

PROLONGED CASUALTY CARE

An Ongoing Series

Maritime Applications of Prolonged Casualty Care Training Scenario

Burn Injury on a Destroyer During Distributed Maritime Operations

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ABSTRACT

As the U.S. Navy further develops the concept of distributed maritime operations (DMOs), where individual components of the naval force will be more geographically dispersed, smaller vessels may be operating at a significant time and distance from more advanced medical capabilities. Therefore, Role 1 maritime caregivers will need to manage injured and disease non-battle injury patients for prolonged periods during current and future contested DMOs. We developed a hypothetical burn injury patient scenario to present an innovative approach to teaching complex operational medicine concepts including austere burn resuscitation, wound care, and Prolonged Casualty Care (PCC) to austere Role 1 maritime caregivers using the Joint Trauma System PCC and Tactical Combat Casualty Care clinical practice guidelines (CPGs) and other standard references. The format includes basic epidemiology of burn injury in the operational maritime environment. The scenario includes a stem clinical vignette, followed by expected clinical changes for the affected patient at specific time points (e.g., time 0, 1 hour, 2 hours, and 48 hours) with expected interventions based on the PCC CPG, appropriate guidelines, and available standard shipboard equipment. Through this process, opportunities to improve both training, clinical skills sustainment, and standard shipboard medical supplies are identified.

KEYWORDS: *Prolonged Casualty Care; Tactical Combat Casualty Care; maritime military; critical care; burn injury; burn resuscitation*

Introduction

Throughout history Sailors and Marines embarked on naval warships have been exposed to the risk of burn injury during both naval warfare and routine operations. While this risk is greatest during naval combat, deployed crewmembers have suffered thermal injury from various types of ordnance during attack or mishap, including equipment failure in mechanical ship spaces, accidental collisions, high-pressure steam injury, electrical injury, toxic gas and smoke inhalation, chemical and fuel burns, food preparation accidents, and jet blast injury during aircraft carrier flight deck operations.¹⁻⁸

This hypothetical scenario is based on real burn injuries that have occurred on deployed naval vessels. It is part of an ongoing educational series published in this journal, "Maritime Applications of Prolonged Casualty Care," describing the management of critically ill or injured patients, using Joint Trauma System (JTS) TCCC and Prolonged Casualty Care (PCC) clinical practice guidelines (CPGs), when evacuation to a higher level of care is not possible.⁹ This scenario has two goals. First, it is an educational tool or "road map" for isolated Role 1 maritime caregivers, such as Independent Duty Corpsman (IDC), describing how a patient with severe burn injury should be managed in an austere shipboard environment over the course of 86 hours using JTS CPGs. If a specific decision or intervention is not addressed by these guidelines, appropriate interventions are recommended based on expert consensus and literature review. A secondary goal of this scenario is to function as a clinical tabletop exercise to identify capability, training, and supply gaps

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that, when closed, may improve casualty survivability during distributed maritime operations (DMOs).

Scenario

Setting

A U.S. Navy Arleigh Burke-class guided-missile destroyer (DDG) with a crew of 314 is conducting solo arctic operations approximately 72 hours away from advanced medical care. Current medical capabilities include standard Role 1 DDG personnel and equipment including one Independent Duty Corpsman, two junior Corpsmen, and two total (stacked) ward beds. Basic point-of-care labs are available including rapid complete blood count (CBC) using QBC star, dipstick urinalysis (UA), finger-stick glucose using a glucometer, and fecal occult blood testing.¹⁰ There is no ultrasound, electrocardiogram, or x-ray capability.

Patient

A 28-year-old man was brought to DDG Main Medical after a transformer exploded in a confined space while he was working on the ship's electrical system. He was not in contact with an electrical power source when the incident occurred; however, he was not wearing his fire-retardant coveralls correctly as they were "half-mast" tied around his waist, with only a t-shirt protecting his torso. His shirt caught fire, requiring swift action from the response team. He was quickly removed from the site of the explosion, but no medical treatment was given during transport. Upon arrival to Main Medical, his shirt is charred, and he is now experiencing pain, hearing loss, and difficulty breathing.

The patient's medical history is notable for a 10-pack-year smoking history and having previously recovered from a COVID-19 infection within the last 12 months; no hospitalization had been required. He is not on any current medications.

Time 00 Minutes

The patient's presenting vital signs are as follows: heart rate (HR), 130bpm; blood pressure (BP), 189/65mmHg; respiratory rate (RR), 30 breaths/min minute; peripheral oxygen saturation (SpO₂), 92%; temperature, 37°C; weight, approximately 90kg.

During physical examination he appears alert, oriented to person, place, time, and has full recall of the incident. He is complaining of significant pain in his arms and chest, with obvious burns to the bilateral upper extremities. The patient's face is free of burns and there is no soot seen in the oropharynx.

Recommended interventions are to treat the patient as a trauma patient first: perform a full primary and secondary survey evaluating for traumatic injury in addition to assessing and managing his burn injuries.

The primary survey should:

- Assess the airway and consider cervical-spine immobilization due to history of explosion.
- Assess breathing and ventilation.
- Assess pulses with hemorrhage control if encountered.
- Assess neurologic status to include:
 - Level of consciousness via Glasgow Coma Scale (GCS)
 - Pupillary size and reaction
- Expose the patient completely and examine the entire body for injury.

- It is important to prevent the patient from getting hypothermia. Therefore, cover the patient with warm blankets as soon as possible. If possible, be sure to warm any intravenous (IV) solutions.

The secondary survey should be a complete head-to-toe physical exam, including passive and active range of motion of all joints.

