have taken place using HBOCs; however, the following have not been successful. Hemosol created an HBOC called Hemolink. They conducted a trial with their product in a cardiac surgery, which resulted in myocardial infarction in the test arm. Another company, Sangart, conducted two phase II trials in trauma. Their HBOC, MP4OX, failed to achieve its primary endpoint goal: discharged and alive at 28 days. Northfield Laboratories created an HBOC, PolyHeme, and ran one of the few trials that accounted for a delay in RBC availability. A panel of experts found a relationship between PolyHeme and myocardial infarction which could not be ascertained. There were also many protocol violations causing the study to fail and eliminate development.[26]

There is currently 1 HBOC available for use, Hemopure (HBOC-201). Hemopure, used by University of Florida Health, is an HBOC derived from bovine blood. Hemopure has a shelf life of up to 3 years when stored between 2-30 degrees Celsius. Additionally, Hemopure's affinity for oxygen is maintained in a physiological range during storage, but 2,3-diphosphoglyceric acid (DPG) must be replenished in RBCs after storage. Hemopure is currently only available under FDA investigational status, allowing patients under specific circumstances usage of the product.[27] However, Hemopure is also registered for use with the Medicines Control Council of South Africa. This product is one of the more advanced products and may represent a potential source of additional blood supply chain supplementation in the event of unexpected war with difficult-to-sustain blood needs.

Recently, HBOC use was tested in regard to helping COVID-19 patients. One of the main clinical side effects of severe COVID-19 cases is hypoxemia, leading to acute respiratory distress syndrome, and HBOCs are intended to reverse hypoxemia. Simoni et al concluded only oxygenated HBOCs with moderate oxygen affinity, controlled redox chemistry, and anti-inflammatory properties without procoagulant activity could be considered for the future to establish treatment in COVID-19.[28]

Although the science of artificial blood is advancing, biological blood is still the preferred choice when available. HBOCs are beneficial as a volume expander, but circulatory volume must be monitored for signs of fluid overload. Hemopure is not as effective at restoring Hb content and concentration compared to RBCs. However, in emergent situations where biological blood is not available, it offers an alternative for improving oxygen transport.[29]

ErythroMer (KayloCyte) is a donut-shaped

immuno-silent nanoparticle casing which mimics the membrane and surface area of an RBC, allowing for a physiologically realistic gas exchange. This product has no blood antigens, so it does not require blood type matching. This product is designed to emulate normal blood cell physiology, robust storage capability, facile administration, and cost effective, efficient formulation. ErythroMer can be freeze-dried resulting in a longer shelf life than biological blood. It also has context dependent oxygen binding that allows for the distribution of oxygen to target tissues. Due to the close imitation of human physiology, the likelihood of unintended consequences associated with other blood replacement products such as vasoconstriction, the narrowing of blood cells and hypertension is drastically reduced.[30]

VirTech Bio company is in the process of developing an HBOC called OxyBridge. This product is an oxygen-carrying plasma expander used to restore circulatory system parameters in hemorrhaging patients. This product can be administered like a normal blood product through an IV. It is sterile and virus-free, and it is universally compatible with all blood types. Unlike normal biological-based blood products, it does not have to be stored at low temperatures and can last multiple years in a temperature stable room. This product can deliver oxygen, maintain blood pressure, and improve coagulation when combined with plasma. It can be used in the prehospital setting as a low volume resuscitation fluid when blood is not an option during hemorrhage. OxyBridge can improve oxygen uptake through the lungs by delivering oxygen to reduced flow regions. OxyBridge may even prevent the need to go on a ventilator. This product also has applications for COVID-19 patients. It can be used as a compliment to circulating RBCs to increase oxygen uptake and release during conditions of hypoxia due to lung damage and vasculature occlusions (i.e. COVID-19 patients).[31]

*Perfluorocarbon-Based Artificial Oxygen Carriers (PFOCS)*: Another product with potential to transport essential gases such as oxygen is perfluorocarbons or perfluorocarbon-based artificial oxygen carriers (PFOCs). The main difference between HBOCs and PFOCs is that HBOCs use hemoglobin, a physiological-based oxygen carrier; whereas, PFOCs work with fully synthetic materials, perfluorocarbons. Compared to HBOCs, PFOCs are applicable for therapy of decompression sickness, smoke/carbon monoxide poisoning, and tumor therapy. Their chemical inertness prevents enzymatic degradation, so no toxic intermediates form, one of the major problems with HBOCs. However, PFOCs' physical properties require a blood-compatible form for intravenous administration. Wrobeln et al synthesized nano scaled PFOCs with a perfluoro decalin (PFD) core surrounded by a biocompatible albumin shell (capsules) and then replaced 95% blood volume in a rat model with capsules in a plasma-like solution (treatment group) or the plasma-like solution without the capsules (control group). They concluded the capsule treatment adequately supplied the rats with enough oxygen. Furthermore, the oxygen supplied by the capsules prevented hypoxia on a cellular level. They expressed more trials need to be done to have proof the capsules do not harm the spleen, but there is promise for this technology.[23]

*Polyhemoglobin*: Polyhemoglobin (polyHb) is a blood substitute with the ability to serve as an oxygen carrier with platelet-like activity. It is formed from cross-linking fibrinogen to hemoglobin to form polyhemoglobin-fibrinogen (polyHb-Fg). When tested in vitro, this product showed similar clotting times to whole blood (WB), compared to polyHb, which had substantially slower times.[32] This product is currently in phase 3 trials and shows significant possibility for introduction to humans in the future. In another trial, a tempol compound was cross-linked to a hemoglobin molecule to produce a PolyHb-Tempol in order to overcome the defects of HBOCs. PolyHb-Tempol did not show any toxicity toward endothelial cells. Observations of cell morphology showed a significant ability to inhibit or eliminate oxidative stress induced by superoxide free radicals. These results suggest the potential for PolyHb-Tempol as an HBOC, but it needs further development.[32,33]

*SynthoPlate*: SynthoPlate is an artificial blood product designed to mimic platelets. More than 2 million platelet transfusions are given to casualties suffering traumatic injuries every year.[34] However, biological platelet transfusions face several complications: limited donor availability, short shelf life (3-5 days), and a high risk of contamination. SynthoPlate eliminates these consequences.[34] Even though SynthoPlate has not been used on humans, it has been tested in mice. A study completed by Shukla et al found SynthoPlate did not aggregate resting platelets or promote coagulation in plasma, but it could amplify the recruitment and aggregation of active platelets at the bleeding site. They also found it dramatically reduced bleeding time in thrombocytopenic mice to levels similar to normal mice. They concluded these results show promise for the future of SynthoPlate as a platelet substitute for treating platelet-related bleeding complications.[35] Considering the short shelf life of platelets and the complications associated with the distribution of blood products in the combat theater, this product could make a major difference in prolonged field care and prehospital care. Successful administration of this product would improve patient outcomes by increasing

the administration of a key component in blood clotting.

*Platelet-Like Cells*: Biological platelets are versatile and essential for preventing and stopping bleeding. Platelet-like cells (PLCs) are designed to replicate platelets' ability to target and clear unwanted antibodies, deliver specific payloads, and initiate and assist with coagulation. PLCs are anucleate, so these cells do not bring exogenous nuclear deoxyribonucleic acid (DNA) into the patient's body avoiding possible consequences. PlateletBio is able to produce genetically engineered PLCs with the ability to deliver targeted payloads specific to various diseases.[36]

The company's original goal was to develop platelets to address the platelet shortages at blood donation centers. They then expanded their goal to develop platelets into cell therapies. Their main goal is to develop a treatment for immune thrombocytopenia—a blood disorder in which the immune system mistakenly sees a patient's platelets as foreign and destroys them.[37] Although PlateletBio is not specifically aimed at designing a product for trauma resuscitation, their research and products have the potential to impact future research aimed at treating trauma cases.

*Dried Plasmas*: Plasma is important for blood coagulation, maintaining hemostatic balance, endothelial integrity, and supporting healthy organ function. Plasma transfusions are commonly used in treatment of many types of traumas that result in blood loss and uncontrollable hemorrhage. The early administration of plasma has proven to be very beneficial. However, plasma is frozen after collection to extend shelf life. This is problematic for many transfusion situations, especially trauma situations in the combat setting where frozen storage and thawing capabilities are not readily available.[38]

Velico Medical, a medical technology company, is developing a single-unit spray drying platform (FrontlineODP), which produces a dried plasma product for transfusion and can overcome storage requirements. It does not have to be frozen, making it an optimal product for remote locations where storage capabilities are limited. Currently, the device and resultant plasma were granted FDA approval to proceed with a phase-I (human) clinical study. Due to this approval, the Biomedical Advanced Research and Development Authority (BARDA) provided Velico with more funding to further their research and the development of these products.[39]

Teleflex, a global provider of medical technologies, developed a freeze-dried plasma (FDP) stable candidate that can be stored at room temperatures.[40] Recently, Teleflex submitted a biologics license application (BLA) to the FDA. Upon further trials, this product shows promise as being a candidate for treatment in trauma situations following success in subsequent trials.[41]

*Liquid Plasma*: Research has shown early and balanced administration of blood products for treatment of traumatic hemorrhage leads to decreased mortality, making quick plasma administration imperative. FFP has limited shelf life and takes time to thaw, which can delay its administration. Liquid plasma (LP) is a currently researched alternative, because it can be given immediately when a transfusion is needed. LP is never frozen, compared to normal plasma, which is normally frozen after collection. LP has a longer shelf life compared to thawed plasma, and once collected it can be refrigerated and stored for at least the shelf life of WB, from which the plasma was made.[42] A study completed by Beattie et al tested the use of LP in the massive transfusion protocol (MTP). They hypothesized the use of LP would improve optimal plasma/RBC ratios, initial plasma transfusion times, and clinical outcomes in severely injured patients. They concluded initial resuscitation with LP optimizes early plasma administration and improves clinical outcomes. These results indicate LP as a possible alternative to FFPs, particularly in MTPs, but it also has implications for trauma resuscitation.[43] LP is not approved for use in the general population, but it is approved for patients undergoing massive transfusion due to life-threatening trauma or hemorrhage.[42]

*Fibrinogen Concentrates*: Human fibrinogen concentrates (HFCs) are an established prevention and treatment for congenital fibrinogen-related bleeding disorders, but recent studies have shown they can be used as treatment for hemorrhage in trauma. No plasma-derived HFC is approved for use in the US, as there are some problems to overcome. All products considered have similar purification and inactivation steps, but the manufacturing processes differ for each product. These differences might lead to small clinical differences in composition,[44] but these differences may lead to the faster development of a product specific and effective for the treatment of trauma.

*Enzyme Concentrates*: Sufficient amounts of activated thrombin are needed to convert soluble fibrinogen into insoluble strands of fibrin, forming a fibrin clot and catalyzing multiple other coagulation-related reactions. Impaired thrombin generation is a cause of coagulopathy and excessive bleeding in cardiac surgery. Frozen plasma (FP) and prothrombin complex concentrate (PCC) are used to replenish depleted coagulation factors and improve thrombin generation in bleeding patients. FP is the main treatment for this purpose, however, there

are implications that should be overcome to improve patient treatment. PCCs offer a potential alternative to FP in management of bleeding. The advantages of PCCs over FP include the following: availability of pathogen reduction, no need for ABO blood group matching, and absence of thawing (allowing for easier storage and timely administration). However, PCCs do not contain the full, balanced complement of procoagulants and anticoagulants present in FP. Therefore, they may be less effective in restoring hemostasis, may carry a higher thrombosis risk, or both.[45] More trials are needed to conclude whether PCC is a suitable replacement for FP. Fibrinogen and Factor XIII show an exceptional capability to improve fibrin clot firmness, and they showed the ability to restore several clinical clotting parameters including rotational thromboelastometry (ROTEM) clot amplitudes and maximal clot firmness values. These concentrates have coagulation restoring characteristics and hold promise as an alternative for treating massive transfusion (MT) and hemorrhage upon further trials and testing.

*Nanoparticles*: Nanotechnology is focused on bioengineering synthetic blood substitutes and semi-synthetic RBC substitutes for enabling oxygen transport, platelet substitutes for hemostasis, and WBC substitutes for enabling cell-specific immune response. Polymer nanoparticles have been shown to interact with activated platelets to enhance clotting. These particles show promise in stopping bleeding and are currently under research. These particles do face some challenges involving their temperature range over which they remain effective. In order to be effective, nanoparticles must be administered within minutes of injury, but due to their temperature restrictions, they are likely not a viable option for combat field use. One study conducted by Lashof-Sullivan et al developed a synthetic substitute using nanoparticles with a poly(lactic-co-glycolic acid) (PLGA) core and poly(ethylene glycerol) (PEG) arms, which can interact with activated platelets to reduce bleeding. These particles are stable at room temperature but not extreme temperatures. They also investigated the use of a poly(lactic acid) (PLA) core with the hopes it will have a broader viable temperature range. They concluded hemostatic nanoparticles with a PLA core are an effective hemostatic agent. Further research is needed in order to assess these particles' efficiency in large animal models and define safe storage conditions.[46] Lab harvested extracellular vesicles also show potential as a synthetic blood product. Platelet derived-extracellular vesicles are small vesicles that carry heterogeneous cargo loads and surface ligands.

## Discussion

In scenarios where hemorrhage persists after traditional methods of control, survival is dependent on early administration of blood products. Administering blood products in the combat setting has many logistic hurdles, and even more exist in the prehospital setting. Most blood products require blood type matching, must be refrigerated, have a short shelf-life, and have limited availability due to lack of donors. Due to the limits and restrictions on biological blood products, development of synthetic and semisynthetic surrogates of blood is being prioritized. The purpose of artificial blood products is to mimic and perform the functions of the blood components until such time as biological products are available. Artificial blood has the potential to be stored as small volume deliverables for long periods of time at various temperatures, could be reconstituted and administered quickly in austere settings, and avoids the need to be blood type matched.[47]

## Future Research

Most potentially survivable deaths occur in the prehospital setting before surgical capabilities can be reached. Improved methods of prehospital care is the solution to reducing mortality. A study completed by Schauer et al analyzed prehospital data within the Department of Defense Trauma Registry (DODTR). From January 2007 to March 2020, the study found that 28,950 encounters within the DODTR received prehospital care. Although there was a rapid decline in combat casualty volume since 2014 on a per-encounter basis, there was no observable drop in procedural volume.[48] Future large-scale combat operations will increase the likelihood of PFC, as well as reduced air superiority will further prohibit immediate evacuation and promote the need to push more capabilities forward. One study of 54 cases of PFC found almost half of the patients (48.1%) were administered fluids, but 96.1% of these casualties (of the 48.1%) received crystalloids.[49] Traditional blood products must be refrigerated, properly stored, and have short storage lives, all of which inhibit use in the PFC setting. However, the easier storage and administration requirements of artificial blood products would enable their use far forward.

