Combat Casualty Care in Arctic or Extreme Cold Environments

Considerations for the Army Health System

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ABSTRACT

The Department of the Army's 2021 strategy to "Regain Arctic Dominance" highlights the operational necessity of sustaining combat readiness in Arctic or extreme cold environments (AoECE). Presented are five scenarios inspired by casualties that illustrate capability gaps and best practices as the Army Health System applies tactical combat casualty care (TCCC) in austere, frigid climates: (1) adapting TCCC to the AoECE as a unique environment; (2) technological limitations in the prevention and treatment of hypothermia; (3) freezing cold injury (FCI) and non-freezing cold injury (NFCI) treatment and the institutional need for a cold injury center; (4) a proposal for a FCI rule-out pathway to preserve the fighting force; (5) carbon monoxide poisoning and logistical constraints. These scenarios emphasize the need for research, procurement, and doctrine tailored specifically to the AoECE, as environmental exposure and equipment capability will be a decisive factor in casualty survivability and force regeneration.

Keywords: *cold environments; tactical combat casualty care; non-freezing cold injury; freezing cold injury; cold weather; Arctic; Army Health System; frostbite; hypothermia*

Introduction

In 2021, the Department of the Army outlined a new plan to "Regain Arctic Dominance."[1] This strategy underlines the importance of maintaining capabilities in Arctic or extreme cold environments (AoECE). Reprioritizing for this environment and preparing to conduct multi-domain operations (MDO) against a near-peer threat requires an assessment of current medical capabilities and identification of capability gaps. As part of this renewed emphasis on the Arctic environment, several gaps have been identified as tactical combat casualty care (TCCC) practitioners support exercises in the harsh Arctic climate.

While cold weather injury patterns are not new to military operations, we suggest that a lack of emphasis on the region during the Global War on Terrorism has resulted in a loss of institutional knowledge for effective large-scale treatment of these injuries in austere and far-forward environments. Modern practices in TCCC have exhibited deficiencies in the prevention and treatment of cold-weather injuries, and medical equipment sets (MES) require supplementation for the frigid environment. Our objective is to illustrate the effect the Arctic region has on these systems and provide recommendations to improve them. Adapting to the extreme cold through equipment adjustments and modifying existing techniques will enable TCCC practitioners to preserve the standard of care expected from previous conflicts.

Methods

Five scenarios were created to describe the medical treatment challenges that military providers encounter in the AoECE. These scenarios are based on real-world injury patterns encountered by the authors while providing medical support in the Arctic region.

Adapting TCCC to the Arctic as a Unique Environment

Scenario 1

> A 24-year-old mechanic is crushed by a wheeled vehicle during a routine training exercise in remote Alaska. A North Atlantic Treaty Organization (NATO) 9-line medical evacuation (MEDEVAC) is immediately requested, and a medic begins to perform a primary assessment in accordance with TCCC guidelines. The medic exposes the casualty to assess for injury and identifies a flail chest and signs of hemorrhagic shock. Subsequently, the exposed casualty shows signs of moderate hypothermia. A hypothermia prevention and management kit (HPMK) is applied to the casualty, but the chemical heater will not activate in the frigid environment. The medic is unable to provide the TCCC-recommended medications immediately because they have frozen in his aid bag. Without the ability to actively rewarm or provide appropriate medications, the casualty becomes unconscious before MEDEVAC arrives.

The characteristics of AoECE have forced TCCC practitioners operating in these regions to modify existing techniques. Trauma casualties are treated according to the MARCH algorithm: massive hemorrhage, airway, respiratory, circulation, hypothermia/head injury.[2] This standardized pathway prioritizes injuries that the Joint Trauma System (JTS) has identified as leading causes of mortality on the battlefield. In the AoECE, hypothermia prevention should persist throughout casualty care. Hypothermia's role in the trauma diamond of death—a

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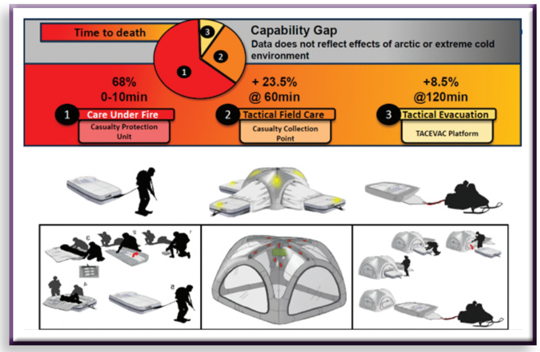
series of physiologic injuries resulting in impaired coagulopathy—is well documented.