Point-of-care ultrasound is incredibly useful in evaluating injured patients. It can identify free intra-abdominal, pericardial, and pleural fluid, which can be concerning for hemorrhage or cardiac injury after explosion and blunt injury. *Note: there is no current ultrasound capability on a DDG.*

Significant findings on primary and secondary surveys include: No external signs of hemorrhage. He is speaking clearly with a GCS of 15 (E4, M6, V5);¹¹ alert and oriented to person, place, and time. He has full recollection of the event without any memory gaps. No evidence of soot in the oropharynx; voice is normal. The patient's clothing was completely removed while maintaining c-spine stabilization. No midline, cervical, thoracic, or lumbar spine tenderness to palpation. Breath sounds clear throughout, with some pain and splinting with deep breathing on the right side of his chest. Strong but rapid palpable pulses distally in all four extremities. Abdomen is soft, non-tender, and non-distended. Pelvis is stable and non-tender to lateral compression. No obvious long bone deformities. On the anterior chest, a combination of erythema, edema, blisters, and charred skin consistent with 2nd and 3rd-degree burns is identified. The posterior torso has minimal blistering and erythema. On both upper extremities, he has circumferential erythema, edema, pink-white skin, and charred burns concerning for 2nd and 3rd-degree burns.

The patient's diagnosis is severe burn injury of the torso with circumferential upper extremity involvement concerning for second- and third-degree burns.

Initial Burn Treatment Principles include:^{8,11-17}

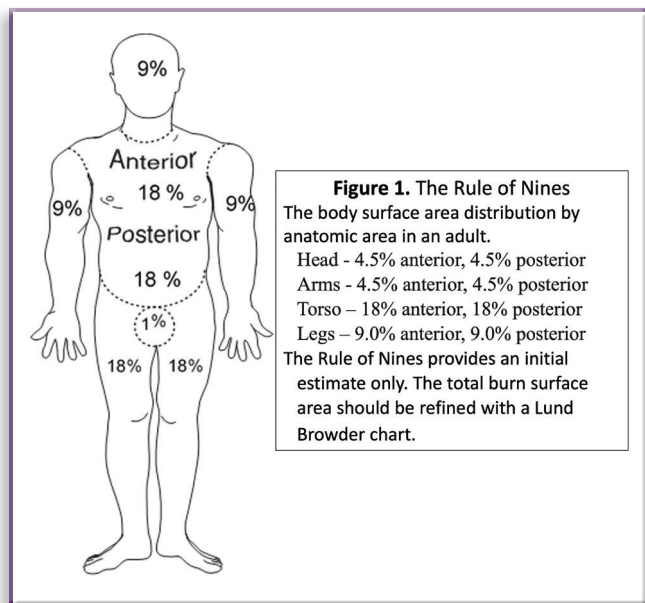
1. Following TCCC treatment guidelines and performing a complete primary and secondary trauma survey to identify any potential concomitant traumatic injuries.
2. Assessing the airway initially and with serial exams. Maintaining a high index of suspicion for the development of airway obstruction from either inhalation injury or airway edema. Smoke inhalation injury can occur with burns or explosions in closed spaces. Generalized total body swelling during resuscitation can cause airway edema and obstruction, particularly in patients with >40% total body surface area (TBSA) burns.
3. Keeping the patient eutermic (maintaining body temperature), and avoiding wet dressings to prevent hypothermia.
4. Determining the extent of the burn and beginning initial resuscitation. (The initial burn calculation can be estimated using the rule of nines [Figure 1]).
5. Arranging early telemedicine consultation. While both pictures and videos can provide the consultant with significant data, this may be challenging given the limited bandwidth in the deployed maritime environment. Depending on mission, location, and situation, email and telephone are typically available. The U.S. Army Institute of Surgical Research (USAISR) Burn Center can be reached at:
 - DSN 312-429-2876 (429-BURN)

- Commercial (210) 916-2876 or (210) 222-2876
 - Email to usarmy.jbsa.medcom-aisr.list.armyburncenter@health.mil
6. Evacuating the patient to definitive care.

Burn Severity Calculation¹⁴ considerations include the following:

- **Best:** After wounds are cleaned and debrided, recalculate TBSA using the Lund Browder chart available through the Burn Wound Management Under Prolonged Field Care CPG.¹⁴
- **Better:** Use the rule of nines to estimate TBSA for larger wounds (Figure 1). The patient's hand, including fingers, constitutes about 1% TBSA and can be used to estimate burn wound size for smaller wounds.

FIGURE 1 Rule of nines.



Adapted with permission from the USAISR Burn Center.

Other considerations: toxic inhalation, carbon monoxide poisoning, electric injury, and other traumatic injuries.

Based on the initial burn wound assessment, the patient has 18% for both arms with circumferential burns, 10% for the anterior chest, and 4% for the posterior chest, for a total TBSA of 32%.