Currently, there are several problems associated with blood products and long storage periods. The longer a blood product is stored, the more degradation the product goes through. RBCs under continued storage face oxidative damage, decreased oxygen carrying capability, and membrane deformation.[50] Recently, the advantages of WB over blood components have pushed it forward to the point of injury. However, WB also faces challenges

with storage, specifically storage lesions. Advancements in storage additive solutions could play a crucial role in decreasing long term storage damage.

Future developments in synthetic blood products are also needed to decrease mortality rates and increase blood product availability in the prehospital setting. As of the time this paper was written, there is only one HBOC approved for human use, Hemopure, and only with special permission from the FDA in the US. All other HBOCs discussed are not yet available on the market. All other synthetic blood components such as platelets and RBCs are still under development and are not approved for human use. In order to make synthetic blood products a major contender in the treatment of trauma patients, the synthetic blood products discussed in this paper need to be brought to completion. Further research also needs to be completed to develop the most ideal synthetic blood products and combinations applicable to the treatment of trauma patients. The US military needs to continue to partner with companies demonstrating potentially successful products. Blood product circulation around the battlefield remains challenging in the recent conflicts, where there was uncontested air movement. In future conflicts, we will need products that can be easily scaled on demand, long term storage, with limited or no cold chain requirements.

## Conclusion

Several synthetic blood products are under development and may have promise for future multi-domain operations with prolonged periods of time without evacuation and interruptions of the supply chain. Further development of these products in partnership with the US military may advance the capabilities in far-forward areas.

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## Authors

Ryann S. Lauby is with 59th Medical Wing, JBSA Lackland, TX.

Sarah A. Johnson is with 59th Medical Wing, JBSA Lackland, TX.

Michael A. Meledeo is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

James Bynum is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

MAJ Steven G. Schauer is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; Brooke Army Medical Center, JBSA Fort Sam Houston, TX; and Uniformed Services University of the Health Sciences, Bethesda, MD.

# An Updated Review of Improvised Ground Evacuation Platforms for Austere Special Operations Casualty Transport

CPT Joseph A. Mazarella, CCRN
MAJ Timothy B. Pekari, DSc
LTC Ivan J. Antosh, MD

## Abstract

Introduction: In 2018, the Expeditionary Resuscitative Surgical Team 3 (ERST-3) published a retrospective review on the ground casualty evacuation (CASEVAC) options available to a Special Operations Forces (SOF) unit in the Horn of Africa. Seventeen months following their deployment, ERST-7 provided an update on the improvised ground evacuation platforms in the same area of operations and what has and has not worked based on combat experience and new literature.

Methods: This publication is an update to a retrospective review of various modes of ground transportation used by ERST-7 during their deployment with Special Operations Command Africa from July 2020 to January 2021. The authors excluded all hand-carried litter and air evacuation platforms. The authors discuss litter setup, necessary modifications, litter capacity, strengths and weaknesses, and any recommendations for a Mine-Resistant Ambush Protected (MRAP) vehicle, a full-size pickup truck, and a mid-size pickup truck based on their use during the ERST-7 deployment. The authors also used previous literature to support their recommendations.

Results: The SOF unit to which ERST-7 was assigned still uses two of the four platforms included in the original study. The authors recommend continued use of the MRAP for patient extraction with a solely widthwise patient configuration, weather-proofing the open beds of MRAPs, and outfitting all MRAPs for Tactical Combat Casualty Care (TCCC) if the CASEVAC-designated MRAP is disabled. The pickup trucks functioned well for expedient CASEVAC under non-hostile conditions. However, they should be a last resort for CASEVAC outside friendly-controlled areas due to inadequate cover and concealment for patients and medical personnel providing enroute care.

Conclusions: Vehicles of opportunity available to SOF personnel are constantly changing. Continuous evaluation of local platforms is crucial, especially for partner force personnel who may not have access to dedicated air and ground MEDEVAC platforms. The authors recommend baseline readiness training on CASEVAC scenarios for those units traveling to areas without MEDEVAC assets.

*Keywords: patient transport; ground evacuation; special operations; prolonged field care; casualty evacuation; medical evacuation; austere; CASEVAC*

## Introduction

Special Operations Forces (SOF) have unique operational capabilities, typically functioning in austere environments with nonstandard movement and maneuver tactics. As units deploy to more remote areas, medical capabilities must also adapt to support SOF personnel. One unit that supports such missions is the Expeditionary Resuscitative Surgical Team (ERST), a far-forward, mobile surgical team composed of conventional Army medical forces supporting Special Operations Command Africa units deployed to the Horn of Africa.[1] In 2018, ERST-3 published a review on the unconventional casualty evacuation (CASEVAC) ground transportation platforms available to them while supporting Special Operations Command Africa units in East Africa.[2] Three ERST iterations and 17 months later, ERST-7 provided an update on the CASEVAC ground platforms still

in use in the same area of operations and what has and has not worked based on the recommendations from the ERST-3 publication.

Table 1. Platform overview.

| Improvised Vehicle | Litter Capacity |
|---|---|
| Mine-Resistant Ambush Protected Vehicle (MRAP) | 1 |
| Nonstandard Tactical Vehicle (NSTV): Full-size Pickup Truck | 1-2 |
| Nonstandard Tactical Vehicle (NSTV): Mid-size Pickup Truck | 1-2 |

CASEVAC platforms are considered vehicles of opportunity used to evacuate casualties when dedicated MEDEVAC platforms are not available. CASEVAC vehicles are unregulated and do not always have designated medical personnel on board. They are not marked with any medical symbols, and therefore do not have protection under Geneva Conventions.[3] During their deployments, ERST operated solely with CASEVAC platforms. While the authors focus exclusively on their CASEVAC experiences with the ERST, the recommendations listed in this article are also applicable to any area using similar platforms.

## Methods

The authors will review the various modes of ground transportation used by ERST-7 during their deployment with Special Operations Command Africa based on the experiences from multiple training exercises and mass casualty events (Table 1). The authors excluded all hand-carried litter and air evacuation platforms.

## Results

Our results for each CASEVAC platform include a description of the litter setup, necessary modifications, litter capacity, strengths and weaknesses of the platform, lessons adapted from ERST-3, and any further recommendations. Currently, the Mine-Resistant Ambush Protected vehicle (MRAP) and 2 nonstandard tactical vehicles (NSTVs) are still in use in the area of operations. However, the 2 four-wheel all-terrain vehicles[2] mentioned in the ERST-3 article are no longer in use by the assigned SOF unit due to equipment degradation and maintenance requirements.

*MRAP Vehicle Strengths*: Of the CASEVAC platforms available to this SOF unit, the MRAP is the ideal CASEVAC ground platform. In this platform, the casualty and attendant are protected from enemy small arms fire, shrapnel, and direct blasts from ground-planted improvised explosive devices. There is also adequate working space for multiple medical attendants, as discussed in the original article.[2] However, alternative litter configurations offer different strengths, which the authors will discuss in the recommendations section below.

*MRAP Weaknesses:* Unless one is treating a casualty in the primary assigned CASEVAC vehicle, a casualty's placement necessitates clearing all supplies and equipment out of the other MRAP bed. ERST-7 found no issues with the litter occupying space otherwise used for ammunition or other supplies, as long as users retract the litter handles before lifting the patient through the side door (Figure 1).

The size of the vehicle poses an issue for casualty loading. Lifting the patient into the side door can require up to 6 personnel, depending on the size of the casualty. When traversing forested areas with a casualty, overhead debris and brush can fall onto those in the bed during off-road conditions.[2] Also, the medical attendants in the bed cannot directly communicate to the vehicle commander without the blast door ajar. Thus, the attendants must rely on radio communication, which may pose an issue to equipment designation and mission planning.

Figure 1. Side loading a casualty into a mine-resistant ambush protected (MRAP) vehicle during a training exercise.

Figure 2. Expeditionary resuscitative surgical team (ERST) with patient in mine-resistant ambush protected (MRAP) bed.

Figure 3. Expeditionary resuscitative surgical team (ERST) medical bag configuration in mine-resistant ambush protected (MRAP) bed.

*Recommendations:* Based on ERST-7's use of the MRAP, the most effective method for patient evacuation has proven to be side loading of the casualty widthwise across the back of the bed if tactically feasible (Figure 2). This configuration allows two providers to remain in the bed with the casualty and have access to hanging aid bags (Figure 3). The authors recommend loading the casualty with the head on the driver's side, with the providers facing the vehicle's rear (Figure 1). This positioning gives the provider access to the left side of the chest if the patient requires an open thoracotomy.[4] ERST-3 discusses an alternative litter configuration with the casualty loaded head-first through the blast door (Figure 4). The authors further discuss the pros and cons of these different configurations in the Discussion section.

Figure 4. Patient loaded head-first through mine-resistant ambush protected (MRAP) blast door.[2]

ERST-7 recommends designating and training with one MRAP for CASEVAC that will contain an ERST forward element with optional SOF medical personnel. The vehicle's bed should contain minimal ammunition and other mission supplies, thus leaving room to pre-stage ERST medical bags and space for one litter to fit widthwise. ERST personnel in the backseat of the vehicle also carried a Tactical Combat Casualty Care (TCCC) bag and portable blood cooler with two units of stored whole blood. ERST and SOF personnel should rehearse loading and treating casualties in both assigned CASEVAC MRAP and non-medical MRAP for evacuating multiple casualties, as different vehicles may have different equipment arrangements on board. Based on rehearsals, ERST and SOF medics could load a complete medical equipment set and one litter patient in approximately eight minutes. However, one could hastily load a litter patient in one minute with medical supply setup enroute.

ERST-7 learned from a mass casualty event all MRAPs should include a TCCC aid bag if the designated medical vehicle is incapacitated. The TCCC bag should contain enough supplies to fully treat one casualty as an adjunct to all personnel's field aid pouches. Also, if training time allows, ERST and SOF medics can train on loading through the blast door if it is the only viable option given the tactical situation. Last, the authors also recommend weather-proofing the bed

of the MRAP with netting, a tarp, or a combination of the two (Figure 5).

Figure 5. Mine-resistant ambush protected (MRAP) bed can be weather-proofed using a cargo net or tarp secured to four points around the bed. Image captured from top of vehicle.

*Nonstandard Tactical Vehicle (NSTV)[5] Full-Size Pickup Truck Strengths:* As stated in the ERST-3 article, this NSTV is "light-weight and highly mobile… Easy to load and unload patients… Easy access for the attendant, (with) minimal setup required after securing device [is] mounted."[2]

*NSTV Full-Size Pickup Truck Weaknesses:* Unlike the MRAP, the main weaknesses in NSTVs are the lack of protection and space for those in the truck beds. The truck bed is typically occupied by equipment or storage space, so providers may find it difficult to transport more than 1 casualty on this NSTV. Also, the medical attendant may have difficulty communicating with team members inside the cab.[2]

*Recommendations*: ERST-7 does not recommend any changes to the proposals in the original article. This platform is ideal for expedient use in varied low-threat environments. The low tailgate profile and open bed restrict its use in prolonged field care and transposition in unsecure areas.[2] If this NSTV is the only choice for medical evacuation in hostile territory, providers should prepare a way to secure the casualty inside of the cab of the vehicle with a support device for protection from enemy munitions.[6]

*NSTV[5] Mid-Size Pickup Truck Strengths:* Like the full-size pickup NSTV, operators of the mid-size pickup truck can load 1 to 2 casualties and quickly secure for transport, ideally over short distances. There is ample space for multiple medical attendants in the one casualty configuration.

Figure 6. Mid-size pickup truck with 2 litters secured with cravats.

*NSTV Mid-Size Pickup Truck Weaknesses:* Due to the roll bars on the truck's bed, loading a second casualty is more challenging and should be utilized for the lighter, less critical casualty. Even more so than the full-size pickup truck, casualties and medical attendants are exposed to the elements and potential hostile hazards. Due to the shallow bed, both patients and medical attendants are less secure than the MRAP and full-size pickup truck alternatives.

In the 2-litter configuration, there is minimal space for even 1 medical attendant. There is limited space for medical equipment as well. Also, there are no safety restraints for the medical attendant(s) in the truck bed.

*Recommendations:* Like the full-size pickup, the mid-size pickup serves as an expedient CASEVAC platform over short distances when enemy contact is unlikely, such as during range operations or practicing indirect fire missions. One to 2 casualties can be placed lengthwise in the truck bed and secured to hooks located around the bed with rope, paracord, cravats, etc. (Figure 6). Multiple medical attendants can fit in a 1 litter configuration, while 2 litters can only allow for 1 attendant.

## Discussion

Due to operating in remote environments in small, autonomous teams, SOF and their supporting units must often rely on independent CASEVAC for evacuation from the point of injury to a higher level of care.[7] A Department of Defense Trauma Registry data analysis by Kotwal and colleagues showed out of 1,017 ground CASEVAC patients in Afghanistan from 2008 to 2014, six (0.6%) patients died enroute, and 34 (3.3%) died at the Role 2 facility. Alternatively, 1% of casualties died enroute, and 4.5% died at Role 2 facilities for MEDEVAC transports.[8] Therefore,

deploying units should become familiar with the CASEVAC platforms available to them, as they are a viable option for saving lives compared to MEDEVAC treatment.