While the current guidelines acknowledge the importance of early and aggressive hypothermia management, exposing casualties to AoECE conditions during tactical field care (TFC) will inevitably decrease core temperature. One potential mitigation for this is to adjust MARCH to MhARCH, resequencing hypothermia management to occur immediately after massive hemorrhage.[3] Units operating in these climates can expect temperatures as low as –54°C (–65°F), which is further exacerbated by wind chills.[1] Exposure to these conditions can affect outcomes, as a decrease in core body temperature from 37.0°C to 36.2°C (98.6°F to 97.2°F) is a positive predictor of mortality.[4] For these reasons, the authors recommend a field-expedient shelter composed of a vapor barrier (tarp, bothy bag, etc.) to create a bubble of warmth during tactical field care.

FIGURE 1 *CASEVAC Ecosystem RDT&E design aligned with CoTCCC phases of care in support of optimized hypothermia management, TCCC provider/ casualty sheltering, and TACEVAC support for temperature-sensitive items at the point of injury and expedited casualty movement to definitive resuscitation.*



(Credit: MAJ, Titus J. Rund; OV-1 graphics by CW2 Matthew L. Perkins and SSgt Kyle M. Overholser.)

CASEVAC = casualty evacuation; RDT&E = research, development, testing, and evaluation; TACEVAC = tactical evacuation.

TCCC practitioners operating in AoECE have adopted specific techniques within the MARCH framework to mitigate hypothermia during each step. During the massive hemorrhage assessment, TCCC practitioners reach through the sleeves, vents, waistband, and other clothing gaps to identify hemorrhage instead of an external blood sweep. This technique aims to discover substantial bleeding that may be masked by several clothing layers while minimizing casualty exposure to the elements. During airway management, diminished hand dexterity from the extreme cold increases cricothyrotomy difficulty compared to other adjuncts. For needle thoracostomies, the second intercostal space is preferred due to its easier access through insulating clothing. Intravenous (IV) lines are discouraged outside of a bubble of warmth (i.e., field-expedient shelter or climate-controlled environment) in favor of intramuscular (IM) injections. IM administration prevents unnecessary casualty exposure and fluid freezing within IV extensions and saline locks.

AoECEs have unique considerations, and many capability gaps have been identified regarding limitations in the delivery of medical care. Addressing these gaps requires rediscovering and preserving knowledge from previous cold weather conflicts and developing new solutions with current technology. Much like operating in a chemical, biological, radiological, nuclear, and explosives (CBRNE) environment, the AoECE requires technical capabilities tailored to the environment. Emphasis is placed on moving a casualty rapidly to a tent or field-expedient shelter to provide a bubble of warmth and allow for better casualty exposure and further TCCC care. A casualty evacuation (CASEVAC) ecosystem is undergoing research, development, testing, and evaluation (RDT&E) and is patent-pending by the Department of Defense (DoD). The CASEVAC ecosystem expedites casualty evacuation and improves casualty care by providing a temperature-controlled casualty collection point and evacuation method.[4] In AoECE, integrating distributed environmental protection across the formation is necessary to meet the standards of prehospital care established by the Committee on Tactical Combat Casualty Care (CoTCCC) (Figure 1).

Temperature-sensitive medications are often carried close to the TCCC practitioner's body instead of an aid bag to prevent freezing. This has been effective for small quantities of medications; however, medication chests within the MES are highly susceptible to freezing. While research has been conducted into the safety and efficacy of many medication freeze-thaw cycles, it is not easily accessible or fully inclusive of all battlefield medications.[5,6] Centralizing temperature stress data for medications and their containing ampules or vials within a commonly referenced organization, such as a JTS Clinical Practice Guideline (CPG), would improve medical logistic planning in the AoECE. Adhesives on occlusive dressings, cleaning solutions (i.e., alcohol prep pads), and other common TCCC recommended Class VIII may not be effective in the AoECE. There is no perfect solution for temperature-regulated portable storage in light infantry units. Previous attempts to use chemical heaters (i.e., hand warmers) in smaller medication chests have been ineffective.