Initial recommended interventions include the following:

- Continuous patient monitoring including HR, BP, pulse oximetry, and capnography.
- Obtaining IV access x2 with 16-gauge angiocatheters.
- The IV can be placed through burned skin if necessary.
- Consider longer catheters to prevent catheter dislodgement due to progressive peripheral edema from large-volume crystalloid resuscitation.
- If needed, consider alternate IV sites due to upper extremity burns such as ultrasound-guided peripheral IV access in the lower extremity, or intraosseous access. Note: no ultrasound on DDG.
- Secure the catheter with sutures or staples to prevent dislodgement during movement.
- Do not bolus crystalloid IV fluids unless hypotensive.
- Fluid resuscitation (all formulas given here are for adults only)^{11,13-15}

- All patients with a burn size >20% TBSA will typically need burn resuscitation. Some patients with 10%–19% TBSA will need resuscitation.
- **Best:** Calculate burn resuscitation needs using the rule of tens:
 - For adults weighing >40kg and <80kg, initial rate = 10×TBSA.
 - If >80kg, add 100mL/h for every 10kg >80kg.
 - Administer Lactated Ringer's (LR) at a calculated rate: in this patient's case, 32%×10=320mL/h. As the patient weighs 90kg, the total IV fluid rate should be 420mL/h.
 - Consider fresh frozen plasma (FFP) infusion or 5% albumin as resuscitation adjunct to minimize fluid creep and prevent edema in non-burned tissue 8–24 hours after the initial injury. If using a colloid (plasma or 5% albumin), decrease LR rate by half. That is, give half the rule of nines dose as LR, and half as colloid. Change (titrate) the rate hourly as explained below. Note: No FFP or 5% albumin on DDG.
 - Place indwelling urinary catheter for accurate urinary output (UOP).
 - Use the JTS Burn Care CPG flow sheet to document resuscitation and UOP.¹⁵
 - Decrease the rate of LR by 25% if UOP is greater than 50mL/h for 2 consecutive hours.
 - Increase the rate of LR by 25% if UOP is less than 30mL/h.
- **Better:** Alternative routes for fluid resuscitation include enteral via oral or nasogastric tube using pre-made or improvised electrolyte solutions.^{14,18,19} Over the counter electrolyte drinks (e.g., Gatorade) are not adequate for oral resuscitation and requires baking soda and salt to be added if it is going to be used. The World Health Organization (WHO) Oral Rehydration Solution is recommended by the Burn Wound Management in Prolonged Field Care CPG.¹⁴ If possible coached oral resuscitation is preferred over resuscitation via nasogastric tube (NGT). Do not resuscitate enterally with plain water, as it can cause hyponatremia.
 - Since awake, with a normal GCS, this patient's resuscitation can be supplemented with coached oral resuscitation using an appropriate oral resuscitation fluid.
 - **Minimum:** Rectal infusion of electrolyte solutions.
 - **Carefully review the Burn Management in PFC CPG before initiating enteral or rectal burn resuscitation.**
- Laboratory data will provide clinical information. However, none are lifesaving and should not delay the initial therapy of IV fluids. Consider the point-of-care laboratory evaluation (if available) to obtain the following:
 - CBC
 - Blood gas analysis to assess base deficit and lactate. Note: Not available on DDG
 - Blood glucose
 - Electrolyte assessment. Not available on DDG
- Supplemental oxygen by nasal cannula, face mask or non-rebreather as indicated in hypoxic patients to maintain oxygen saturation of <92%; if resources are limited, patients with no concerns for traumatic brain injury may consider maintaining oxygen saturation of 88% or higher.
- Pain medication, including oral medications if the airway remains stable. Consider IV narcotics such as fentanyl, hydromorphone, ketamine, and morphine; caution should

always be taken for concerns of hypotension, apnea, and allergic reactions.

Initial wound care includes the following:¹⁴

- Use a clean sheet or dry gauze (recommended). It is important not to disturb any blisters. To prevent hypothermia, avoid wet and or moist dressings. Refrain from applying cool compresses or dressings to the burn, as they can lead to hypothermia. However, a brief application of cold water as first aid immediately after injury is beneficial, especially for small burns.
- Cleanse the wounds and debride loose, dead skin if evacuation is anticipated to take longer than 24 hours. Washing the skin with antibacterial soap (preferably chlorhexidine gluconate) in clean water, and dressing wounds with any available dry dressings will decrease burn wound infection risk.
 - Cleaning and debriding burn wounds is a resource-intensive procedure and should only be attempted provided appropriate resources are available including personnel and dressing supplies. Pain control is required to permit dressing care.
- Silver-impregnated nylon dressings are now available on cruisers (CG) and DDG. Once placed, they are covered with sterile gauze and moistened with sterile water. This type of burn dressing can be left in place for up to 7 days which is advantageous in the deployed maritime environment characterized by limited supplies. *This may be best used just prior to evacuation.*

Time +90 Minutes

Having established IV access, with LR being administered at 420mL/h, the patient's vital signs are as follows: HR, 120bpm; BP, 87/55mmHg; RR, 25 beats/min; SpO₂, 92% on room air; temperature, 35.5°C.

UOP is 15mL (dark in color). The patient appears alert and oriented ×4, answering questions appropriately. White blood count is 21,000; hemoglobin, 15; hematocrit, 45; and platelet count, 485,000.

Wounds are dressed with dry gauze initially as described above. Two mg of morphine is administered with 30mg of ketamine. Pulses are present at bilateral wrists.

Recommended interventions include the following:

- Elevating extremities to reduce edema.
- Because the UOP is too low, increasing the IV fluid rate by 25% (0.25×420mL/h); *the new LR rate is 525mL/h.*
- Arranging a telemedicine consultation with the USAISR Burn Center, if possible.
- Reassessing the airway and work of breathing.
- Administering tetanus vaccine, if needed.
- Preventing further hypothermia.
- Checking blood sugar.
- Continuing to trend the UOP, lactate, and base deficit for endpoints of resuscitation. *Note: Only UOP is available on DDG.*

Additional medications should be given for the following indications:

- Pain control
 - Acetaminophen at a maximum dose of 1g every 6 hours.
 - Avoid non-steroidal anti-inflammatory drugs (NSAIDs) due to side effects (renal impairment, gastritis).