As mentioned earlier, ERST-7 explored multiple ways to load litters into the available CASEVAC platforms. ERST-3 proposed 2 configurations for loading a patient into the MRAP in the original article. The first is headfirst through the rear blast door (Figure 4), and the second is widthwise across the bed's back (Figure 2).[2] While the rear-load is a viable option, ERST-7 found some pitfalls to this specific configuration:

1. It prevents a third individual from being able to sit in the middle backseat of the vehicle.

2. It splits the providers into different areas of the vehicle, leaving one inside for access to the patient's head and the other outside in the bed managing the rest of the patient, which the authors found to hinder communication and ability to assess and treat the casualty effectively.

3. The providers would have to decide whether to place the truck bags inside or outside of the cabin, which could also cause issues when needing to find medical supplies during transport.

4. ERST-3 required using a wooden platform in the bed of the vehicle for the litter to remain level, thus adding extra equipment.[2]

5. With the high risk of improvised explosive devices while enroute, an open blast door posed a threat to all personnel inside the vehicle in the event of a detonation.

Therefore, ERST-7 recommends the widthwise configuration for transporting 1 litter patient.

If a sports utility vehicle is available for CASEVAC, the authors found it beneficial to include recommendations from a 2020 *British Medical Journal* article on a CASEVAC in an austere location with this type of vehicle. The authors of this article used this platform to evacuate patients with the assistance of an "I" shaped wooden support base that secured the litter stirrups to the main cabin after folding down one side of the passenger seats.[6] This method could be used for any CASEVAC platform with a hatchback trunk space.

The authors found no limitations to this study. Overall, ERST-7's best practices recommendations are as follows:

1. Anticipate using all ground and air vehicles for CASEVAC and, if possible, dedicate at least 1 platform for MEDEVAC in these austere environments.

2. Continue use of the MRAP for patient extraction with a solely widthwise patient configuration.

3. Units should weather-proof the designated medical MRAP bed by securing a camouflaged tarp to the four corners of the vehicle's bed (Figure 5).

4. Outfit all MRAPs for TCCC if the medical MRAP is disabled.

5. The NSTVs discussed above should be used for short missions in non-hostile territory, such as range operations or partner force training in the vicinity of friendly forces. If an NSTV is the only option for CASEVAC for high threat operations, plan to transport causalities inside the vehicles.

6. Before deployment, forward-deployed medical units should add additional training on their possible CASEVAC platforms to prepare for this unique challenge.

## Conclusion

In a rapidly-changing, austere environment that contains multiple SOF units and partner forces, the evacuation platforms medical teams have at their disposal are also constantly changing. Incoming medical units should continue conducting joint training operations with SOF to maintain familiarity and continuity of care within these nonstandard ground evacuation platforms. Additionally, evaluate all possible partner force platforms for vehicles of opportunity and continue training partner force personnel to load, unload, and secure medical casualties appropriately. The authors encourage all future units deploying to austere locations to continue to evaluate CASEVAC options and provide to this growing body of literature for all types of deployed environments.

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## Authors


CPT Joseph A. Mazarella is with Critical Care Nursing Department, Walter Reed National Military Medical Center, Bethesda, MD.

MAJ Timothy B. Pekari is with Department of Orthopaedics, Evans Army Community Hospital, Fort Carson, CO.

LTC Ivan J. Antosh is with Department of Orthopaedic Surgery, Brooke Army Medical Center, Fort Sam Houston, TX.



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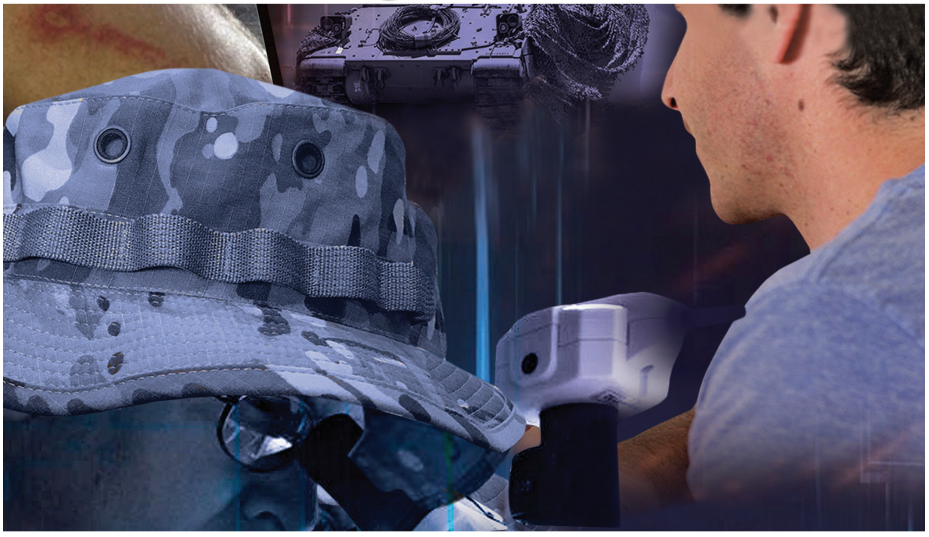

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# An Innovative Civilian Research Model to Inform Combat-Relevant Prolonged Casualty Care

Nee-Kofi Mould-Millman, MD
COL (ret) Sean Keenan, MD
Julia Dixon, MD, MPH
Elmin Steyn, MBChB
Hendrick J. Lategan, MBChB
Shaheem de Vries, MBChB, MPhil
Lina V. Mata, MD
Chandni Patel
MAJ Steven G. Schauer, DO, MSCR
MAJ Andrew D. Fisher, MD, PA-C LP
MAJ Michael D. April, MD, DPhil
Adit A. Ginde, MD, MPH
COL Vikhyat S. Bebarta, MD

## Abstract

Prolonged Casualty Care (PCC) is a major US military research focus area. PCC is defined as the need to provide patient care for extended periods when evacuation or mission requirements surpass capabilities and/or capacity. US military experts have called for more data relevant to PCC. In response, we aimed to develop an innovative research model using a tiered system of trauma care in the Western Cape of South Africa as a framework for studying relevant US military trauma care and outcomes in a natural prolonged care environment. The objective of this report is to describe the research model and to illustrate how various components of the model may be helpful to provide data relevant to US military PCC. To develop the model, we used a combination of published data, open access reports, and expert opinion to identify, define, and compare relevant components of the Western Cape trauma system suitable for researching aspects of US military PCC. Several key features of the research model are as follows: In the Western Cape, patients are referred from primary and secondary to tertiary facilities (analogous to escalating capabilities by advancing roles of care in the US military). Western Cape civilian trauma providers' capabilities range from prehospital basic life support to definitive trauma surgical and critical care (comparable to US military Tactical Combat Casualty Care to advanced definitive surgical care). Patterns of injuries (e.g., high rates of penetrating trauma and hemorrhagic shock) and prolonged times from injury to definitive surgical care in the Western Cape system have relevance to the US military. This civilian research model for studying PCC is promising and can inform US military research. Importantly, this model also fills gaps in the South African civilian system and is useful for other prolonged trauma care communities worldwide.

*Keywords: trauma; injury; combat casualty care; prolonged care; global health; prehospital care; military; South Africa*

## Introduction

Prolonged Casualty Care (PCC) has become a major focus area for the US military combat casualty care research program because prolonged durations of field care may worsen clinical outcomes.[1-5] For military expeditionary and contingency operations outside of developed combat theaters, transport times are frequently delayed.[2,6-8] Further, the US Army's future Multi-Domain Operations concept (MDO) will require prolonged periods of evacuation and care, likely measured in hours and days.[9-11] MDO describes how the US Army, as part of the joint force, can counter and defeat a near-peer adversary capable of contesting the US in all domains (air, land, maritime, space, and cyberspace) in armed conflict.[9]

Accordingly, US military experts have called for more data relevant to PCC.[2,12] Data from prior US wars, such as those stored in the US Department of Defense Trauma Registry (DODTR), overwhelmingly reflect care provided in non-PCC scenarios, with limited case series and reports of PCC.[1,13] Further, much of the existing trauma data comes from US civilian populations, which is less relevant to combat and PCC due to short transport times, differing injury profiles, and high resource

availability.[14-17] Hence, innovative research models are necessary to provide data highly relevant to prolonged care scenarios in resource-limited and austere settings, with combat-relevant injury profiles.

The US Department of Defense (DOD) has already made research investments in novel combat-relevant research locations outside the USA (EpiC Study, W81XWH-19-2-0055, 2019-2022; EpiC Study, W81XWH-20-2-0042, 2020-2024; and EMS-TruShoC Study, FA8650-18-2-6934, 2018-2021). One key location is the Western Cape of South Africa because of the large burden of combat-relevant trauma (over 200,000 injuries per year with 6,770 injury deaths in 2016), further typified by prolonged durations from injury to definitive treatment within a resource-constrained health system.[18,19] Gang wars and high rates of penetrating trauma are widespread within the Western Cape, especially in dense, informal settlements.[20-22] The prolonged durations of care, in part, are a consequence of the tiered system of care facilities, which are linked by formal prehospital transport and care. Upon arrival at facilities, patients receive high quality emergency and trauma care, albeit, under severe resource constraints. In the Western Cape, examples of typical durations from scene to initial facility include 0.75-hours median (interquartile range [IQR] 0.6-1.1) for emergency medical services (EMS) transported casualties, and 2.75-hours (IQR 0.8-2.2) for non-EMS self-transported patients (Brenda Beaty, MSc, email communication, August 2021).[23,24] Initial stabilizing hospital resuscitation is often prolonged with a median of 2.8-hours (IQR 1.6-4.7), with about one-third (30.1%) transported onwards to a higher level of care.[24] The mean duration from injury to trauma center arrival is 11.2 hours (standard deviation [SD] 11.1) (Brenda Beaty, MSc, email communication, August 2021). At trauma centers, time to surgical intervention is greater than 10 hours in about one-half (48%) of patients, with up to one-quarter experiencing delays of 24 hours post-injury.[25] In rural areas of the Western Cape, the aforementioned times may be 40-50% longer due to resource limitations and long transport distances.[26]

The objective of this study is to describe how the Western Cape's tiered system of trauma care can serve as one model for studying trauma care and outcomes relevant to US military casualty care in a natural prolonged care environment. This research model may prove useful to help inform PCC practice for the military while simultaneously leading to benefit for civilian populations in South Africa and internationally.

## Methods

The model is a product of the review of existing data sources and policy documents along with opinion from relevant US military and civilian experts in research and systems of care. First, we reviewed relevant US military and South African civilian documents to delineate the following: definitions of injury and prolonged care; priorities of care in PCC contexts; system configuration, capabilities, and tiers of providers; data capture processes; durations of care; and patient and injury characteristics. We then compared all stages of care in the Western Cape civilian and US military disrupted trauma care systems. Next, we consolidated all findings to develop the final research model.

## Results

*Injury & Prolonged Care Definitions:* "Injury" and "trauma" will be used interchangeably. We will apply the following DOD definition of injury: "A term comprising such conditions as fractures, wounds, sprains, strains, dislocations, concussions, and compressions."[27,28] PCC is the need to provide patient care for extended periods of time when evacuation or mission requirements surpass available capabilities and capacity to provide that care (LTC Jamie Riesberg, MD, e-mail communication, August 14, 2021). PCC reflects prehospital care where the patient(s) exceeds the Role 1 (defined below) capability, and the providers must manage difficult and/or multiple complex casualties beyond their capabilities due to overwhelming numbers or delay in evacuation. As per the original Prolonged Field Care (PFC) definition, patients managed beyond the "doctrinal planning time" (i.e., 10 minutes to first-responder care, 1 hour to resuscitative care, and 2 hours to surgical care per US Army and NATO) are in a PFC/PCC situation.[27,29]

"Delayed presentations" and "referral delays" are the most relevant Western Cape civilian terms with equivalence to US military PCC. Delayed presentations occur among patients who experience injuries but do not access emergency medical systems (EMS) or hospitals until significantly later in the progression of their injuries.[30-32] Referral delays are due to in-hospital or EMS delays associated with recognizing and/or executing transfers to higher levels of care, and prolonged transit times during ground ambulance transport.[33]

*Priorities in Prolonged Care Situations:* In the deployed US military setting, PCC situations often describe evacuation to surgical care and definitive medical care as measured in days, not hours.[2] The operational context incorporates the concept of delayed or prolonged patient evacuation with advanced en-route care, acknowledging the goal of managing patients is to ultimately deliver them to a robust, fixed medical facility as soon as practical.[2] Goals of care, as defined by Tactical Casualty

Combat Care (TCCC), are to reduce preventable deaths on the battlefield.[34] All military medical evacuation deemed urgent or urgent-surgical must occur in less than 60 minutes to a facility or role of care capable of surgical stabilization/treatment.[35]

Table 1. Comparing settings and goals of trauma care in Western Cape civilian and US military prolonged casualty care.

| | Setting | Goals of Care | Prolonged Care Situation |
|---|---|---|---|
| **US military** | PCC will occur in remote and austere settings, removed from definitive care due to the combat environment. | 100% survival of all patients with survivable and potentially survivable injuries to arrival at Military Treatment Facility. | In PCC, patient's needs exceed expected care capabilities. Timeframe is hours to days. |
| **WC civilian** | Trauma care is escalated by patient progression through a tiered health system that is geographically dispersed and resource-constrained. | To provide equitable, timely, and judicious use of limited resources for an entire civilian population. | Routinely, patient needs exceed facility resources necessitating a transfer ('referral') to a higher level of care. This can contribute delays of hours to 1-2 days. |

*WC: Western Cape of South Africa; PCC: prolonged casualty care*

The Western Cape civilian health system is a large referral-based system with a high volume of trauma patients, typical of many low- and middle-income countries.[36] The health system aims to provide a full spectrum of trauma care in stepwise manner that is resource-efficient.[37] Trauma patients "advance" through a tiered system of care (dictated by the degree and type of injury), with those requiring specialty trauma care being "referred" to the tertiary facility (trauma center).[38] Western Cape government ambulances perform extrication, transport, and out-of-hospital treatment from the scene and also during inter-facility transfers.[39,40] Delays to receiving definitive care or life-saving interventions are not infrequent because patient caseloads (and demand) far exceed available resources, and/or are due to prolonged transit times during ambulance transport especially from rural settings.[30] Hence, the Western Cape civilian and US military PCC settings are similar in that patients will receive resource-limited care for prolonged durations before arrival at definitive surgical care (Table 1).