This temperature problem extends to resuscitative fluids. Traditional golden-hour boxes for fresh whole blood are not conducive to preserving the recommended temperature range of 1–6°C (34–43°F) in extreme cold. A walking blood bank is a logical solution for fresh, warm blood; however, the citrate in transfusion bags will freeze if not kept warm. Freeze-dried plasma provides a more temperature-stable fluid; however, the sterile water it requires for reconstitution limits its use to warm environments. The immediate solution is to store resuscitative fluids in warmed vehicles. However, all forms of transportation are slower in extreme temperatures and deep snow, delaying resuscitative capabilities.

It is highly likely that line medics will not be able to effectively carry the same equipment that they have been accustomed to carrying during the Global War on Terrorism operations. Alternative solutions using high-mobility off-road vehicles (i.e., snowmachines) for parasitic power generation are currently undergoing RDT&E. This RDT&E effort is assessing the feasibility of parasitic power generation to provide for active casualty rewarming, increased mobility, and the timely delivery of temperature-sensitive items (i.e., prehospital blood, medications, and other CASEVAC medical supplies) at the point of injury.[3]

Technological Limitations in Hypothermia Management

Scenario 2

A 19-year-old vehicle gunner is brought to the Role 1 after conducting a convoy mission where he was exposed in the gunner's hatch in –40°C (–40°F) temperatures. He is litter-bound, unresponsive to verbal stimuli, and his core temperature is 31.7°C (89.2°F). A hypothermia wrap is constructed with his sleep system and an HPMK, and warmed IV crystalloids are provided. Ambient temperatures in the Role 1 are 4°C (40°F), and after one hour of treatment, the casualty's condition has minimally improved.

Hypothermia treatment capabilities are limited in organic equipment sets. TCCC guidelines recommend using the HPMK for the prevention and treatment of cold weather injuries. The included method of active rewarming in an HPMK is the Ready-Heat (TechTrade, Orlando, FL), a chemical 4-panel blanket. These chemical heaters have difficulty activating as ambient temperatures drop below –18°C (0°F). Also included in the HPMK is a reflective vapor barrier. While acceptable for passive rewarming, it is unlikely that endogenous thermogenesis will be sufficient in the AoECE. This limitation can be exacerbated as casualties progress through echelons of care. The current tentage for a Role 1 or Role 2 struggles to maintain temperature in extreme cold environments. During a 2021 training exercise, a 25th Infantry Division Role 2 never exceeded 11°C (51°F), far from the 27°C (80°F) standard for a trauma bay.[7]

The JTS hypothermia CPG recommends IV fluids, traditionally warmed to 40°C (104°F), as an adjunct treatment of hypothermia.[8] Several IV warmers have been issued in equipment sets, namely the Buddy Lite (Belmont Medical Technologies, Billerica, MA) or Thermal Angels (Estill Medical Technologies, Dallas, TX). Neither of these have demonstrated the ability to reach the target temperature of 40°C (104°F). A 2021 study examined four standard-issue U.S. Army IV heaters at a range of altitudes, flow rates, and temperature fluids; none could reach 37°C (98.6°F).[9] Both the Thermal Angel and Buddy Lite achieved 32°C (89.6°F) less than 20% of the time.[9] With current equipment, active rewarming through IV fluids is not possible. As a final option, the hypothermia CPG recommends 3M Bair Huggers (Solventum, Eden Prairie, MN) for active rewarming. The authors have implemented these with the 2nd Brigade 11th Airborne with great success in several AoECE exercises. Unfortunately, Bair Huggers are not included on the Modified Table of Organization and Equipment, making their acquisition difficult for Arctic-aligned units.

Freezing and Non-freezing Cold Injury Considerations

Scenario 3

A 37-year-old artilleryman presents to the brigade casualty collection point immediately following a mass tactical airborne operation in –29°C (–20°F) temperatures. He complains of numbness in his distal fingers. He is provided hand warmers and instructed to put on his arctic mittens. He presents 48 hours later to the Role 2 with continued numbness, blisters, and a woody induration in his distal fingers. He is diagnosed with full-thickness frostbite and evacuated to the next echelon of care.