- Morphine 2–4 mg IV every 3–4 hours as needed for pain control.
- If pain persists and patient is able to tolerate oral medication, give the following instead of acetaminophen:
 - Acetaminophen/oxycodone (Percocet; 5mg): 1–2 tabs by mouth every 4–6 hours as needed. *Note: Only acetaminophen/codeine available on DDG.*
 - Acetaminophen/codeine: 1–2 tabs by mouth every 4–6 hours, as needed.
 - Gabapentin 300mg by mouth every 8 hours.²⁰ *Note: not available on DDG.*
- Venous thromboembolism (VTE) prophylaxis, if no evidence of solid organ or traumatic brain injury and in conjunction with a burn, trauma, or critical care expert. Providing a patient with potential traumatic brain injury or solid organ injury VTE prophylaxis with heparin or enoxaparin may be catastrophic. Given the patient's normal GCS, severe traumatic brain injury is unlikely but possible given the blast mechanism of injury. Solid organ injury is also possible given the mechanism of injury.
 - *Better:* Heparin 5000U subcutaneous 3 times/day. *Note: Heparin is not available on DDG. Heparin is preferred in patients with renal insufficiency.*
 - *Best:* Enoxaparin (Lovenox) 30mg subcutaneous daily. *Note: Only 10 doses of 30mg injection are available on DDG. Use with caution in patients with concern for renal impairment and following telemedicine consultation.*
- Nausea/vomiting
 - Consider ondansetron (Zofran) in the following dosages:
 - 1–2 tabs sublingual every 4–6 hours, as needed.
 - 4mg IV, may repeat one time in 2 hours if nausea/vomiting returns.
 - ◆ Check QT on a cardiac monitor or electrocardiogram before giving, if possible. *Note: No electrocardiogram or three-lead cardiac monitoring is available on DDG.*
- Gastrointestinal prophylaxis medications are indicated in this patient because of the extent of burns.
 - *Minimum:* Ranitidine or famotidine by mouth.
 - *Better:* Omeprazole by mouth.
 - *Best:* Pantoprazole IV or by mouth or H2 blockers IV or by mouth *Note: Not available on DDG.*

Daily nursing and progress notes should be documented.²¹ This should include full documentation of assessment, along with nursing progress notes for significant events, as needed. See the nursing care plan in prolonged field care for full details.²¹

Routine nursing care²¹ includes the following:

- Maintaining the head of bed elevated >30°.
- Depending on the patient's ability to move, consider repositioning every 2 hours or having the patient ambulate.
- Performing frequent neurovascular assessment. Bilateral upper extremities are at significant risk for compartment syndrome given the patient's circumferential burns.
- Documenting strict intake and output (I&Os) to track the patient's fluid status.
- Continued monitoring of the airway, pulse, UOP, and pain control.

Time +12 Hours

The patient's vital signs are as follows: HR, 110bpm; BP, 98/66mmHg; RR, 25 breaths/min; O₂ saturations 96% on room air; temperature, 36.5°C.

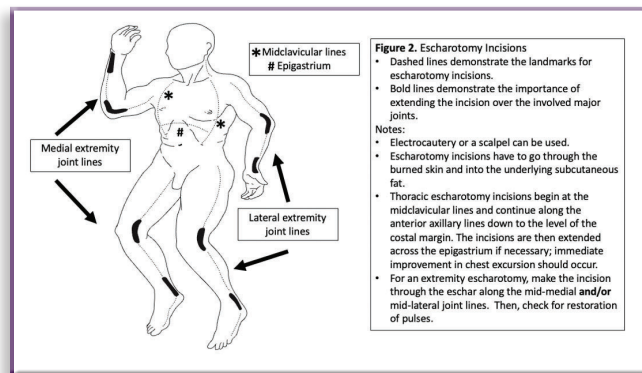
The IV fluid rate is LR at 525mL/h, with total estimated IV fluids at 6,142.5mL (~6.1L). Cumulative total UOP is 426mL (dark), approximately 55mL/h.

A single episode of vomiting controlled with ondansetron. Now, with increasing pain in upper extremities, the patient is not responding to previous medications. Radial pulses are absent in right upper extremity and diminished in the left upper extremity.

Recommended interventions include the following:

- Possible escharotomy (Figure 2) of the upper extremities to resolve limb ischemia (eschar syndrome).¹⁵ *Note: this is different than a compartment syndrome requiring a fasciotomy.*
- Indications: Restore perfusion to extremity due to eschar syndrome and improve ventilation if circumferential burns of the chest are limiting thoracic excursion.
 - Obtain surgical consultation if able.
 - Expect an increased need for analgesia and sedation.
 - Anticipate bleeding.
 - Ideally use electrocautery for escharotomy, if not available use a scalpel.
 - Consider changing the dressing to silver-impregnated nylon dressings.
 - The patient should not be dressed in silver sulfadiazine, bacitracin, or gentamicin creams until evaluated by a surgeon. Covering the patient with a clean bedding sheet or applying Xeroform with loose-fitting Kerlix may be more appropriate in this setting. Ensure dressing is not placed circumferentially around extremities.

FIGURE 2 Escharotomy incisions.



Adapted with permission from Driscoll IR, Mann-Salinas EA, Boyer NL, et al. Burn Care (CPG ID:12) Joint Trauma System Clinical Practice Guideline. Published May 11, 2016. Accessed October 31, 2023. <https://learning-media.allogy.com/api/v1/pdf/9e2f0f44-e42d-4b0f-ab06-6665e31badfb/contents>

Recommended nursing care includes:

- Maintaining the head of the bed elevated >30°.
- Continuing to elevate burned extremities to reduce edema even after escharotomy.
- Checking BP and pulses every hour or more to ensure adequate resuscitation and return of circulation to extremities.
- Checking IV sites.
- Documenting strict intake and I&Os to track the patient's fluid status.
- Ensuring the patient is repositioned or ambulates every 2 hours.

