Maritime Applications of Prolonged Casualty Care

Drowning and Hypothermia on an Amphibious Warship

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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 significant time and distance away 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 hypothetical drowning and hypothermia patient scenarios to present an innovative approach to teaching complex operational medicine concepts, including the management of hypothermia and acute respiratory distress syndrome, as well as Prolonged Casualty Care (PCC) to austere Role 1 maritime caregivers using the Joint Trauma System PCC Clinical Practice Guidelines (CPGs) and other standard references. The format includes basic epidemiology of drowning and hypothermia 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 CPGs, appropriate guidelines, and available shipboard equipment. Through this process, opportunities to improve both training and clinical skills sustainment, as well as standard shipboard medical supplies, are identified.

KEYWORDS: *prolonged casualty care; tactical combat casualty care; military; maritime; critical care; drowning; hypothermia; acute respiratory distress syndrome*

Introduction

Naval warships are floating industrial environments, and embarked Sailors and Marines face occupational hazards during both routine operations and naval warfare; none more dangerous than drowning. The World Health Organization (WHO) defines drowning as "the process of experiencing respiratory impairment from submersion/immersion in liquid." Aspiration results and can cause significant airway and lung injury, hypoxia, and acute respiratory distress syndrome (ARDS).[1] The terms "near drowning" and "secondary drowning" are frequently used to describe situations where a person is immersed in water or aspirates a small volume of water. But these are not accepted terms, and death due to drowning, drowning with morbidity, or drowning without morbidity are the preferred terms.[2] Previous studies have found as little as 1–2mL/kg of fluid aspirate can cause hypoxemia and increased morbidity, while most severe drownings involve aspirations of 3–4mL/kg and are associated with much higher morbidity and mortality.[3] Drowning is a devastating cause of death around the world, particularly in the developing countries and in youth, taking approximately 372,000 lives globally each year. Drowning prevention has become the main focus of many maritime safety organizations globally, as up to 90% of drownings are determined to be preventable[4]; it also has prompted the WHO to create a World Drowning Prevention Day (July 25th) to bring more attention to the devastation wrought by drowning.[5,6]

In military personnel, drowning can occur under a variety of situations, including but not limited to training incidents in open water or pools, aviation mishaps over water, vehicle rollovers on combat patrols near bodies of water, ship collisions causing hull breach, man-overboard events during maritime mishaps and recreational accidents while attempting to enjoy a sunny day at a nearby source of water.[2,7–14] To prepare military caregivers to manage the care of drowned patients while forward deployed or in training environments, the Joint Trauma System (JTS) has recently updated its drowning clinical practice guideline (CPG).[15]

A frequent consequence of water immersion/submersion is hypothermia, which can be deadly when associated with concomitant traumatic injury, particularly in austere and operational military environments. Hypothermia can occur in

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warm or cold temperatures but is accelerated when a person is submerged in water and accelerates further the colder the water becomes.[16,17] Even with warmer waters globally, including temperatures exceeding normothermic body temperatures, exposure to air while wet can instigate hypothermia.[18] Hypothermia has long been a recognized risk for increased mortality in trauma patients and combat casualties and was the topic of one of the first JTS CPGs, published in 2006.[19] Hypothermia, along with acidosis and coagulopathy, is part of the so called *lethal triad* to treat and avoid in patients with traumatic injury. Recently, hypocalcemia has also been recognized to be associated with morbidity and mortality in injured patients; added to the lethal triad, these four conditions are often referred to as the "diamond of death," and its treatment has become integrated into Tactical Combat Casualty Care (TCCC) guidelines.[20–23]

Prevention is a mainstay of both drowning and hypothermia, particularly in high-risk military operational environments. For example, in the 2020 Amphibious Assault Vehicle open ocean training mishap, failure to apply appropriate operational safety protocols was found to be a contributing factor leading to 9 deaths and 1 severe pulmonary injury from drowning in the crew of 15 Marines and Sailors.[12] No matter the operational or training environment, it is vital for all active-duty personnel to be well trained in prevention and treatment of drowning and hypothermia and well versed in the operational safety protocols and operation risk management procedures specific to their military platforms and occupations.