Operations in AoECE increase the frequency of frostbite during military operations.[10] Off-the-shelf water-circulating food warmers, such as a sous vide, have been used successfully to treat frostbite in both civilian and military settings.[11–13] The sous vide device can be set to the desired therapeutic temperature of 39–40°C (102–104°F) and maintain that temperature indefinitely as long as reliable power is available. The device is often used in conjunction with a five-gallon bucket to immerse the frozen extremity in the heated circulating water bath. Bleach may be used at 0.5–2ppm (mg/L) to mitigate bacterial growth during prolonged periods of preheated water.[14] Aloe vera and ibuprofen may also be stored with the sous vide in the five-gallon bucket for an all-in-one freezing cold injury (FCI) kit (Figure 2). The sous vide device is the standard of care for frostbite in the 11th Airborne Division and multiple emergency departments in the state of Alaska. However, like the Bair Hugger, it is not included in standard medical equipment sets, reducing access for Soldiers suffering from frostbite.

FIGURE 2 *An 11th Airborne frostbite kit: A 5-gallon bucket, sous vide, extension cord, and ibuprofen. Aloe vera and bleach may be added if available.*

(Image courtesy of CPT David Reynhout)

Additionally, there is no standardized practice for the early grading of freezing injury (i.e., Cauchy frostbite grading).[15] Army Regulation 40-501 provides guidance on profiling; however, it does not integrate objective physiological metrics to guide profile creation. Soldiers diagnosed with any degree of frostbite are placed on a permanent profile, labeling them as at risk for future cold-weather injury regardless of clinical assessment or clinician judgment. Because of the reliance on Soldier symptom reporting for FCI, this policy inadvertently allows Soldiers to preferentially withhold symptoms when profiles may hamper career progression. The creation of an FCI physiological recovery pathway that is logistically simplistic yet scientifically informed will significantly improve the current return-to-duty pathway.

Descriptive ICD-10 coding, profiling, and evidence-based guidelines to oversee FCIs and non-freezing cold injuries (NFCI) are not currently managed under a specialty center like the Army Heat Center. Establishing a high-reliability organization for the AoECE (i.e., AoECE Injury Center) would support standardizing care and data collection to inform the force and improve DoD policy for timely disposition and force regeneration. The United Kingdom's Cold Injury Clinic (CIC), which provides FCI and NFCI care pathways within the UK Ministry of Defence, could be a reference point for developing a U.S. cold weather center.

Freezing Cold Injury: A Proposal for Return to Duty Guidelines to Preserve the Fighting Strength

Scenario 4

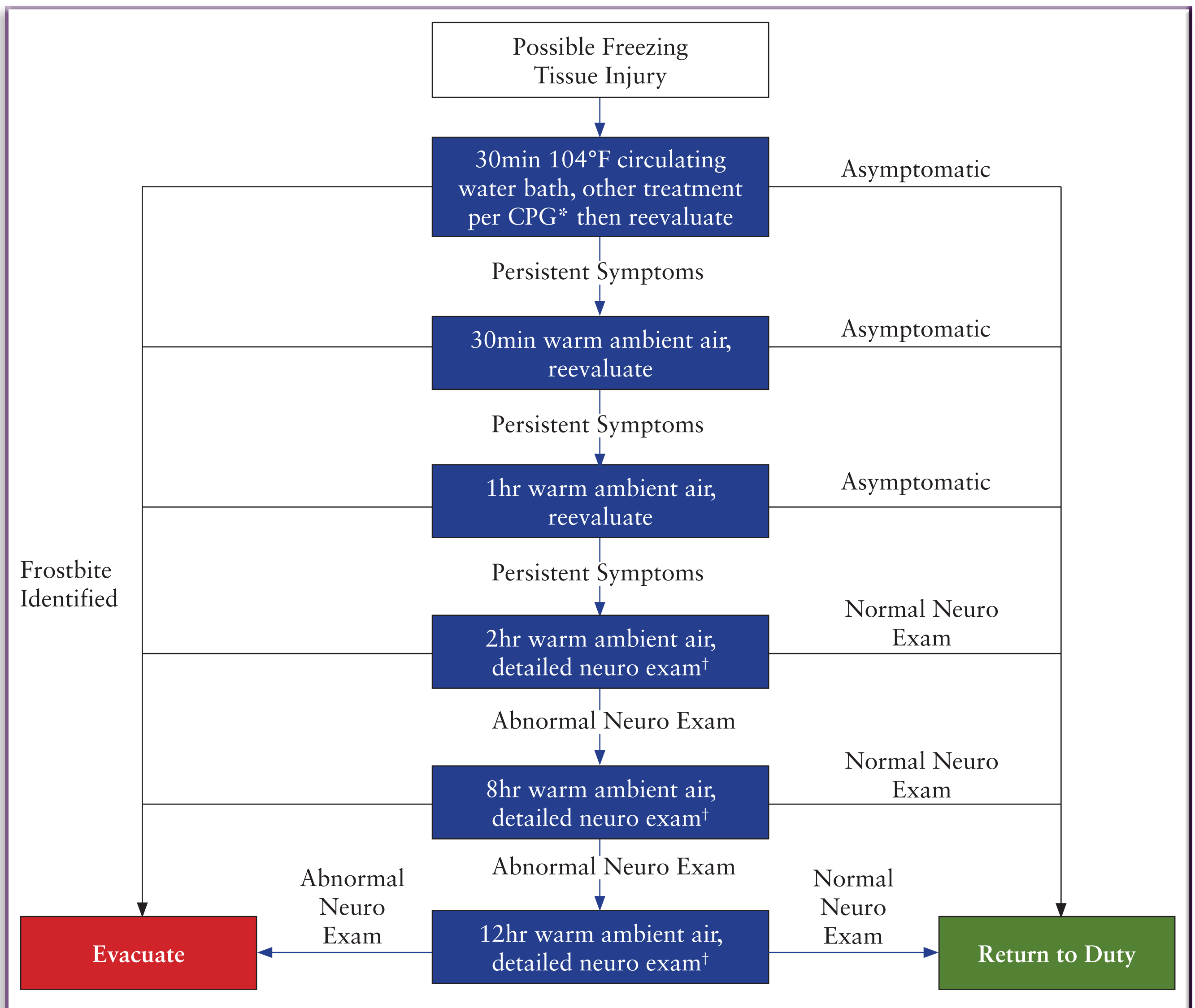
During an airborne operation with an ambient temperature of –27°C (–15°F), a company of paratroopers is isolated overnight without appropriate cold-weather equipment. Twenty paratroopers report a mix of hand and foot redness, numbness, and paresthesias. They are initially screened by unit medics and then present to the Role 1 for further cold-weather injury evaluation.