- Encouraging coughing and deep breathing hourly and reassess thoracic burns.
- Assisting the patient with oral/dental care.

Time +24 Hours

The patient has been maintained on IV fluid resuscitation with good urine output. At 14 hours post-burn, IV fluids decreased to 400mL. However, over the last 90 minutes, HR and RR have increased, UOP and BP have started to decrease, and the patient is complaining of chest wall pain on the right side.

The patient's vital signs are as follows: HR, 119; BP, 84/60mmHg; RR, 25–30 breaths/min; SpO₂ 90% on room air; temperature, 37.8°C.

The IV fluid rate is LR at 400mL/h, with a cumulative total IV fluid input of 11,192mL (~11.2L). Cumulative total UOP is 1400mL over 24 hours (10mL/h over the last 3 hours despite an increase in the IV fluid rate).

Providers were unable to run more laboratory data because of limited capabilities on DDG.

Extremity pain is well controlled with scheduled acetaminophen and as-needed IV morphine. New bruising is noted on the right lateral chest with decreased breath sounds; right-sided splinting with pain somewhat worse with deep breaths.

Assessment includes the following:

- Differential diagnosis: Burn shock, progressive pulmonary failure secondary to inhalation injury, delayed presentation of thoracic trauma with hemothorax, infection, delayed presentation of solid organ injury with bleeding.
- Repeating primary and secondary surveys, including chest and abdominal ultrasound:
 - Ultrasound of the right chest demonstrates large fluid density. No significant intra-abdominal free fluid identified on abdominal ultrasound. *Note: Ultrasound is not available on DDG.*
 - Palpable crepitus of lateral rib tracking to the posterior chest.

Recommended interventions include the following:

- Arranging telemedicine consultation.
- Treating the likely diagnosis: traumatic hemothorax.
 - Placing a chest tube (1400mL of blood returned).
 - Activating DDG walking blood bank and transfusing 1–2 units of fresh low-titer O– whole blood and reassessing BP (goal is MAP of 65mmHg or greater). *Note: Walking blood bank is not a routine capability on the majority of Role 1–capable warships including DDG. Intermittently, some ships may have the training and equipment.*
 - Maintaining IV fluids.
 - Monitoring UOP and peripheral pulses.
 - Checking pH and electrolytes if possible.
 - Administering 1g of calcium gluconate in conjunction with whole blood transfusion. *Note: Not available on DDG.*
 - Tranexamic acid (TXA) is not indicated because the patient is more than 3 hours from the initial injury.
- Decreasing IV fluid rate to LR at 320mL/h.
 - Goal UOP: 45mL/h (0.5mL/kg/h).
- Providing oxygen to maintain an SpO₂ of 92% or greater.

- If applicable, holding chemical VTE prophylaxis and not restarting it.
- Checking blood glucose.

Recommended nursing care includes the following:

- Maintaining the head of the bed elevated $>30^\circ$.
- Maintaining elevation of burned upper extremities and radial pulse checks every hour.
- Checking BP every hour or more frequently.
- Cleansing burns with chlorhexidine, if tolerated, and re-dressing with silver-impregnated nylon dressings if not already done.
- Flushing any unused IV line every 12 hours and checking the IV site (peripheral edema can inadvertently dislodge the IV catheter).
- Performing urinary catheter care.
- Documenting strict I&Os to track the patient's fluid status.
- Ensuring the patient is repositioned or ambulates every 2 hours.
- Encouraging coughing and deep breathing hourly when awake.
- Assisting the patient with oral/dental care.

Time +48 Hours

The patient had been administered 1 unit of warmed fresh whole blood 18 hours ago with a good response. The IV fluid rate was decreased to 300mL/h at Time +30 hours post-burn and then 200mL/h at +38 hours post-burn. Over the preceding 12 hours, HR, UOP, and BP improved; however, RR and respiratory distress increased. Eight hours previous, the patient was started on supplemental oxygen by non-rebreather or face mask for an SpO₂ of 88%.

The patient's vital signs are as follows: HR, 97bpm; BP 112/78mmHg; RR, 35 breaths/min; SpO₂, 94% on 10–15L non-rebreather or face mask; temperature, 36.5°C.

The IV fluid rate is LR at 200mL/h, with a cumulative total IV fluid input of 17,992mL (~18 L) or 6,800mL over 24 hours. UOP is 100mL/h over the last 3 hours, yellow in color. Cumulative total UOP is 2,800mL (1,400mL over 24 hours).

Providers were unable to run more laboratory data because of limited capabilities on DDG.

The patient's extremity pain is well controlled with scheduled acetaminophen and as-needed IV morphine. Bilateral upper extremity pulses are intact. Chest tube output is <250mL of serosanguinous fluid. Crackles are heard in the posterior chest bilaterally.

Patient Assessment of Clinical Information:

- Pulmonary edema from resuscitation versus lung injury from thoracic trauma.
- Stable upper extremity burns with escharotomy.

Recommended interventions include the following:

- Arranging telemedicine consultation.
- Decreasing IV fluid rate by 25%. *New IV fluid rate: 150mL/h.*
- Titrating oxygen to $>92\%$ SpO₂; consider a simple face mask if requiring $>8L$ of oxygen.
- Encouraging deep breathing and positional changes as tolerated.