*System Configuration:* In the US military, there are escalating capabilities defined by advancing roles of care.[27] Each role is also characterized by a combination of phases:

- Role 1 is pre-surgical/prehospital care. It is the first medical care military combatants receive.
- Role 2 is a continuation of resuscitation started in Role 1 with a focus on advanced trauma management and emergency medical treatment, but little to no patient holding capacity. Surgical capability is offered at some facilities.
- Role 3 is care at a military treatment facility equipped to provide care to all categories of patients, to include damage control resuscitation and surgery, and postoperative treatment. This role of care expands the support provided at Role 2 and includes patient holding capability and ancillary services. Patients unable to tolerate and survive movement over long distances will receive surgical care in a hospital as close to the supported unit as the tactical situation allows.[27]
- Role 4 care is in US-based hospitals and robust overseas military treatment facilities. Role 4 represents the most definitive medical care available within the medical care system.[27]
- En route care allows transport and care between roles of care. This may be in the form of dedicated ground and air medical assets, and care provided on ad hoc (non-medical) platforms. This includes basic medical evacuation through sophisticated inter-facility transfer of critical patients.[27] Prioritization for prehospital evacuation is a I-IV scale system which defines most urgent to convenience assignments for medical evacuation.[27]

In the Western Cape civilian health system, patients are referred from primary facilities via secondary, ultimately ending up at the tertiary care center, based on need:

- Primary: Community Health Centers (CHCs) are the entry point for the majority of patients. CHCs offer basic trauma resuscitative care by generalist physicians or mid-level providers and are open 24/7 for emergency visits.[41,42] Patients requiring urgent or emergent treatment undergo stabilization followed by transfer to secondary hospitals. Patients requiring the highest level of care, such as specialized radiology or sub-specialist care, undergo transfer to a tertiary hospital.[41,42]
- Secondary: Each secondary hospital serves 3 to 5 CHCs. Emergency medicine (by specialists and non-specialists) is typically available with more elaborate laboratory testing and radiology. Secondary level facilities can be either district (which support CHCs) or regional hospitals (which support district hospitals). District hospitals provide

limited surgical resuscitative care, stabilization, and convalescent care—often an intermediary site between the scene and a tertiary care facility.[42] Regional hospitals exceed capabilities at district hospitals and provide basic surgical trauma care by general surgeons (no subspecialty surgical care), and often offer in-patient intensive care and convalescent care.[42] Regional hospitals are often staffed by emergency medicine specialists and general surgeons.[41,42]

- Tertiary: Patients requiring the highest level of care, such as specialized radiology (CT, MRI, and interventional capabilities) and subspecialist surgical care, then undergo transfer to a tertiary hospital.[41,42] A full spectrum of care from initial and damage control resuscitation to damage control surgical and definitive surgery is provided, as well as in-patient intensive care and convalescent care.[42]

Table 2. US military roles of care and Western Cape civilian equivalence.

| U.S. Mil Role | U.S. Mil Characteristics | U.S. Mil Types of Treatment and Resources | Western Cape equivalent* |
|---|---|---|---|
| 1 | Immediate lifesaving measures; Combat and operational stress preventive measures; Patient location and acquisition (collection) | Bleeding control of massive hemorrhage; managing airway, respiration, and circulation and preventing or treating hypothermia and shock; protecting wounds; immobilizing fractures; forward resuscitation, not including surgical care.[27] | EMS<br>Primary level |
| 2 | Advanced trauma management; Emergency medical treatment; Combat and operational stress control | Fresh whole blood and/or blood products (packed red blood cells, frozen plasma, cryoprecipitate), intravenous fluids, limited X-ray, limited laboratory, dental support, advanced trauma management, emergency surgery, and resuscitative care.[27] | Secondary level |
| 3 | Expansion of advanced trauma management; Patient holding capability; Ancillary services | Advanced resuscitation; Initial wound surgery; Postoperative treatment; emergency and specialty surgery, intensive care, medical specialty care.[27] | Secondary level (regional only)<br>Tertiary level |
| 4 | Most definitive medical care | Specialized surgery and the full range of preventive, acute, restorative, curative, rehabilitative, and convalescent care found in United States base hospitals and robust overseas facilities.[27] | Tertiary level |

** The lowest level of Western Cape government facility capable of offering a comparable US military level of trauma treatment.*
*US Mil: US Military*

- Transport: Western Cape EMS is a government-operated, traditional, ambulance-based dispatch model staffed by a 2-person crew, usually basic life support (BLS) paired with intermediate or advanced life support (ILS or ALS, respectively). Ambulances deploy from bases via central dispatch to the scene (i.e., primary response) or to a facility (i.e., inter-facility transfer.[43-45]

- Prioritization System: Major Trauma Criteria (MTC) defines criteria for bypassing nearby facilities to a trauma center. The South African Triage Scale (SATS) triages based on anticipated resource needs (red=emergent, orange=very urgent, yellow=urgent, green=routine). Both MTC and SATS are used pre- and in-hospital.[46,47]

Figure 1. Photos showing a few components of the trauma care system of Western Cape, South Africa.


**Photo 1:** Western Cape Emergency Medical Services ambulances


**Photo 2:** Tygerberg Hospital trauma center and tertiary level hospital

**Photo 3:** Khayelitsha Hospital emergency center, Cape Town metropolitan area

**Photo 4:** Worcester Hospital intensive care unit, Cape Winelands

Hence, the disrupted US military and Western Cape civilian trauma care systems have conceptual similarities in configuration since both are tiered, connected by prehospital care, and based on principles of escalating capacities of care at each progressive tier (Table 2). Typical facilities and resources of the Western Cape civilian trauma care system are shown in Figure 1.

*Cadres & Capabilities of Trauma Care Providers:* The US military capabilities and cadres of trauma care providers are summarized as follows:

- Role 1: First Responder Care capability provided by nonmedical combatants (TCCC Tier 1 and 2 non-medics), by combat and SOF Medics (TCCC Tier 3 and 4), and by front-line physicians and physician's associates.

- Role 2: Forward Resuscitative Care (FRC) capability provided by small resuscitative surgical teams with limited resources and limited or non-existent holding capability/capacity (damage control surgery).

- Role 3: Theater hospitalization provided by forward surgeon and full surgical teams with some medical specialties available (damage control surgery and definitive surgery).

- Role 4: Definitive care provided by surgeon at a medical treatment facility (MTF), including definitive and reconstructive surgical care.

- En route care delivered by Combat Paramedic and SOF medics (using Critical Care Paramedic and Flight Medic scope). En route care above tier 2 is provided by specialized Air Evac teams comprised of specialty trained medics and nurses.

The Western Cape civilian provider cadres and capabilities are summarized as follows:

- Basic prehospital care delivered by EMS BLS providers (trauma capabilities are between advanced first aid and a US emergency medical technician [EMT]).

- Intermediate prehospital care delivered by EMS ILS providers (trained in basic prehospital trauma life support), similar to a US advanced emergency medical technician (AEMT).

- Advanced prehospital care delivered by EMS ALS providers (with trauma capabilities at the level of advanced prehospital trauma life support), similar to a US paramedic.

- Emergency center physicians (generalist or specialist) have training in the equivalent of advanced trauma life support (ATLS).

- General surgeons offer a narrow scope of trauma surgeries, often restricted to simple exploratory laparotomies and basic thoracic procedures.

- Trauma and specialty surgeons offer full scope of surgical services, including neurosurgical, vascular, thoracic, and orthopedic specialty care.

Table 3. Comparison of providers' cadres and capabilities between Western Cape and US military.

| | Far forward (least capabilities) → → → | | | Definitive care (highest capability) | |
|---|---|---|---|---|---|
| **US military capability** | First responder care (TCCC) | Forward resuscitative care; En route care | | Theater hospitalization | Definitive care |
| **WC civilian capability** | Lay responder care | Prehospital care (EMS); District Hospital | Prehospital care (EMS) | Regional hospital; Trauma Center | Trauma (tertiary) Center |
| **US military providers** | Combat Life Savers (TCCC) | Combat paramedics, ALS, small surgical teams | Flight paramedics and nurses | Forward surgeon & robust surgical teams. | MTF surgeon & surgical team. |
| **WC civilian providers** | BLS, ILS, | ILS, ALS | ALS / Emergency Center generalist | Emergency Center specialist; Regional hospital surgeon | Emergency Center specialist; Trauma Center surgeon |

*ALS: advanced life support; BLS basic life support; ILS: intermediate life support; MTF: Military treatment facility; TCCC: Tactical Casualty Combat Care; WC: Western Cape of South Africa*

While the goal of US military trauma care is to provide resuscitative care and surgery far forward, limited teams in larger and/or disrupted operations (in austere environments or large-scale operations without clear freedom of movement, i.e., PCC) more closely mirror the situation of Western Cape medical facilities and care provision in more dispersed facilities (Table 3).

*Data Capture Systems for Trauma:* The flagship product of the Joint Trauma System is the Department of Defense Trauma Registry (DODTR), which supports US military performance improvement initiatives with global collection and aggregation of combat casualty care epidemiology, treatments, and outcomes.[48] The registry electronically captures and documents from US/Non-US military and US/Non-US civilian personnel in wartime and peacetime from the point of injury (POI) to final disposition.[49,50] As of January 2017, the DODTR housed data from over 132,000 trauma patient records, representing 80,000 unique patients. The DODTR has informed many data-driven advancements in military and civilian trauma care.[51-54]

In the Western Cape, there is near 100% EMS data collection via an electronic medical record system. In hospitals, clinical data is initially recorded on paper charts and subsequently scanned into an electronic database by clerks. Laboratory and radiology results are available in real time through online portals. Patients have one medical record identifier shared across all Western Cape government health centers. Less than 10% of records are missing at a given time.[18] The Western Cape Forensic and Pathology Services conduct autopsies on 100% of trauma deaths within 2 weeks, required by national law.[55]

*Patient Population & Injury Profiles:* In the US military, between 2006-2021, 18,571 active duty personnel died

| | Far forward (lowest capabilities/resources) → → → | | | | Definitive care (highest capabilities/resources) | | |
|---|---|---|---|---|---|---|---|
| | Transport and Evacuation | Stabilization and initial care | Damage Control Resuscitation | Damage Control Surgery | Definitive surgery | Convalescent Care | Rehabilitative Care |
| U.S. mil – role 1 | X | X | X | | | | |
| WC – EMS (scene) | | X | X | | | | |
| WC – EMS (IFT) | | X | | | | | |
| WC – 1$^{O}$ level | | | X | | | | |
| WC – 2$^{O}$ level (district) | | | X | | | | |
| U.S. military – role 2 | | | X | X | | | |
| WC – 2$^{O}$ level (regional) | | | X | X | | | |
| U.S. military – role 3 | | | X | X | X | X | |
| WC – 3$^{O}$ level | | | | X | X | X | X |
| U.S. military – role 4 | | | | | X | X | X |


*1$^{O}$: primary; 2$^{O}$: secondary; 3$^{O}$: tertiary; IFT: inter-facility transfer; Mil: military; WC: Western Cape*

Figure 2. Conceptual model for research equivalency comparing US military roles of care with Western Cape civilian trauma tiered system.[64-66] Community Health Centers serve as the entry point for many trauma patients seeking care and offer basic initial trauma stabilization and initial resuscitation. District Hospitals provide non-surgical resuscitative care, stabilization, and convalescent care, often an intermediary site between the scene and a tertiary care facility.[42] Regional Hospitals exceed capabilities at District Hospitals and provide general surgical, basic surgical trauma care, no subspecialty surgical care, but offer in-patient intensive care and convalescent care.[42] Regional hospitals often provide emergency medicine specialists and general surgeons.[41,42] Trauma Center offers a full spectrum of care from initial and damage control resuscitation to damage control surgical and definitive surgery, including intensive unit care and rehabilitation services.

during various US Armed Forces operations.[56] Of 614 US Special Operations Command fatalities, between September 2001 to 2018, 97.7% had an injury-related cause of death as follows: gunshot wound (30.3%), multiple/blunt force injury (34.5%), blast injury (30.7%), and other injury (4.5%).[57] From Operation New Dawn, the most prominent mechanism of death was catastrophic tissue destruction (82.6%), hemorrhage and other mechanisms (8.7%) and hemorrhage only (8.7%).[58] Various other military operations have yielded similar findings.[59] In prior wars, the US military reported nearly 90% of combat fatalities occur before the casualty reaches a MTF.[34] During recent French military operations, the median time from injury to a Role 2 military treatment facility was 130 minutes, exceeding 120 minutes in 57% of cases and 240 minutes in 26%.[60] The median time to arrival in Role 4 hospital is 25 hours.[60]

Epidemiologically, in the Western Cape injuries accounted for 14% of all deaths in 2016 (approximately 6,770 in 2016), with the majority being male (80%) and 20 to 39 years of age.[37] Homicides (51%), accidents (38%), and suicides (11%) accounted for the majority of all injury deaths (Brenda Beaty, MSc, e-mail communication, August 20, 2021). There has been a yearly increase in the number of homicides from 2010 to 2018, especially due to homicide from firearms (age-standardized rate doubled from 17 to 35 per 100,000 population from 2010 to 2016). Road traffic injuries were the leading cause of unintentional injuries (35% motor vehicle, 25% pedestrian fatalities), followed by fires (14%), and drowning (approximately 9%) in 2016.[37]

Dominant mechanisms of injury are predominantly blunt (34%-43%) and penetrating (57-63%), with 7.5% incidence of hemorrhagic shock and 1.9% burns (Brenda Beaty, MSc, email communication, August 2021).[24] Causes of injuries in South Africa are predominantly road pedestrian and vehicular passenger collisions (13%-22%), gunshot wounds (9.1%), stab wounds (16-31%), blunt injuries (17-23%), falls (17%), and crush injuries (5.7%).[61-63] Dominant injured body regions are thorax (43%); head, neck, face (38%), extremities (17.3%), and multiple areas (35%).[2]

Overall, the following features of the Western Cape system are relevant to US military PCC: high rates of inter-personal inflicted injuries; high rates of penetrating injuries; times from injury to first facility; and lengthy times from injury to Role 4 or trauma center.