Cold-weather injuries as non-battle injuries are resource- and manpower-intensive. Identifying frostbite can be a slow and arduous process that congests heated environments needed for more severe casualties. This is especially true early in the disease process, when the primary symptom is numbness, without the blisters, discoloration, or induration associated with more developed frostbite. Inappropriate disposition and immediate re-exposure to freezing temperatures dramatically worsens the disease and may result in amputation of the affected tissue. Efficiently differentiating transient post-cold exposure neuropathy or erythema from permanent tissue damage will improve throughput within the medical treatment facility and rapidly return Soldiers to duty.

Figure 3 is a pathway in development by the 2nd Brigade 11th Airborne that enables quick and conservative frostbite rule out. Soldiers presenting with signs and symptoms consistent with frostbite are initially treated as presumed frostbite with a warm water bath and other adjunctive treatments.[16] The Soldier is then serially evaluated by medical staff to evaluate for symptom resolution or definitive signs of frostbite, such as blistering or persistent and demarcated skin discoloration. If symptoms improve, the Soldier is returned to duty. If subjective symptoms persist, serial neurological examinations are performed. These exams include sensitivity to light touch, hot/cold sensitivity, and two-point discrimination. If the Soldier has a normal examination, then they are thought to not have a significant frostbite injury and will be able to self-identify future symptoms of frostbite when re-exposed to the cold.

In limited initial testing, of the 14 Soldiers who entered the pathway and were returned to duty, none re-presented later for frostbite during the exercise. Most Soldiers were either returned to duty or diagnosed with frostbite within two hours. Further research is required to validate this pathway. Due to harsh field conditions or other circumstances, some Soldiers may continue to describe subjective symptoms without apparent underlying injury. It is unclear if the presence of residual

FIGURE 3 *2/11 ABN DIV frostbite rule-out pathway.*



*Joint Theater Trauma System Clinical Practice Guideline, Frostbite and Immersion Foot Care (CPG: 59).
†Neurological examination includes sensitivity to light touch, hot/cold discrimination, and 2-point discrimination.
Soldiers with clinical signs or symptoms of possible frostbite are serially evaluated and treated until recovery or evacuation of a definitive frostbite diagnosis can be made.
CPG = clinical practice guideline; neuro = neurological.

subjective symptoms increases the risk for long-term injury if re-exposed to a cold environment. This pathway attempts to safely return these Soldiers to duty to best reconstitute the commander's combat power within 24 hours. The efficient and safe disposition of large numbers of Soldiers with possible frostbite is a significant problem for medical units in Arctic conditions and is an active area of study.