- Continuing daily burn wound care per protocol versus leaving silver-impregnated dressings on.
- Assessing for any evidence of infection. No prophylactic antibiotics are indicated for burns or thoracic trauma.
- Assessing for evidence of coagulopathy.
- Continuing pain management.
- Checking blood sugar.

In the austere setting, burn wound care similar to the initial debridement above unless silver-impregnated dressing were used. The risk of using silver-impregnated nylon dressings after initial debridement by those inexperienced in burn debridement and wound care puts the patient at risk for burn wound sepsis. Given that very few active-duty naval caregivers routinely manage burn wounds (if at all) as resources and the operational situation allow, daily wound care as described above should be performed to mitigate the risk of burn wound sepsis. Silver-impregnated nylon dressings can be placed when ready for MEDEVAC.

Recommended nursing care includes the following:

- Maintaining the head of bed elevated $>30^\circ$.
- Checking BP and pulse every hour or more frequently as needed.
- Checking chest tube dressing and connections to an evacuation device.
- Flushing any unused IV line every 12 hours.
- Performing urinary catheter care.
- Documenting strict I&Os to track the patient's fluid status.
- Ensuring the patient is repositioned or ambulates every 2 hours.
- Encouraging coughing and deep breathing hourly when awake.
- Assisting the patient with oral/dental care.
- Maintaining euthermia.

Time +72 hours

UOP is stable. At 60 hours post-burn, IV fluids were turned down to 100mL/h. Work of breathing and oxygenation improved. The team is notified that MEDEVAC is available in 12 hours.

The patient's vital signs are as follows: HR, 92bpm; BP, 100/68mmHg; RR, 22–28 breaths/min; SpO₂ 94% on 4L via nasal cannula; temperature, 37.5°C.

The IV fluid rate is LR at 100mL/h, for a cumulative total IV fluid input of 20,992mL (~21L) or 3,000mL over 24 hours. Cumulative total UOP is 4000mL (50mL/h over the last 12 hours, yellow).

Chest tube output is <100mL. No bleeding is seen through dressings from escharotomy sites.

Unable to obtain additional laboratory data.

The patient's pain is well controlled with scheduled acetaminophen and as-needed IV morphine and intermittent ketamine with position changes.

Recommended interventions include the following:

- Arrange telemedicine consultation. If diuretics are given for pulmonary edema, it should only be done in conjunction with a telemedicine burn unit consultation.

- Continuing current care.
- Avoiding over resuscitation (goal UOP: 45mL/h (0.5mL/kg/h).
- Titrating oxygen to >92% SpO₂, continuing to encourage deep breathing position changes.
- Checking blood sugar.

Recommended nursing care:

- Changing IV dressings if needed. *If the IVs were not placed under sterile conditions, they should be definitively replaced now (or sooner) because of the risk of superficial thrombophlebitis.*
- Continuing daily wound care, debridement (if necessary), and dressing changes.
- Maintaining the head of the bed elevated >30°.
- Checking BP readings and pulses every hour or more frequently if needed.
- Flushing any unused IV line every 12 hours and checking the IV sites.
- Performing urinary catheter care.
- Documenting strict I&Os to track the patient's fluid status.
- Ensuring the patient is repositioned or ambulates every 2 hours.
- Encouraging coughing and deep breathing hourly when awake.
- Assisting the patient with oral/dental care.

Recommendations to prepare the patient for MEDEVAC include the following:

- Making copies of all documentation and labs to send with the En Route Care (ERC) team.
- Providing the patient with eye and ear protection.
- Dressing all wounds with silver-impregnated nylon.
- Reinforcing all tubes and lines with sutures or staples. Use cotton ties around the head for NGT or endotracheal tubes (if patient has them).
- Ensuring all fluids/medication bags are labeled.
- Labeling all lines with tape approximately 6 inches from the IV site with medication or type of fluid infusing to the site.
- Empty urinary catheter bag.
- Considering administering 4mg IV ondansetron before flight.
- Checking blood sugar before the flight.
- Re-dosing pain medication before the flight, anticipating that pain will increase due to the stressors of flight.
- Reviewing the Medication Administration Record with the ERC team.

Discussion

This maritime PCC scenario describes the management of a single patient with a 32% TBSA burn after an isolated mishap on a DDG during DMOs. As there is currently no standardized PCC training curriculum for Role 1 maritime caregivers, this scenario was created as a training tool to demonstrate how JTS CPG-based burn care and resuscitation would be performed during DMOs. This DDG-based clinical burn scenario identified several education, training, and supply gaps. What follows is a review of naval burn epidemiology followed by analysis of these gaps that, if improved, may increase the survivability of burn injury in austere maritime environments.

Burn Injury During Routine Naval Operations

Common mechanisms of a major burn during routine naval operations include propulsion casualties from engines, boilers,

or nuclear reactors resulting in steam or scald injuries and boiler room explosions. Accidental collisions with other ships or mishaps with the storage or transport of explosive ordnance can also result in major burn injuries. During periods of relative peace, a naval warship is most at risk of major fire while in port during scheduled maintenance periods as evidenced by the loss of the USS Bonhomme Richard (LHD 6) in 2020.^{2,6,8,22} The true incidence of minor burn injuries is unknown, but anecdotally, maritime caregivers manage them frequently. One study of 196 extended submarine patrols from 1997 to 1998 identified 915 medical events and injuries, of which 5.6% were categorized as burns. Most were relatively minor and occurred in food preparation areas, engine rooms, trash disposal areas, and other mechanical areas; 3.2% were categorized as electrical injuries, typically occurring in engine rooms and other mechanical areas.⁷