Epidemiology

The incidence of drowning worldwide continues to be a significant burden of disease, particularly in the developing world, where 91% of unintentional drowning events occur. Drowning is a top seven cause of death in all age groups under the age of 24 years, a notable figure, as 44% of the entire military population is under that age.[5,24] Alcohol consumption is a frequently related cause of drowning, particularly in young males, which is applicable to the military population but less so in the operational environment.[7]

The incidence of drowning during high-risk training events is unknown, but some epidemiologic data is available describing the risk to embarked personnel on naval warships. According to data obtained from the Naval Safety Command, between 1970 and 2020 there were 216 drowning incidents involving 435 Sailors, 59.7% of which were fatal.[25] While the incidence of "man overboard" events on U.S. Naval vessels has been steadily decreasing since 1970, they are associated with a significant mortality rate. Between 1970 and 2020 there were 220 reported man-overboard incidents involving 352 personnel, with an associated mortality of 71.9%.[10] An analysis of maritime naval mass casualty incidents (MCIs) between 1980 and 2020 found a total of nine noncombatant MCIs with a total of 87 deaths, 17 of which were due to drowning.[10] A final study assessed U.S. military deaths between 2013 and 2017, citing a total of 359 drownings among active-duty personnel, but this figure is a combination of both operational and recreational causes.[7]

Hypothermia alone is a significantly less frequent cause of death but has been associated with significant mortality. An epidemiologic analysis of international civilian hospital admissions from 1979 through 1985 found that men are three to four times more likely to experience hypothermia and have a 30% higher associated mortality.[26] Extremes of age are a major concern, as both youth and older people have less ability to thermoregulate, but these populations are generally not a part of the military population and are less relevant to this manuscript. Hypothermia with trauma is associated with double the risk of mortality compared with normothermic trauma patients.[5,19,23,24] Patient temperature <36°C is an independent risk factor for mortality in trauma patients and is also correlated to an increase in blood product consumption.[27] In a civilian trauma population, 80% of patients who did not survive their traumatic injury were found to have temperatures <34°C, underlying the fact that most severe traumas are or rapidly become hypothermic, and their risk for death increases significantly.[28]

Scenario

Setting

A U.S. Navy Landing Platform Dock (LPD) underway in the Bering Strait is conducting freedom of navigation operations. The crew includes 386 ship's company and 800 embarked Marines—1,186 total personnel. Medical capabilities include 20 stacked ward beds and 6 intensive care unit (ICU) beds, each with cardiac monitoring and ventilator capability (Zoll EMV+ ventilator). Available laboratory capability includes rapid complete blood count (CBC), using QBC STAR (Drucker Diagnostics, Port Maltilda, PA), an I-STAT (Abbot Point of Care Inc., Abbott Laboratories, Chicago, IL) (capable of providing chemistry, electrolytes and lactate), dipstick urinalysis (UA), finger-stick glucose with glucometer, and fecal occult blood testing. The LPD has basic X-ray capability and an ultrasound machine, but none of the caregivers have received formal ultrasound training.[29] The available medical staff consists of two General Medical Officers (GMOs), the ship's Senior Medical Officer (SMO) and a Marine Battalion GMO, one Independent Duty Corpsman, and 32 Corpsmen from a combination of ship's company and embarked U.S. Marine Corps (USMC) units. Neither the SMO nor the GMO are residency trained and are relatively new to the operational environment. The SMO recently completed a surgical internship and the GMO, a transitional internship 3 months before the current period. Due to the ship's location and sea state, it is 48–72 hours before medical evacuation (MEDEVAC) is likely to be possible.

The ship encounters sea states of 6–8 feet, and two Marines performing chain inspections on the flight deck fall overboard after the ship sways dramatically from a large wave. Patient 1 falls directly into the water and was not witnessed to strike any objects. Patient 2 slams into the tail rotor of a UH-1Y before falling overboard. Neither were noted to be wearing life preservers. The episode is witnessed, and man-overboard procedures are activated immediately. Water temperatures are 3°C. Due to the sea state, the deployment of the rigid hull inflatable boat (RHIB) and recovery efforts are delayed. The injured casualties are spotted a short distance from the ship, and Patient 1 is seen holding onto Patient 2, who appears unconscious. Recovery by RHIB takes approximately 50 minutes. Both patients are evaluated in the well deck before going to the ship's Main Medical department.

Patients

Patient 1 is a 20-year-old male, awake and oriented to name, place, and date. No past medical history reported. A primary survey was performed and no abnormal findings or evidence of traumatic injury were identified. He is taken to the ship's medical ward.

Patient 2 is a 20-year-old male, lethargic and not answering questions. He is unable to give his medical history but a fellow Marine from his berthing indicates he takes an unknown medicine for migraines. He is placed on a stretcher and taken to the ship's ICU.

Time 00 minutes

Patient 1

Patient 1's vital signs are: heart rate (HR), 62 beats per minute (bpm); blood pressure (BP), 105/62mmHg; respiratory rate (RR), 24 breaths/min; peripheral O_2 saturations (SpO_2), 99%; temperature, 33°C; and weight, 82kg.

The physical exam is unremarkable and no traumatic injuries were identified during the head-to-toe secondary exam. The patient is cold to the touch, neurologic exam is unremarkable, and peripheral capillary refill time (CRT) is greater than 3 seconds, assessed at the ventral surface of his right index finger.