Carbon Monoxide as an Example of Logistical Constraints in the AoECE

Scenario 5

During a brigade-level training rotation with ambient temperatures below –37°C (–35°F), a supporting Role 2 is presented with 10 casualties complaining of headaches, confusion, and muscle weakness. Their accompanying platoon medic reports they spent all night in their ahkio tent with the heater on and believes the carbon monoxide detector was not functioning. Role 2 providers clinically diagnose carbon monoxide poisoning and, without the ability to assess carboxyhemoglobin levels, triage on presentation. Because of the significant oxygen requirement for the treatment of carbon monoxide (CO) poisoning, only two casualties are definitively treated at the Role 2, while eight casualties are evacuated via three ground transports to the nearest hospital.

Carbon monoxide exposure is a significant threat in AoECE, as fuel-based heaters remain a standard method of warmth for sleeping quarters. While carbon monoxide detectors are used within Akio tents to mitigate exposure, they are susceptible to human and equipment failure. Additionally, available CO detectors are limited to commercial off-the-shelf (COTS) products intended for use in fixed facilities and not engineered for the rigors of military use in field operations. As the temperature drops, Soldiers may use creative methods to stay warm with butane or other fuel-based heaters, causing CO poisoning outside of enclosed environments.[16] While most exposures manifest with headaches, nausea, and dizziness, severe exposures may present with neurological impairment and cardiac dysrhythmias.[17,18]

The primary treatment method for a conscious CO poisoning is 100% O_2 via a nonrebreather mask at 15 liters-per-minute (LPM) until the carboxyhemoglobin (COHb) level is <10% and for an additional four hours if the casualty is suffering from additional sequela or high-level exposure.[18,19] Oxygen capabilities within a BCT are available in D-size O_2 cylinders. A full D-tank will provide 21 minutes of O_2 therapy at 15LPM, quickly expending available O_2 supplies. It is possible to extend O_2 supplies and increase the removal of COHb using an emergency evacuation hyperbaric stretcher; however, this traditionally requires approval from a hyperbaric medical officer and presents significant logistical considerations.

Obtaining a COHb level requires equipment beyond the capabilities of a Role 2 lab section, limiting providers to triage and direct treatment based on clinical presentation or other comorbidities. This becomes problematic in diagnosing if the history is not suggestive of CO exposure or, in triage, if multiple casualties present with CO exposure.[17] Wearable colorimetric carbon monoxide badges are a possible early detection tool; however, their practicality in a frequently dark field environment where thermal stress cycling occurs is undetermined. The Medical Capability Development Integration Directorate's development of an MES-AoECE supplement with a COTS handheld COHb oximeter (analogous to environment-specific CBRNE detection equipment) enables a quantifiable prehospital diagnosis; this supports real-time monitoring, appropriate disposition for medical evacuation, and the preservation of limited resources (like oxygen) in an environment with contested logistics.

Conclusion

Operations in AoECE demand an environment-specific approach. The renewed emphasis on the Arctic environment has enabled assessments in the prehospital delivery of medical care, helped identify capability gaps, and aided in the development of best practices. However, significant capability gaps impacting casualty survivability and disability still exist without clear solutions.

Hypothermia remains a persistent threat and an obvious contributor to mortality. Active rewarming methods capable of functioning in subzero temperatures and improved environmental protection at the point of injury will increase survivability by preventing further heat loss and optimizing a casualty's physiology until more definitive resuscitation can begin at higher echelons of care. Fluid warmers capable of sustaining temperatures above the hypothermic level are needed. Procuring sheltering that provides a bubble of warmth through tactical field care and fielding improved tentage with robust heaters for military treatment facilities will improve hypothermia prevention and treatment. Further research is needed to identify "warm chain" storage options for temperature-sensitive items (e.g., blood, medications) and to enable temperature-controlled transport of medications at individual or collective levels.

Adjusting the Modified Table of Organization and Equipment or fielding an MES-AoECE Supplement for units operating in the AoECE to include Bair Huggers, sous vides, and handheld carbon monoxide oximeters would fill critical capability gaps. Combined, these adjustments improve Army Health System capabilities in the AoECE and will reduce the already high mortality expected in an MDO.

Author Contributions

DJR drafted the original manuscript. MTC, SEM, and TJR assisted in manuscript editing and drafting.

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