*Civilian Model to Study Military PCC:* From the comparisons above, we construct a civilian research model (Figure 2) based upon areas of similarity between the

Western Cape civilian system and US military PCC which considers settings and goals of care, system configuration, cadres and capabilities of providers, and patient injury profiles.

## Discussion

Using existing data, available documents, and expert opinion, we describe a research equivalency model, based on the Western Cape civilian injury profile and system of trauma care and is useful for studying interventions and outcomes directly relevant to PCC situations. Findings will directly benefit the South African population, future wounded US combatants experiencing PCC, and injured civilians in resource-constrained systems worldwide.

This model is a reasonable civilian approximation of the US military disrupted care situation. Strengths of this model are that it reflects a system with inherent delays in treatment and arrival at medical centers. Further, it will represent both large overall numbers and a large breadth of patients with a heavy proportion of trauma casualties—both blunt and penetrating. Though some mechanisms of trauma may differ from typical military trauma, the model will represent many of the mechanisms seen with expeditionary and contingency military operations. The inherent physiology of hemorrhagic shock patients and traumatic brain injuries should be well-represented in the overall sample size. Additionally, current record keeping allows for tracking of patients through the tiers of care.

The model has a few notable limitations. First, providers in the Western Cape prehospital system do not have the same baseline trauma care training as the US military, especially TCCC. There are, however, an equivalent proportion of US-standard EMT and paramedic populations. Additionally, there are relatively few blast injuries in the Western Cape population compared to the US military population, which will hinder blast-related research. Next, even though the Western Cape government prehospital care has an ATLS scope, the small numbers of paramedics relative to the large trauma patient load means proportionally fewer life-saving interventions performed compared to the US military's far-forward setting. Last, the capabilities of each Western Cape facility can be slightly variable (e.g., not all regional hospital have operational critical care beds or blood products), thereby necessitating the research model be slightly adapted based on specific health facilities under consideration.

There are also important ethical and research design aspects of US military-sponsored global health research. Foremost, the South African population must be a primary beneficiary of such work, which includes both trauma patients (via evidence-driven care improvements) and the healthcare community (via enhanced research capacity and knowledge gained). To further maximize global impact of such work, DoD funded research should be designed to be mutually-beneficial and generalizable, thereby benefiting global communities and simultaneously advancing specific needs of the US military i.e., a win-win. Including South African leadership and representation on research teams, executing balanced agreements, ensuring ethics approvals by all parties are examples of strategies to help ensure sound ethics and maximal impact from US military-sponsored research.

Current PCC research efforts in South Africa include a large-scale epidemiologic assessment of early resuscitative interventions and outcomes in an ongoing DoD-funded study titled, "Epidemiology and Outcomes of Combat-Relevant Prolonged Trauma Care (EpiC): A Prospective Multicenter Prehospital Study in South Africa." The EpiC study is due to conclude in September, 2024.

## Conclusion

We propose a civilian research equivalency model useful for studying prolonged casualty care. This model is promising to inform US military PCC research and to augment current sources of military-relevant trauma data from the DODTR and US civilians. Importantly, research with this model will also directly help to fill scientific and clinical gaps in the South African civilian trauma care system and be useful for other prolonged trauma care communities worldwide.

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## Authors

Nee-Kofi Mould-Millman is with Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO.

COL (ret) Sean Keenan is with Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO; Joint Trauma System, Defense Health Agency, San Antonio, TX; and CU Anschutz Center for COMBAT Research, University of Colorado, Aurora, CO.

Julia Dixon is with Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO.

Elmin Steyn is with Department of Surgery, Stellenbosch University, Western Cape Province, South Africa.

Elmin Steyn and Hendrick J. Lategan are with Department of Surgery, Stellenbosch University, Western Cape Province, South Africa.

Shaheem de Vries is with Western Cape Government Health, Emergency Medical Services, Cape Town, South Africa.

Lina V. Mata is with Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO.

Chandni Patel is with Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO.

MAJ Steven G. Schauer is with US Army Institute of Surgical Research, Fort Sam Houston, TX.

MAJ Andrew D. Fisher is with Department of Surgery, The University of New Mexico, Albuquerque, NM.

MAJ Michael D. April is with 40th Forward Resuscitative Surgical Detachment, 627th Hospital Center, Fort Carson, CO.

Adit A. Ginde is with Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO.

COL Vikhyat S. Bebarta is with Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO; and CU Anschutz Center for COMBAT Research, University of Colorado, Aurora, CO.

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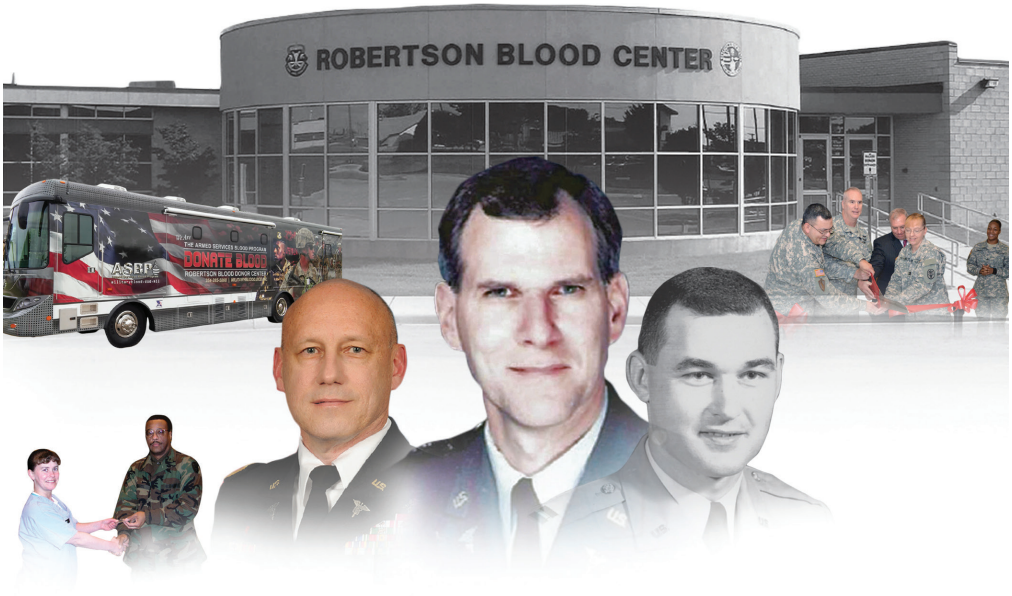

# An Analysis of Patient Movements during Sustained Combat Operations in the US Central Command: Implications for Remote Support Capabilities

Terence W. Shaw, II
COL (ret) Kevin K. Chung, MD
COL Ramey L. Wilson, MD, MPH
MAJ Michael D. April, MD, DPhil, MSC
COL Jeremy C. Pamplin, MD
LTC Kevin R. Gillespie, DMD
Jose Salinas, PhD
MAJ Steven G. Schauer, DO, MS

## Abstract

Background: The US Central Command (CENTCOM) area of responsibility (AOR) spans 20 nations in the Middle East, Central, and South Asia. Evacuations outside this AOR include all injury types and severities; however, it remains unclear what proportion of evacuations were due to disease and non-battle injuries (DNBI). Understanding these patterns may be useful for defining future medical support requirements for multi-domain operations (MDO). We sought to analyze encounters obtained from the Transportation Command Regulating and Command & Control Evacuation System (TRAC2ES) data for medical evacuations within CENTCOM.

Methods: We obtained all encounters within TRAC2ES from February 2009 to November 2018. We analyzed data using entered demographic data and keyword categorization of free text information provided by the medical officer requesting patient movement.

Results: There were 50,036 patient movement requests entered into TRAC2ES originating from the CENTCOM AOR for both military and civilian personnel. After removal of ineligible entries (e.g. military working dogs), the number of eligible subjects was 49,259—13% combat (n=6,389) and 87% were noncombat (n=42,870). The primary age group requiring evacuation was 18-29 (59%) and were mostly male (87%). Most went by routine status (80%), followed by priority (16%). Most of the transfers originated from Afghanistan (58%) and Iraq (22%), with Germany serving as the primary destination (79%). Results showed the total number of patient evacuations increased from 2009 to 2010 and then decreased from 2011 to 2017. The most frequent body region associated with the transfer was the extremities for both combat (54%) and noncombat (32%).

Conclusions: Out of theater disease and non-combat injury evacuation rates were nearly 7 times higher than for combat related injuries. Our results highlight the need for additional research and development resources of DNBI-related medical care. As we move into future MDO with limited evacuation capabilities, we will need support solutions to cover the full gamut of DNBI.

*Keywords: disease; nonbattle; battle; combat; non-combat; transfer; military; injury*

## Introduction

To support both Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) requirements for medical care, the US Central Command (CENTCOM) deployed a comprehensive trauma system in 2005 with the goal of improving care on the battlefield. The goal of the Joint Trauma System (JTS) is to manage medical care delivered on or near the battlefield. With the focus on trauma care, non-trauma casualties and their evacuation out of theater have garnered less attention, despite the fact disease and non-battle injuries (DNBI) historically have represented a significant burden to medical care in the battlefield.[1] Because the majority of DNBI medical encounters are not captured by the JTS, there are limited data readily available on what proportion of medical evacuations are attributable to DNBI.[2]

Historically, DNBIs have resulted in significantly higher medical resource consumption and loss of readiness

than battle injuries (BI), even during active combat operations.[1,2] During the height of OIF, DNBIs accounted for 75% of all hospitalizations, 900 DNBI deaths, and over 37,000 injuries and illnesses, posing a threat to mission readiness, mission effectiveness, and unit cohesion due to reduced military personnel availability.[2] Outside of preventive medicine efforts, however, DNBI remains a relatively underreported area of research within the deployed setting, and as a result, receives less attention from the Department of Defense (DoD) research and development community.

Table 1. Keywords used to categorize the encounters.

| | |
|---|---|
| Battle | Cardiovascular |
| Blunt Object | Dermatologic |
| Bullet | Endocrine |
| Combat | Equipment Accidents |
| Crush/Falls | Gastrointestinal |
| Explosive/Explosion/Blast | HEENT |
| Fire | Infectious Disease |
| Firearm | Motor Vehicle Collision |
| Grenade | Musculoskeletal |
| Gun | Neurologic |
| IED | Pulmonary |
| Knife | Cardiovascular |
| RPG | Gastrointestinal |
| Battle | Urinary |

*Improvised Explosive Device: IED; Rocket-Propelled Grenade: RPG; Head, Eyes, Ears, Nose, Through: HEENT*

In 2004, the US Army Center for Health Promotion and Preventive Medicine (USACHPPM) devised and implemented a strategy for centralized DNBI surveillance for the Afghanistan and Iraq operations.[3] The objective was to identify and code the causes of DNBIs, then track the rates and trends over time. Medical and nonmedical data systems were identified and analyzed by USACHPPM for their potential contribution to centralized, systematic DNBI surveillance. However, their system was generally based on occurrence of such events and the impacts of these casualties to operational readiness and forces available to non-medical commanders. They did not typically address resource consumption, such as use of medical evacuation platforms.

As the military transitions into a posture focused on large scale combat operations (LSCO) in support of multi-domain operations (MDO), future conflicts will likely require the deployment of larger forces during large operations and a more distributed battlefield, which will have impacts on the ability to mass and concentrate large medical resources together and increase the need to move patients between different nodes of care. During recent conflicts, the US military has benefited from nearly uncontested freedom of movement by air.[4] However, future MDO may have significantly limited periods of air superiority and thus limited opportunities for evacuation. Technologies such as telemedicine and clinical decision support systems may help improve forward medical care if patient movement is delayed, and in many cases, can avoid DNBI evacuation altogether.[5-12] In order to best estimate the patient evacuation requirements future conflicts might include, we sought to analyze patient movement requests originating from the CENTCOM AOR to better understand the mix between combat and DNBI injuries and illness requiring movement out of the theater.

## Methods

*Ethics:* The US Air Force 59th Medical Wing regulatory office reviewed the protocol and determined it was exempt from the Institutional Review Board (IRB) oversight. Only de-identified data was used for analysis.

*Database Description:* The US Transportation Command (TRANSCOM) is the combatant command with the responsibility to oversee all patient movement for the US military enterprise. The TRANSCOM Regulating and Command & Control Evacuation System (TRAC2ES) is the electronic platform used to request, synchronize, coordinate, and track all regulated patient movements for the DoD. As an information system, TRAC2ES assembles, assesses, and prioritizes patient movement requirements, assigns resources, and distributes data to relevant parties. Data entry into TRAC2ES includes an initial patient summary with demographics, primary diagnosis, evacuation priority level, origin, and destination. Additionally, medical providers can provide a free text history to provide details of pertinent history and describe initial clinical course. Other details of the database have been described previously.[5,13-16]

*Data Analysis:* The principal investigator received general training on applicable military terminology as well as instruction on combat versus noncombat type medical care. Using a keyword list developed by several coinvestigators, the TRAC2ES free-text capture section was searched for categorization. Commercially available database and statistical analysis software was used to recode the dataset using the predefined keywords (Table 1). We report our findings using percent and volume for binary variables, medians, and interquartile ranges for ordinal variables, and means and confidence intervals for continuous variables.

## Results

There were 50,036 patient movement requests entered into TRAC2ES originating from the CENTCOM AOR for both military and civilian personnel. After removal

of ineligible entries (777 were excluded due to age <18 or military working dog status), the number of eligible subjects was 49,259—13% combat (n=6,389) and 87% were noncombat (n=42,870). The primary age group requiring evacuation as 18-29 (59%) followed by 30-39 (24%) and were mostly male (87%). Most went by routine status (80%) followed by priority (16%). Afghanistan (58%) and Iraq (22%) were the most frequent originating location with casualties transferring to Germany (79%). The 2010 year was busiest accounting for 23% of all study period evacuations (Table 2). Most of these evacuations originated in Afghanistan with a destination of Germany, primarily using military air transportation. It was worth noting between 2009 and 2011, military aircraft was the most common mode of transportation used to transport patients with non-combat rather than combat injuries. The most frequent body region associated with the transfer was the extremities for both combat (54%, n=3,434) and noncombat (32%, n=13,967) (Table 3).