While infrequent, major burn injuries during routine operations are associated with high mortality when they occur. An analysis of all major mishaps on U.S. Navy surface warships between 1970 and 2020 found an overall decrease in the incidence of thermal injury over each decade of the 50-year study period. When comparing the first decade of the study (1970–1979) to the last (2010–2019) thermal injury rates decreased, specifically the incidence of fire-/burn-/smoke- (14.8 to 0.126 per 100,000 person-years), electric- (0.451 to 0.126 per 100,000 person-years) and explosion-related injuries (1.25 to 0 per 100,000 person-years). Over 50 years, there were 103 fire, burn, or smoke inhalation injury events on surface ships and submarines resulting in 923 casualties, of whom 13% died. There were 16 explosion events with 106 casualties, 27 chemical exposure/inhalation injury events with 104 casualties, and 32 electric injury casualties with mortality rates of 60.4%, 27.9%, and 90.6%, respectively.⁶ There was a more than two-fold higher mortality rate (19% vs. 8.3%, $P<.5$) from all chemical-, fire-, and burn-related injuries on Role 1 (no surgical capability) surface ships (e.g., DDG) and submarines when compared to Role 2 (with surgical capability) ships.⁶ The reason for this mortality discrepancy is unclear, but the severity of thermal injury, available shipboard supplies and medical capability, and time/distance from a higher level of care may all be factors.

Burn Injury During Naval Warfare

During naval warfare, the risk of burn injury on surface warships and submarines is significant. Most of what is known about burn injury during war at sea relevant to modern combat operations comes from the Allied experiences during World War II and the 10-week long war between the United Kingdom and Argentina over the Falklands in 1982. Maritime caregivers must be prepared to manage multiple patients with severe burn-related injuries for both short and long periods, including burn shock resuscitation, inhalation injury, and concomitant traumatic injuries. While allied navies are performing DMOs now to develop tactics and techniques for the potential of future large-scale multi-domain combat operations, a missile attack on U.S. and allied naval vessels is a current threat. At the time of this writing, open-source news outlets have reported multiple drone missile targeting of allied warships and successful attacks of commercial vessels in the Red Sea region.²³ Burn injury was the second most common type of injury pattern (22%–26% of injuries) after penetrating injuries in survivors of air and submarine attacks on U.S. Navy vessels in World War II. The 1987 Exocet missile attack on

the USS Stark (FFG-31) and the 2000 improvised explosive device attack on the USS Cole (DDG-687) resulted in significant damage to each ship, killing nearly 10% of the combined crews. Of the 58 injured survivors from both ships, burn or inhalation injuries occurred in 22.4%. Modern openly available casualty estimates of an attack and loss of an aircraft carrier crewed by 5,500 personnel suggest that nearly 50% will be killed immediately from blunt force trauma, burns, inhalation injury, or drowning. Of the survivors, 1,030 will have major injuries including an estimated 309 survivors with some type of burn or inhalation injury. Therefore, to prepare for both current DMOs, and a potential future large-scale war at sea, all maritime caregivers need both training and clinical experience in the acute and prolonged management of severely burned casualties.

Maritime Burn Care Training and Supply Gaps

The burn injury clinical experience and training gap for naval caregivers has been well documented.^{8,22} Individual units and medical departments are taking steps to close this gap, but widespread curricular and doctrinal changes are needed. Box 1 lists common readily available resources to maritime caregivers, used in this scenario, to help prepare them to manage burn-injured and critically ill casualties in austere environments until formal training beyond TCCC is available to Role 1 maritime caregivers.

BOX 1 Readily Available Austere Burn Care Resources

Joint Trauma System Clinical Practice Guidelines available at: https://jts.health.mil/index.cfm/PL_CPGs/cpgs

- Tactical Combat Casualty Care (TCCC) Guidelines
- Prolonged Casualty Care Guidelines (PCC)
- Burn Wound Management in Prolonged Field Care
- Burn Care Clinical Practice Guideline
- Inhalation Injury and Toxic Industrial Chemical Exposure
- Airway Management in Prolonged Field Care
- Analgesia and Sedation Management in Prolonged Field care
- Documentation In Prolonged Field Care
- Telemedicine Guidance in the Deployed Setting

Burn Related Journal Articles and Book Chapters

- Burn, Inhalation, and Electrical Injuries¹
- War at Sea: Burn Care Challenges—Past, Present, and Future.⁸
- Guidelines for Burn Care Under Austere Conditions: Surgical and Nonsurgical Wound Management¹⁷
- Tactical Combat Casualty Care Maritime Scenario: Shipboard Missile Strike. Burn, Inhalation, and Electrical Injuries.¹⁹

Specific procedures required to manage burn injuries during DMOs are included in Box 2. Most of these are not part of routine pre-deployment training curricula for Role 1 maritime caregivers, particularly burn wound care, escharotomy, placing chest tubes, and intubation. However, refresher training in the indications and performance of these procedures should be part of pre-deployment training activities. Severely burned patients often require intubation because of airway edema related to inhalation injury or from ongoing resuscitation (e.g., >40% TBSA). For example, during the 26-nation Rim of the Pacific naval exercise in 2022, a boiler room fire occurred on a coalition nation corvette injuring two Sailors with 86% and 70% TBSA cutaneous burns and concomitant inhalation injury. One required intubation before medical evacuation and the other immediately upon arrival to the nearest medical treatment facility.⁸ However, endotracheal tubes and ventilators are not available on cruisers, destroyers, or submarines. Therefore, cricothyroidotomy with bag-valve mask (BVM) and a positive end-expiratory pressure (PEEP) valve are the

only options for IDCs on these platforms. Managing one patient requiring airway and respiratory support with a BVM is time- and labor-intensive for one patient, let alone multiple patients. Depending on the operational situation and whether or not the ship is under threat, maritime caregivers can utilize non-medical crew to assist with this critical task. Other equipment and medication shortfalls identified that would help in managing this patient include ultrasound, three-lead cardiac monitoring, nasogastric tubes, subcutaneous heparin, and the supplies, training, and protocols required to establish a walking blood bank. While ten 30mg doses of enoxaparin are available on destroyers, heparin is not. Subcutaneous heparin may be a more versatile drug for chemical VTE prophylaxis in austere environments, in which renal function (beyond UOP) cannot be monitored.