Table 2. Comparison of patient characteristics between two groups.

| | Overall n = 49259 | Percentage % | Combat n = 6389 | Percentage % | Non-Combat n = 42870 | Percentage % |
|---|---|---|---|---|---|---|
| **Demographics** | | | | | | |
| Age | | | | | | |
| 18-29 | 29028 | 59% | 4925 | 77% | 24103 | 56% |
| 30-39 | 11740 | 24% | 1161 | 18% | 10579 | 25% |
| 40-49 | 6203 | 12% | 252 | 4% | 5951 | 13% |
| 50-59 | 1951 | 4% | 39 | 1% | 1912 | 5% |
| ≥60 | 337 | 1% | 12 | 1% | 325 | 1% |
| | | | | | | |
| Male | 43073 | 87% | 6223 | 97% | 36850 | 86% |
| Female | 6186 | 13% | 166 | 3% | 6020 | 14% |
| | | | | | | |
| **Evacuation Status** | | | | | | |
| Priority | 8164 | 16% | 2736 | 43% | 5428 | 13% |
| Routine | 39293 | 80% | 3151 | 49% | 36142 | 84% |
| Urgent | 1802 | 4% | 502 | 8% | 1300 | 3% |
| | | | | | | |
| **Origin** | | | | | | |
| Afghanistan | 28785 | 58% | 5569 | 87% | 23216 | 54% |
| Germany | 15 | <1% | 4 | <1% | 11 | .03% |
| Iraq | 10989 | 22% | 570 | 9% | 10419 | 24% |
| Kuwait | 7471 | 15% | 217 | 3% | 7254 | 17% |
| Others | 1999 | 4% | 29 | 1% | 1970 | 5% |
| | | | | | | |
| **Destination** | | | | | | |
| Afghanistan | 5696 | 11% | 1559 | 24% | 4137 | 10% |
| Germany | 38973 | 79% | 4690 | 73% | 34283 | 80% |
| Iraq | 1304 | 3% | 35 | 1% | 1269 | 3% |
| Kuwait | 2312 | 5% | 51 | 1% | 2261 | 5% |
| Others | 974 | 2% | 54 | 1% | 920 | 2% |
| | | | | | | |
| **Actual Year** | | | | | | |
| 2009 | 9859 | 20% | 1018 | 16% | 8841 | 21% |
| 2010 | 11307 | 23% | 1814 | 28% | 9493 | 22% |
| 2011 | 9918 | 20% | 1806 | 28% | 8112 | 19% |
| 2012 | 6035 | 12% | 1000 | 15% | 5035 | 12% |
| 2013 | 3951 | 8% | 358 | 6% | 3593 | 8% |
| 2014 | 2764 | 6% | 163 | 3% | 2601 | 6% |
| 2015 | 1326 | 3% | 46 | 1% | 1280 | 3% |
| 2016 | 1238 | 3% | 55 | 1% | 1183 | 3% |
| 2017 | 1378 | 3% | 66 | 1% | 1312 | 3% |
| 2018 | 1483 | 3% | 63 | 1% | 1420 | 3% |

## Discussion

During combat operations, excessive injuries directly impact theaters of operations and individual units' overall mission readiness.[17] While the majority of attention during military operations and conflicts is focused on the care and treatment of soldiers injured in combat, illnesses and non-combat injuries have outnumbered combat-related casualties in every major US military operation from World War I through Vietnam.[17] During deployments, injuries can result in limited duty or non-duty days directly impacting unit and mission readiness. As a result, it is essential to identify the leading variables causing DNBIs to determine prevention and safety strategies to mitigate these types of injuries.

Between February 2009 and November 2018, we reported on a demographic analysis of TRAC2ES data for medical evacuations from the CENTCOM theater of operations. TRAC2ES reported 42,870 medical evacuation requests for CENTCOM military and civilian employees during this timeframe, compared to 4,217 for US Pacific Command (PACOM) and 961 for US Africa Command (AFRICOM).[13,14] The disparity in these numbers is most likely due to AFRICOM's lower operational and combat tempo along with a lower volume of personnel within the footprint compared to CENTCOM, highlighting the importance of evaluating multiple data capture systems to better understand the demands of the medical theater.[18] According to statistics from the DoD Trauma Registry and Training, CENTCOM prehospital documentation indicates substantial differences in completeness and quality compared to PACOM. It is worth noting the data only included evacuated patients in TRAC2ES; any patients who were treated entirely by local medical institutions (military or civilian) or were evacuated using a procedure not approved by the military were excluded. As such, we cannot comment on the severity of those patients. It is plausible they were minor injuries and did not require evacuation, or, conversely, they may have been too severely injured to wait a long period of time for medical transport.

Table 3. Chief complaint primary body location.

| | Combat (n=6207) | Noncombat (n=42870) |
|---|---|---|
| **Burns/Skin** | 105 (2%) | 461 (1%) |
| **Extremities** | 3434 (54%) | 13967 (32%) |
| **Truncal** | 381 (6%) | 11077 (26%) |
| **Face** | 589 (9%) | 1538 (4%) |
| **Head/Skull** | 934 (15%) | 7% (3193) |
| **Behavioral Health** | 315 (5%) | 5023 (12%) |
| **Disease/Infections** | 5 (<1%) | 1% (523) |
| **Other/Unspecified** | 626 (10%) | 17% (7088) |

DNBIs accounted for 87% of all CENTCOM evacuation requests throughout the study period. This highlights the need for maintaining a broad scope of medical capabilities throughout theater—either in person or via offset remote support capabilities. As we enter large scale combat operations, the need to support a huge gamut of medical ailments will be required to maintain the fighting force. A previous study by Nguyen et al found a reduction in the need for evacuation after implementation of a telehealth system.[9] Similar to our study, they found the majority of these requests were due to DNBI with orthopedics being the most common. While this study was small in size and only one country within CENTCOM, the results would likely be amplified in future large scale events in which deployments happen at the brigade or division level. The US military should continue to invest in perfecting these systems in preparation for the next conflict.

Limitations range from incomplete and inconsistent patient evacuation data captured by systems that were not tracked by TRAC2ES or treated in a local military or civilian facility, particularly nonregulated patient movements, which are often not captured within TRAC2ES. The lack of primary diagnosis and mechanisms of injury data make it more challenging to investigate the precise reason for patient movement. Additionally, medical transcribers and data entry employees entering data into TRAC2ES may lack the required medical background or knowledge, resulting in inaccurate or missing data they may not have considered significant. These limitations combined and the lack of standardized documentation protocols across the CENTCOM theater of operations often lead to poor data collection and quality. The limited input of high-quality data limits the ability to draw conclusions and implement targeted solutions. Prior research has shown combat medical documentation, particularly for DNBIs, is often inconsistent, of poor quality, and delayed.[19,20] Higher quality and timely data capture is needed.[21]

## Conclusion

During sustained combat operations in CENTCOM, disease and non-combat injury accounted for nearly 7-fold more evacuations out of theater than those due to combat related injury. Our dataset highlights the need for research and development resources into DNBI related medical care. Moreover, as we move into future MDO with limited evacuation capabilities, the need for solutions that help increase capability and thus capacity of caregivers to manage the full gamut of medical care will be required at the point of need. Finally, poor overall data availability, quality, and timeliness are important challenges to achieving modernization priorities for military medicine.

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## Authors

Terence W. Shaw, II is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX, and University of Texas at San Antonio, TX.

COL (ret) Kevin K. Chung is with Uniformed Services University of the Health Sciences, Bethesda, MD.

COL Ramey L. Wilson is with Uniformed Services University of the Health Sciences, Bethesda, MD.

MAJ Michael D. April is with Uniformed Services University of the Health Sciences, Bethesda, MD; and 40th Forward Resuscitative Surgical Detachment, Fort Carson, CO.

COL Jeremy C. Pamplin is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

LTC Kevin R. Gillespie is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

Jose Salinas is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

MAJ Steven G. Schauer is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; Brooke Army Medical Center, JBSA Fort Sam Houston, TX; and Uniformed Services University of the Health Sciences, Bethesda, MD.

# Battle Injury Patterns Sustained Noncombatant Military Occupational Specialty Service Members

Giselle Tapia
LTC Jason F. Naylor, DSc, PA-C
MAJ Michael D. April, MD, DPhil, MSc
MAJ Steven G. Schauer, DO, MS

## Abstract

Background: The US military has been engaged in the Global War on Terrorism for nearly 2 decades. This asymmetric warfare has exposed many noncombat military occupational specialties (MOS) personnel to combat. We assessed what proportion of casualties were combat versus noncombat MOS personnel.

Methods: This is a secondary analysis of a previously described dataset from the Department of Defense Trauma Registry (DODTR). We included US military casualties sustaining battle injuries from January 2007 to March 2020 with a documented MOS. We classified each casualty as combat versus noncombat MOS personnel.

Results: There were 2,037 casualties who met inclusion for this analysis. Within these groups, there were 1,554 (76%) combat and 483 (24%) noncombat personnel. The median ages were 24 and 25, with more males among the combat MOS personnel (99% versus 93%). Army personnel comprised the largest proportion of both groups (78% versus 75%) with most injured by explosive (73% versus 78%). Median injury severity scores were similar (9 in both groups) as was survival (98% versus 98%). The annual proportion of battle injuries comprised of noncombat MOS personnel fluctuated year-to-year. The proportion of noncombat personnel with a medic in their chain of care was similar to combat personnel (25% versus 26%), as was the proportion undergoing medical evacuation by ground (11% versus 11%) or air (87% versus 86%). All prehospital interventions occurred in similar proportions except for ketamine administration (8% combat versus 3% noncombat MOS personnel).

Conclusions: Our study showed noncombat MOS personnel comprised nearly one in four casualties. Injury patterns were similar between combat and noncombat MOS personnel with nearly identical consumption of resources except for ketamine. More data is necessary on noncombatant MOS personnel battle injury patterns to guide commanders and medical leaders for future mission planning in resource constrained environments.

*Keywords: battle; injury; non-combat; military; specialty; combat; trauma*

## Introduction

*Background:* Service members belonging to noncombat arms military occupational specialties (MOS) comprise a significant portion of personnel deployed to combat operations. Most existing data focuses on battle versus non-battle injuries. However, like pediatric patients, noncombat MOS personnel are likely to experience distinct, combat-related injury patterns requiring unique consideration.[1-4] Unfortunately, noncombat MOS personnel remain relatively understudied in terms of battle injuries.[5,6] All battle injuries, whether they involve primary combat or noncombat MOS personnel, affect the overall readiness of military units for battle.[7] Moreover, understanding the incidence and patterns of non-battle injuries sustained by noncombat MOS casualties is imperative to project accurately the medical resources needed to support combat operations. Underestimates will lead to the medical personnel becoming overwhelmed (e.g. mass casualty [MASCAL]);[8] whereas, overestimates

will lead to unnecessary expenditure of scarce resources. Both can have a detrimental effect on the mission planning as the US military has a limited number of medical personnel and equipment.

In general, injuries among noncombat MOS personnel were relatively common during the recent asymmetric conflicts in Iraq and Afghanistan.[5-7,9] As the US military transitioned from direct combat to peace keeping and stability operations, troop levels (primarily combat arms units) decreased.[10,11] This resulted in a resource-limited environment wth the potential need for prolonged field care (PFC) of both combat and noncombat personnel suffering conflict-related injuries. The volume of battle injuries these noncombat personnel sustained during the operations in Iraq, Syria, and Afghanistan remains unclear. One study from Operation Iraqi Freedom found primary noncombat MOS personnel were more likely to consume medical resources overall, but this study was not solely focused on battle injuries.[12]

The US military's new operating concept is multi-domain operations with commanders charged to begin preparing for future large scale combat operations (LSCO). In such future missions, the military will face more devastating weapons than encountered during the wars in Iraq and Afghanistan. These weapons will have longer reach capabilities such as artillery and mortar systems. Consequently, commanders will likely sustain casualties not only in vicinity of the forward line of troops (FLOT) but also in support areas in the rear. Data guiding commanders on the proportions of noncombat personnel likely to sustain injuries during combat operations would facilitate mission planning and placement of resources in the battlespace.

*Goal of this Study:* We describe the incidence and injury patterns among noncombatant MOS service members during combat engagements in Iraq and Afghanistan.

## Methods

*Data Acquisition:* We requested all encounters within the Department of Defense Trauma Registry that had at least one prehospital assessment or intervention recorded from 01 January 2007 to 17 March 2020. The US Army Institute of Surgical Research (USAISR) regulatory office reviewed this protocol and determined it was exempt from Institutional Review Board oversight. This sub-analysis is taken from the overall dataset which was previously described.[10]

*Department of Defense Trauma Registry (DODTR):* The DODTR, formerly known as the Joint Theater Trauma Registry (JTTR), is the data repository for DoD trauma-related injuries.[13,14] The DODTR includes documentation regarding demographics, injury-producing incidents, diagnoses, treatments, and outcomes of injuries sustained by US/non-US military and US/non-US civilian personnel in wartime and peacetime (including humanitarian) from the point of injury to final disposition. Short-term outcome data are available for non-US casualties. The DODTR comprises all patients admitted to a Role 3 (fixed-facility) or medical treatement facility (MTF) with surgical capabilities with an injury diagnosis using the International Classification of Disease 9th Edition (ICD-9) between 800-959.9, near-drowning/drowning with associated injury (ICD-9 994.1) or inhalational injury (ICD-9 987.9). They must be admitted within 72 hours of injury. The DODTR defines the prehospital setting as any location prior to reaching a forward resuscitative and surgical detachment (FRSD), field hospital (FH), or hospital center (HC), to include the Role 1 (point of injury, casualty collection point, battalion aid station) and Role 2 without surgical capabilities (temporary limited-capability forward-positioned hospital inside combat zone).

*Analysis:* We performed all statistical analysis using standard software. We present continuous variables as means and 95% confidence intervals, non-parametric continuous variables and ordinal variables as medians and interquartile ranges, and nominal variables as percentages and numbers. We analyzed the data under the assumption of accurate documentation of all care rendered. We determined the proportion of battle injuries sustained by non-combat personnel each year. We also compared characteristics, interventions, and evacuation modalities between casualties belonging to combat versus non-combat MOSs using inferential statistics.

We categorized casualties belonging to any of the following Army MOS series as combat MOS personnel: 11 (infantry), 12 (engineering), 13 (artillery), 14 (air defense), 15 (aviation), 18 (special forces), 19 (armor), 21 (engineering). We then cross-referenced this list with the reported occupational specialties in the other branches and categorized personnel with specialties similar to these MOSs as combat personnel. We categorized all other casualties with listed specialties not included in these lists as noncombat MOS personnel.

## Results

Within the DODTR from 01 January 2007 to 17 March 2020 there were 10,182 US military encounters with documentation of prehospital activity. Of these, 2,037 met inclusion for this analysis. Within these groups, there were 1,554 (76%) combat and 483 (24%) noncombat personnel. The median ages were 24 and 25, with

more males in the combat roles (99% versus 93%). The Army made up the largest proportion of both groups (78% versus 75%) with most injured by explosive (73% versus 78%). Median injury severity scores were similar (9 in both groups) as was survival (98% versus 98%) (Table 1). The annual proportion of battle injuries comprised of noncombat MOS personnel fluctuated year to year (Figure 1). The proportion with a medic in their chain of care was similar (25% versus 26%), as was the proportion undergoing medical evacuation by ground (11% versus 11%) or air (87% versus 86%) (Table 2). All prehospital interventions occurred in similar proportions except for ketamine administration (8% versus 3%) (Table 3).

Table 1. Comparison of the combatant versus noncombatant data among battle injuries.

| | | Combatants n=1554 | Noncombatant n=483 | p-value |
|---|---|---|---|---|
| Demographics | Age | 24 (21-28) | 25 (22-30) | <0.001 |
| | Male | 99% (1552) | 93% (450) | <0.001 |
| Service | Army | 78% (1225) | 75% (363) | <0.001 |
| | Navy | 2% (26) | 10% (48) | |
| | Marine | 18% (284) | 10% (51) | |
| | Air Force | 1% (19) | 4% (21) | |
| Mechanism of Injury | Explosive | 73% (1148) | 78% (378) | 0.276 |
| | Fall | <1% (4) | <1% (1) | |
| | Firearm | 25% (396) | 21% (102) | |
| | Other | <1% (6) | <1% (2) | |
| Composite | Injury Score | 9 (4-17) | 9 (4-17) | 0.396 |
| Serious injuries by body region | Head/neck | 9% (153) | 10% (49) | 0.847 |
| | Facial | 1% (11) | 0% (0) | 0.076 |
| | Thorax | 10% (164) | 9% (44) | 0.360 |
| | Abdomen | 6% (108) | 9% (48) | 0.031 |
| | Extremities | 33% (521) | 31% (152) | 0.401 |
| | Skin | 3% (53) | 1% (9) | 0.095 |
| Outcome | Survival | 98% (1532) | 98% (474) | 0.522 |

## Discussion

Our data suggests the number of noncombat MOS personnel injured fluctuated around 1 in 4 injured with some year-by-year fluctuations. The significant increase seen in 2020 is due to the significant decrease in total battle injuries, and thus, such a change is likely a fluctuation without a clear reason and likely related to the small denominator. Moreover, as previously described, our dataset only contains a partial year for 2020, and thus represents a small sample size.[10] The data seen from years during the major combat operations is likely a better metric. Proportion of casualties expected among primary combatants versus noncombatants may aid commanders in casualty estimates and the associated risk assessment. Moreover, it may aid in the development of risk mitigation strategies. While serious facial injuries were sustained in a lower proportion of noncombat MOS personnel, and conversely a higher number of serious abdominal injuries, these differences have limited clinical significance given the relatively small percentage differences. Resources consumed were nearly identical except for ketamine. This further highlights noncombat MOS personnel consume similar resources when injured; thus, commanders must plan accordingly. The cause for difference in ketamine use remains unclear.

Previously published articles demonstrate the reasoning behind most of these under reported combat injuries among noncombat personnel are due to many factors.[5,12,15] A large percentage of these combat injuries experienced by these noncombat personnel occurred by explosives—the same mechanism seen in other studies of traumatic injuries from the deployed setting.[16,17] This is likely due to incidents such as vehicle-borne improvised explosive devices (VBIED) that target the vehicle rather than particular personnel. As such, there are likely to be noncombat personnel within attacked convoys.

The understanding of these combat-related injuries among noncombat personnel is necessary to inform operational readiness.[7] This is especially important when the US military conducts peace keeping and stability operations as the proportion of noncombat MOS personnel increases as operational requirements for combat arms units decrease. Furthermore, military forces conducting stability operations typically do so within areas of operation with immature logistical and medical infrastructure. This carries immense implications for combat casualty care, namely a requirement to plan and prepare for potential prolonged field care of wounded service members

Figure 1. Percentage of all battle injuries sustained by noncombatant military occupational specialty (MOS) military service members.

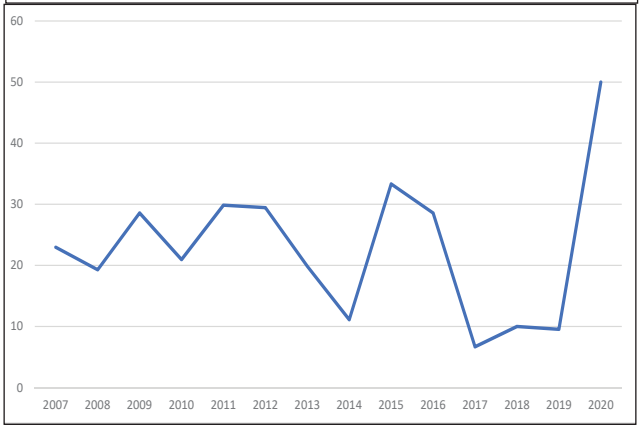

Table 2. Prehospital medical personnel and transport modalities.

| | Combatants n=1554 | Noncombatant n=483 | p-value |
|---|---|---|---|
| Medic/Combat Lifesaver | 25% (398) | 26% (130) | 0.592 |
| Battalion Aid Station | 2% (44) | 2% (11) | 0.511 |
| Ground | 11% (177) | 11% (57) | 0.806 |
| Air | 87% (1364) | 86% (420) | 0.634 |

Table 3. Select interventions among combatant versus noncombatant casualties.

| | Combatants n=1554 | Noncombatant n=483 | p-value |
|---|---|---|---|
| Hemostatic dressing | 3% (49) | 3% (19) | 0.404 |
| Warming | 52% (809) | 52% (253) | 0.901 |
| NCD | 1% (23) | 1% (7) | 1.000 |
| Limb tourniquet | 28% (447) | 27% (134) | 0.686 |
| IO | 3% (55) | 2% (12) | 0.256 |
| Intubation | 2% (41) | 1% (9) | 0.402 |
| Packed red cells | 1% (26) | 1% (7) | 0.838 |
| IV fluids | 12% (189) | 10% (53) | 0.519 |
| Acetaminophen | 2% (40) | 2% (11) | 0.415 |
| Ketamine | 8% (127) | 3% (17) | <0.001 |
| Fentanyl | 19% (306) | 17% (83) | 0.220 |
| Morphine | 27% (422) | 27% (131) | 0.988 |
| Antibiotic | 12% (197) | 11% (57) | 0.610 |

and proactive identification of mitigation measures to prevent injuries and preserve the fighting force. Understanding the specific risks occurring during armed conflict that result in noncombat MOS personnel sustaining injuries may inform risk mitigation strategies.[5] Risk assessment and management is part of any military operation. Data-based assessments of risk to all personnel—not just those typically located at the forward line of troops (FLOT)—would aid mission planners in providing the commander with a realistic and effective risk management strategies.

Our study is not without limitations. First, previous studies have highlighted the low quality documentation often available within the deployed setting, specifically prehospital.[16,18] Second, in order for an encounter to populate within the DODTR, the casualty must be alive when reaching a military treatment facility with surgical capabilities or with on-going life-sustaining interventions. Such capture misses the casualties who expired on the battlefield, which perhaps represents the ripest target for performance improvement.[19] Next, the DODTR only captured an MOS that was classifiable in 2,037 of 10,182, which represents roughly 1 in 5 encounters within our original overall dataset. Thus, the ability to extrapolate our findings to the totality of all casualties remains unclear. Better data capture is necessary to provide commanders with the detailed information they need to make informed risk assessments. As previously stated, other reports note noncombat personnel tend to use more medical resources. The cause for this may be cultural differences among combat versus noncombat personnel and are a factor we cannot account for. Lastly, while our intent is these data will help inform force protection during LSCO, the context of these data were counterinsurgency operations in Iraq and Afghanistan. The nature of injuries at the individual and population levels may be very distinct from those seen during these operations.[20]

## Conclusion

Our study showed noncombat personnel comprised nearly 1 in 4 casualties. Injury patterns were similar among the two groups with nearly identical consumption of resources except for ketamine. The reason for the lower ketamine administration is unclear. Better data is necessary on noncombatant personnel sustaining battle injuries to guide commanders and medical leaders for future mission planning in resource constrained environments.

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## Authors

Giselle Tapia is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

LTC Jason F. Naylor is with Madigan Army Medical Center, Joint Base Lewis McChord, WA.

MAJ Michael D. April is with Uniformed Services University of the Health Sciences, Bethesda, MD; and 40th Forward Resuscitation and Surgical Detachment, 627th Hospital Center, 1st Medical Brigade, Fort Carson, CO.

MAJ Steven G. Schauer is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; Uniformed Services University of the Health Sciences, Bethesda, MD; and Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

# An Assessment of Nursing Skills Required for Sustaining a Casualty during Prolonged Casualty Care: Implications for Training and Preparing for the Next Major War

CPT Kristine E. Wilson, BSN, CEN
1LT Marissa Vasek, BSN
LTC Christopher A. VanFosson, PhD, MHA, RN, NEA-BC
BG Kathleen Flarity, DNP, PhD, CFRN, CEN, FAEN
COL (ret) Elizabeth Mann-Salinas, PhD
LTC Kevin Gillespie, DMD
COL (ret) Sean Keenan, MD
MAJ Andrew D. Fisher, MD, MPAS
MAJ Michael D. April, MD, DPhil, MSc
MAJ Steven G. Schauer, DO, MS

## Abstract

Background: The US military is transitioning rapidly from the Global War on Terrorism in preparation for near-peer combat in a multidomain operations (MDO) and/or large scale combat operations (LSCO) setting. Due to potentially contested freedom of movement in this setting, casualty evacuation may be significantly delayed, resulting in medics and other prehospital medical personnel taking on patient care duties normally performed by nurses in a hospital-based setting. However, the frequency of nursing-type care remains unclear. We seek to determine the nursing interventions typically performed in a facility with patient holding capability during the first 72 hours of care in the deployed setting.

Materials and Methods: This is a sub-analysis of previously described data from the Department of Defense Trauma Registry of US and North Atlantic Treaty Organization (NATO) military personnel from January 2007 to March 2020 with a focus on relevant nursing procedures identified in current Individual Critical Task Lists (ICTL) for critical care, emergency, medical-surgical nurses, and combat medics.

Results: Among all casualties, the most common nursing-related skills performed in the prehospital setting were wound dressing application (33%), administration of parenteral opioids (35%), and administration of ketamine (7%); in the hospital setting were preparation for transfer (60%), managing a post-operative patient (59%), and managing a traumatic brain injury (44%). In the hospital setting, most patients had a blood gas performed (73%), ventilator management occurred for 21% of patients, and administration of packed red blood cells occurred for 21% of patients.

Conclusions: Nursing-type interventions were frequently required during the first 72 hours of casualty care. The frequency of the required interventions demonstrates the need for ongoing nursing skills training for medics supporting casualties in the setting of prolonged casualty care.

*Keywords: prolonged; care; medic; nurse; skill; procedure; military*

## Introduction

*Background:* During the continuous conflicts in Afghanistan and Iraq, the US military sustained the lowest recorded fatality rates for combat casualties in the history of American warfare.[1] This success can be credited to the successful implementation of hemorrhage control, advanced medical care delivered quickly by deployed medical personnel after injury with rapid transport time.[1-4] Early initiation of damage control resuscitation (DCR) and damage control surgery (DCS) are credited with saving lives, though much of the essential care delivered is typically performed by nurses or considered nursing-type skills.[1,5-7] This is even more notable in regards to host nation medical care, both for partner force military personnel and civilians, as they do not get evacuated from theater and, as a result, have prolonged lengths of stay within the deployed US and

NATO military treatment facilities.[8,9]

Doctrinally, the military health system deploys to perform a support mission for direct action forces, but this was modified during recent conflicts. The US military worked to redesign the deployed medical system to better match the missions in Afghanistan and Iraq. This includes the addition of nurses embedded in units at the brigade level as well as development of small, highly mobile teams staffed with emergency and critical care trained nurses.[7,10] Despite this, little published data focuses on the frequency of procedures possibly required for prolonged casualty care (PCC). Such knowledge would be beneficial to the US military as we plan for future missions, which will involve limited evacuation capabilities during LSCO and MDO. In such future operations, and in current operations in remote areas such as US Africa Command PCC may occur with greater frequency. This analysis is based on a framework for prolonged field care (PFC), the ruck-truck-house-plane model, previously described by Keenan and colleagues.[11-14] As stated by Keenan and colleagues, "a popular example of applying operation context of PFC, consider that Everest Base Camp would serve as an example of 'house' and remote search and rescue vehicle, perhaps a snow machine or all-terrain vehicle, as 'truck.'"[13] While we focus on PCC, given the close relationship with PFC we have used this model as it is well described.

*Goal of this Study:* We sought to determine the frequency of deployed nursing skills required for sustaining a casualty for the first 72 hours after injury in accordance with relevant nursing individual critical task lists (ICTLs).