BOX 2 Potential Procedures Required to Manage Burn Injury

- Endotracheal Intubation
- Cricothyroidotomy
- Burn wound care (including cleaning/debridement and burn dressings)
- Escharotomy
- Tube thoracostomy
- Nasogastric tube placement
- Walking blood bank

Space limitations, training costs, lack of a quality assurance mechanism combined with the lack of IDC physician supervisors trained and adept in using ultrasound are reasons given that there is no ultrasound capability on IDC led Role 1 medical departments. Given current technology, ultrasound devices with screens no bigger than the palm of one's hand are ubiquitous in civilian hospitals and could be an incredibly helpful diagnostic tool for austere caregivers. With the appropriate training, ultrasound is useful in assisting with IV access and evaluating various traumatic injuries and disease non-battle injury. Given that Role 1 medical departments are starting to prepare for DMOs, if PCC will be required during a future war at sea, current equipment and supplies should be looked at through the lens of this potential future reality, not the typical naval deployments of the last 20 years. For severely injured or multiple burn casualties, wound care supplies and crystalloid availability may significantly impact the care Role 1 maritime caregivers can provide. On cruisers, destroyers (this scenario), and submarines, available space is at a premium and there is limited space to store crystalloid and wound care supplies. There are several documented incidents of medical departments on U.S. warships managing multiple burned or other injured casualties requiring additional crystalloid and other supplies to be obtained from elsewhere. These incidents include the 1967 ordnance-related major fire on the USS Forrestal, the 1988 USS Stark missile attack, and the 1989 incident when the USS Belleau Wood managed multiple casualties (including severe burns) following a CH-53 helicopter crash.^{8,22} In the present scenario, the patient required approximately 21L of LR over 72 hours for JTS CPG recommended burn resuscitation, or nearly 60% of the available 36L of LR typically stocked on a destroyer. Approximately 60L of normal saline is also available on a destroyer, but large resuscitation volumes of saline have been associated with hyperchloremic metabolic acidosis, renal vasoconstriction, and acute kidney injury and may be associated with increased mortality in certain types of critically ill patients. Normal saline would be the preferred crystalloid in patients with traumatic brain injury. Given that LR is the preferred crystalloid in both sepsis and burn resuscitation, increasing the ratio of available LR relative

to normal saline on small naval warships and submarines may be warranted. But if LR runs out, normal saline is acceptable.

During World War II, U.S. and allied shipboard caregivers routinely managed and resuscitated severely burned casualties; freeze-dried plasma was ubiquitous and critical to these efforts, particularly in those with burn shock.^{24–26} Colloids, such as plasma, used in burn shock resuscitation have been associated with a decrease in many resuscitation-related complications, such as chest and extremity eschar syndromes and abdominal compartment syndromes.^{27,28} While albumin may also be beneficial, many advocate for freeze-dried plasma over albumin for burn shock resuscitation in austere military and shipboard environments.^{25,26} It can be stored for up to 2 years at room temperature either pre-positioned or on ships; it is rapidly reconstituted with sterile water; it has an excellent long-term safety profile (in the modern era) in multiple countries; and it is likely beneficial in treating the epitheliopathy of burn shock. At the time of this writing, freeze-dried plasma is only available to U.S. Special Forces through an emergency release.²⁶

Both appropriate resuscitation and burn wound care are integral to successfully managing patients with burn injuries. Burn resuscitation has been discussed throughout this scenario, but burn wound care warrants further discussion. While those inexperienced in burn wound care may approach it for the first time with trepidation, it is a skill like any other, not a complicated academic subject. In our opinion and experience, people fail because of lack of aggressiveness, not repeating a thorough debridement daily (see above), and not applying an effective antimicrobial (or enough of one). In modern U.S. burn centers, early excision is standard practice,^{17,29} so the importance of wound care may be deemphasized. But in PCC, delayed or inadequate wound care would likely increase the risk of invasive wound infection. Therefore, Role 1 maritime caregivers, such as IDCs, should pursue opportunities through available regional military–civilian partnerships or at the USAISR Burn Center whenever possible to obtain hands on training and clinical experience in how to perform thorough burn wound care. Furthermore, those supervising them should develop the doctrine to facilitate these experiences, given that the vast majority of maritime caregivers leading Role 1 medical departments are IDCs.^{8,22}

Conclusion

While infrequent, the risk of severe burn injury is ever-present in the deployed maritime environment during routine operations. The preceding scenario demonstrates the management of a hypothetical severely burned casualty in the austere deployed maritime environment following JTS CPGs and can be used to guide pre-deployment training exercises. Specific education, training, and supply gaps specific to smaller Role 1–capable surface vessels and submarines are also described. Closing some of these gaps may help deployed maritime caregivers optimally manage severely burned casualties and improve survivability during a future war at sea.

Author Contributions

MDT and MST conceived the study concept. DA, MDT, and MST performed literature review and developed the scenario. DA and MDT drafted the original manuscript. DA, MST, VHD, JC, JJB, JDA, JMG, LCC, and MDT participated in critical revisions.

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