Table 1. Nursing skills of interest.

| ICTL Skills Category | Corresponding DoDTR Procedures Sought |
|---|---|
| Advanced Cardiac Life Support | Cardiopulmonary resuscitation |
| Manage chest tubes | Chest tube placement, chest needle decompression, documentation of a pneumothorax, and hemothorax |
| Setup arterial line placement | Documentation of arterial access or arterial line placement |
| Management massive blood transfusion protocol | Administration of whole blood, packed red blood cells, fresh frozen plasma, freeze dried plasma, platelets, cryoprecipitate |
| Manage a patient on a mechanical ventilator | Ventilator placement |
| Establish a walking blood bank | Whole blood administration |
| Interpret arterial blood gas | Laboratory data reported for arterial or venous blood gas sample (e.g. pH or base excess) |
| Assist in rapid sequence intubation | Administration of paralytics and/or documentation of intubation |
| Placement of a rapid infusion catheter | Placement of an IV/IO |
| Manage a burn patient | Documentation of at least 20% total burn surface area |
| Titrate vasoactive medications | Documentation of vasopressors |
| Perform procedural sedation | Administration of benzodiazepines, etomidate, ketamine, propofol without intubation |
| Monitor intracranial pressure (ICP) | Documentation of ICP monitor placement |
| Manage traumatic brain injuries | Documentation of a serious head injury |
| Perform pain management | Administration of opioids, ketamine |
| Perform wound care | Wound dressing placement |
| Perform an electrocardiogram (ECG) | Documentation of an ECG |
| Manage a surgical patient | Any operative intervention |
| Prepare a patient for transfer | Documentation of transfer to a higher level of care |

*ICTL: Individual critical task list; DoDTR: Department of Defense Trauma Registry: IV: Intravenous; IO: Intraosseous: ICP:Intracranial pressure; ECG: Electrocardiogram*

## Methods

*Data Acquisition:* This is a secondary analysis of a previously described dataset from the Department of Defense Trauma Registry (DODTR) with casualties that had at least one prehospital assessment or intervention recorded from 01 January 2007 to 17 March 2020.[15] The US Army Institute of Surgical Research regulatory office reviewed this protocol and determined it was exempt from Institutional Review Board oversight. We obtained only de-identified data.

*Department of Defense Trauma Registry DoDTR):* The DoDTR, formerly known as the Joint Theater Trauma Registry (JTTR), is the primary data repository for DoD trauma-related injuries.[16,17] The DoDTR includes documentation regarding demographics, injury-producing incidents, diagnoses, treatments, and outcomes of injuries sustained by US/non-US military and US/non-US civilian personnel in wartime and peacetime (including humanitarian) from the point of injury to final disposition. Short-term outcome data are available for non-US casualties. The DoDTR comprises all patients admitted to a Role 3 (fixed-facility) or forward surgical team (FST) with an injury diagnosis using the International Classification of Disease 9th Edition (ICD-9) between 800-959.9, near-drowning/drowning with associated injury (ICD-9 994.1), or inhalational injury (ICD-9 987.9) and trauma occurring within 72 hours from presentation. The registry defines the prehospital setting as any location prior to reaching a forward surgical team (FST), field hospital, or a combat support hospital to include the Role 1 (point of injury, casualty collection point, battalion aid station) and Role 2 without surgical capabilities

Table 2. Characteristics of casualties.

| | | US Military (n=10182) | NATO Military (n=2086) |
|---|---|---|---|
| Demographics | Age | 24 (21-28) | 25 (21-29) |
| | Male | 97% (9951) | 98% (2054) |
| Battle Status | Battle | 73% (7487) | 83% (1748) |
| | Non-battle | 26% (2695) | 16% (338) |
| Mechanism of Injury | Explosive | 57% (5897) | 62% (1309) |
| | GSW | 18% (1916) | 21% (456) |
| | Fall | 5% (580) | 4% (99) |
| | MVC | 5% (522) | 2% (55) |
| | Other | 12% (1267) | 8% (167) |
| Injury Severity Score | | 5 (2-14) | 5 (1-12) |
| Serious injuries by body region | Extremities | 23% (2442) | 24% (517) |
| | Thorax | 9% (930) | 7% (153) |
| | Head/neck | 8% (890) | 7% (165) |
| | Abdomen | 6% (646) | 5% (109) |
| | Skin | 2% (231) | 1% (29) |
| | Facial | <1% (32) | <1% (6) |
| Survival to Discharge | | 97% (9949) | 97% (2039) |

*NATO: North Atlantic Treaty Organization; GSW: gunshot wound; MVC: motor vehicle collision*

(temporary limited-capability forward-positioned hospital inside combat zone).

*Analysis:* We performed all statistical analysis using commercially available software packages. We present continuous variables as means and 95% confidence intervals; non-parametric continuous variables and ordinal variables as medians and interquartile ranges; and nominal variables as percentages and numbers. We analyzed the data under the assumption of accurate documentation of all care rendered.

Table 3. Relevant prehospital skills.

| Skills | Percentage of casualties requiring skills |
|---|---|
| External warming | 49% (6011) |
| Intravenous access | 41% (5107) |
| Administration of parenteral opioids | 35% (4326) |
| Wound dressing | 33% (4114) |
| Administration of ketamine | 7% (930) |
| Administration of benzodiazepines | 6% (719) |
| Administration of paralytics | 3% (449) |
| Assist with intubation | 3% (382) |
| Blood administration | 2% (231) |
| Chest needle decompression | 1% (141) |
| Cardiopulmonary resuscitation | <1% (62) |
| Chest tube placement | <1% (58) |
| Administration of vasopressors | <1% (40) |

Based on our previous experience working with data from the DoDTR, we developed a list of relevant procedures based on the individual critical task lists for 66T (emergency nurse), 66S (critical care nurse), 66H (medical-surgical nurse), and 68C (practical nurse) (Table 1). While PCC is not firmly defined by time, we used the generally accepted 72 hours as the time frame, thus limiting our procedural skills to those required within the time frame from injury. Given the variable data captured in each setting, we categorized the available data into 3 phases of the first 72 hours that generally mirror the operational phases of PFC: ruck/truck (prehospital), house (emergency department, intensive care unit, medical-surgical). Moreover, the DoDTR has different data capture variables across the phases of care. Specifically of note, the drug capture within the hospital system is very limited. While not specifically listed as an ICTL but inherently a required nursing skill, we also sought frequency of continuous drug infusions.

## Results

Within the DoDTR from 01 January 2007 to 17 March 2020 there were 28,950 encounters with documentation of prehospital activity. Of these, 10,182 were US military and 2,086 were NATO forces which met inclusion for this analysis. The median ages of casualties were 24 and 25 among US military and NATO military. Among US and NATO forces, most were male (97%, 98%), battle injuries (73%, 83%), injured by explosive (57%, 62%), with low injury severity scores (5, 5) (Table 2). Extremities were the most frequently seriously injured body region (23%, 24%). Most survived to hospital discharge (97%, 97%). Within the first 72 hours, the most performed interventions prehospital were external warming (49%), administration of parenteral opioids (35%), and wound dressings (33%) (Table 3). In the hospital setting, the most frequently performed interventions were blood gas interpretation (73%), preparing the patient for transfer to a higher level of care (60%), and management of a post-operative patient (59%) (Table 4).

Table 4. Relevant hospital procedures.

| Skills | Percentage of casualties requiring skills |
|---|---|
| Blood gas interpretation | 73% (8958) |
| Prepare for transfer to higher level of care | 60% (7419) |
| Management post-operative | 59% (7300) |
| Manage serious head injury | 44% (5481) |
| Administration of packed red blood cells | 21% (2594) |
| Ventilator management | 21% (2585) |
| Administration of fresh frozen plasma | 19% (2308) |
| Arterial access | 16% (1930) |
| Assist with intubation | 12% (1481) |
| Administration of platelets | 11% (1377) |
| Administration of cryoprecipitate | 7% (938) |
| Chest tube placement | 5% (686) |
| Obtain an ECG | 4% (467) |
| Central line maintenance | 3% (388) |
| Administration of whole blood | 2% (285) |
| Nasogastric tube | 2% (229) |
| Manage severe burn | 1% (112) |
| Management of hemo-/pneumothorax | <1% (71) |
| Manage ICP monitor | <1% (57) |
| Vasopressor infusion | <1% (54) |
| Cardiopulmonary resuscitation | <1% (48) |

*ECG: electrocardiogram; ICP: Intracranial pressure*

## Discussion

Our study reveals several unexpected procedures that may need development amongst medics, or require additional nursing care moved near the point of injury, including blood gas interpretation and longer-term, parenteral opioid administration. These skills are rarely, if ever, performed by medics in the military treatment facilities (MTF); whereas, wound dressings and external warming skills are commonplace.[18] As the most common cause of injury was explosive, followed by gunshot wounds, the use of opioid analgesics can prove to be beneficial in mitigating severe pain.[19] We must highlight this may not be the same in future conflicts. The use of low-order explosives within the recent conflicts may not mirror the use of more powerful casualty-producing weapons such as high-yield mortars and artillery.

With the specter of MDOs, we should remain vigilant in preparation for increased quantities of casualties and maintaining said casualties for extended periods of time in lieu of previous capabilities to expediently evacuate casualties to higher levels of care.

Since 2010, evacuation times maintained an average of less than an hour. However, as troop levels and medical assets decrease, the golden hour/period increases causing the need to hold a trauma case for 36-72 hours.[20] Farr states special forces medics and unit surgeons have begun mission planning for the lack of medical and personnel support by dividing logistical preparations into 4 stages: ruck, truck, house, and plane.[11,13]

During the ruck phase, the medic performs an appropriate tactical combat casualty care assessment and provides interventions in a timely manner.[1,21] This initial response improves the probability of survival.[22] Actions taken during this time are controlling massive external hemorrhaging, protecting the airway with possible adjuncts while assessing for tension pneumothorax requiring needle-chest decompression (1%), obtaining intravenous (IV) access (41.6%), managing burns and providing external warming (49%) and obtaining vital signs.[2,4-6,21-23] During this time, the medic will also provide high-risk medications (35%), IV fluids and fresh whole blood/packed red blood cell transfusions (2%, and 21%, respectively) if available.[24,25] Once in a position where evacuation from point of injury is available, the casualty enters the truck phase. In this phase, the medic has monitoring and increased communications capabilities at hand allowing the medic to provide pertinent casualty information to the next role. During this time, the casualty's vital signs trends and general condition are being monitored, and reassessments continue to occur.

Once the casualty reaches the first dedicated MTF, they have entered the house phase, where increased capabilities are available for casualty management. The house phase is where critical care knowledge can be applied when assisting with rapid sequence intubation (3.1%) and placing casualties on ventilators (21%), as well as obtaining and interpreting point of care testing/venous blood gas (73%).[24] This phase may have surgical capability requiring frequent reassessments post-operatively (59%) and wound care/dressing changes (33%). While providing continual monitoring of vital signs/level of consciousness/Glasgow Coma Scale for potential deterioration and decompensation related to shock or traumatic brain injuries (44%), the medics are also preparing the casualty for transfer (60%). Once medical evacuation becomes available, the entire medical team enters the plane phase and will prepare and package the casualty for safe delivery to a higher level of care.[21]

Since the beginning of nursing integration within deployed units and hospitals, nurses have worked alongside medics and provided a level of comfort, knowledge, and skill to the casualties they tended. As the potential for prolonged field care increases, the nursing interventions and skills most often used should be implemented by medical training leadership into medic training to ensure the high survival continues during future conflicts.[1] This gives nurses the opportunity to coach, teach, and mentor medics to improve competency and efficiency in their medical skills, allowing the medics to become an extension of the nursing team when they are unavailable.[26] During the past 20 years of continuous conflict, nurses have had to learn to improvise, adapt, and overcome supply shortages, minimal staffing, and knowledge deficits in order to provide the best possible care for their casualties. With increased training, exposure, and improvements in technology, they have become integral members of the operational healthcare team. As medical advances endure during this period of asymmetric warfare, nursing and medic teamwork can continue to decrease mortality in battlefield injuries that may otherwise have been fatal in previous conflicts.[20,27]

Our study has several limitations. First, the registry does not capture casualties who died before reaching an MTF. Additionally, medical rules of eligibility may have limited evacuation of humanitarian casualties to military surgical facilities, preventing their inclusion into this particular study. We are only able to describe the overall incidence of a procedure and offer suggestions for future research. We do not know about technical difficulties or other challenges that would highlight training gaps needed for these nursing-type skills. Lastly, data in the trauma registry is dependent upon documentation in austere combat conditions, and previous studies have demonstrated poor documentation rates.[28,29]

## Conclusion

Nursing-type interventions were frequently required during the first 72 hours of casualty care. The frequency of the required interventions demonstrates the need for ongoing nursing skills training for medics supporting casualties in the setting of prolonged casualty care.

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## Authors

CPT Kristine E. Wilson is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

1LT Marissa Vasek is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX.

LTC Christopher A. VanFosson is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX; and US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

BG Kathleen Flarity is with CU Anschutz Center for COMBAT Research, Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO.

COL (ret) Elizabeth Mann-Salinas is with Joint Trauma System, JBSA Fort Sam Houston, TX.

LTC Kevin Gillespie is with US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX.

COL (ret) Sean Keenan is with CU Anschutz Center for COMBAT Research, Department of Emergency Medicine, University of Colorado School of Medicine, Aurora, CO; Joint Trauma System, JBSA Fort Sam Houston, TX; and Uniformed Services University of the Health Sciences, Bethesda, MD.

MAJ Andrew D. Fisher is with University of New Mexico–Albuquerque, Albuquerque, NM; and Texas National Guard, Arlington, TX.

MAJ Michael D. April is with 40th Forward Resuscitation and Surgical Detachment, 627 Hospital Center, 1st Medical Brigade, Fort Carson, CO; Uniformed Services University of the Health Sciences, Bethesda, MD.

MAJ Steven G. Schauer is with Brooke Army Medical Center, JBSA Fort Sam Houston, TX; US Army Institute of Surgical Research, JBSA Fort Sam Houston, TX; and Uniformed Services University of the Health Sciences, Bethesda, MD.

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