Initial recommended interventions include the following:

- Remove all wet clothes and dry the patient; implement external warming measures. Turn up room temperature. It is recommended to use normal blankets to warm and consider using a forced warm air blanket (e.g., Bair Hugger). If an active warming blanket is used, avoid placing it directly on the skin to avoid burn injury.
- Allow the patient to take in warm fluids by mouth, such as hot chocolate or warm chicken broth.

Patient 1's diagnosis is accidental hypothermia I (mild), using the Swiss classification system (Table 1).[17,30] Treatment principles include the following:

- Rewarm the patient. Based on mild decrease in temperature, the patient can improve rapidly through shivering, removal of wet clothes, covering in blankets, and drinking warm fluids.
- For mild hypothermia, there is no need for an involved laboratory work-up, and intravenous (IV) fluids are typically not necessary.
- Note that if a hypothermic patient is not shivering, this is a critical indication they are more than mildly hypothermic and require aggressive warming measures.

Patient 2

Patient 2's vital signs are: HR, 45bpm; BP, 88/52mmHg; RR, 8 breaths/min; SpO_2, unable to obtain; temperature, 29°C; and weight, 70kg.

On primary survey, the patient's airway is patent, breath sounds are coarse but audible bilaterally, HR is slow, peripheral pulse is weak, and there is no visible bleeding. Glasgow Coma Scale (GCS) is calculated at 6 (E1 V1 M4).[31] CRT is >4s and the fingers appear cyanotic in color. Head-to-toe secondary survey reveals a large hematoma to the right parietal scalp and a grossly deformed right midshaft humerus fracture with intact overlying skin and a palpable distal pulse. The remaining extremities are assessed to have normal exams and no obvious torso abnormalities are identified. The patient's pupils are equal and sluggishly reactive from 5 to 2mm. He expels a large volume of pink frothy emesis towards the end of the examination.

Initial recommended interventions include the following:

- Suction the emesis and keep suction readily available, ideally designate another individual to focus solely on airway suctioning.
- Obtain two points of vascular access. If unable to obtain an IV access quickly, then obtain intraosseous (IO) access (proximal humerus preferred, proximal tibia backup location). Once resuscitation has started via IO, IV lines can subsequently be placed for additional access.
- Be gentle with the patient and do not jostle, as this may cause a fatal arrhythmia in a hypothermic patient.
- Remove all wet clothes and attempt to warm the patient. If unable to remove wet clothes for any reason, wrap the patient in an impermeable enclosure/layer. Raise the room temperature. A Bair Hugger, is recommended, if available. If not available, a Hypothermia Prevention and Management Kit (HPMK) is recommended; otherwise, use multiple wool blankets inside of a sleeping bag. Be sure to focus on warming the core first, as rapid warming of the extremities can cause vasodilation, allowing cold blood to return to the core and worsen central hypothermia.
- Remember this patient is at risk for significant traumatic injury in addition to their hypothermia. Place cervical collar on the patient, given traumatic mechanism of injury. Perform and Extended Focused Assessment with Sonography in Trauma (E-FAST) to look for evidence of intra-abdominal free fluid, evaluate the heart and pericardial space, and look for evidence of pneumothorax or hemothorax.
- E-FAST: no evidence of intra-abdominal, pericardial, or pleural free fluid; lung sliding normal bilaterally.
- Send i-STAT and CBC labs, including electrolyte panel and hemoglobin/hematocrit and lactate levels.
- Start warm IV 0.9% normal saline (NS). The recommended temperature output of fluids is 38°C at a rate of 150mL/h using a battery-operated fluid warmer and IV pump. If a fluid warmer is not available, medical heat packs or meals ready-to-eat (MRE) warmers could be applied to the outside of the IV fluid bag to warm. Avoid microwaving IV fluid bags as this is unsafe. The preferred crystalloid is NS as the hypothermic liver does not metabolize lactated Ringer (LR) well.
- If the patient's GCS is <8, protecting the airway is recommended. Initial recommendations during primary and secondary survey include placing the patient on facemask oxygen for pre-oxygenation, especially given the lack of a

TABLE 1 *Swiss Classification of Hypothermia with Recommended Warming Techniques*[16,30]

Stage	Core temperature, °C	Overview	Rewarming techniques
Mild (I)	35–32	Conscious and shivering	Passive external
Moderate (II)	32–28	Impaired and not shivering	Passive and active external
Severe (III)	28–22	Unconscious and vital signs present	Passive and active external, invasive internal warming
Profound (IV)	<22	Unconscious with no vital signs present	Passive and active external, invasive internal warming

*Adapted from Hight M., Less K., and Deslarzes et al.

measurable O_2 saturation (secondary to the severe vasoconstriction form hypothermia). Consider using a nasopharyngeal airway (NPA) or oropharyngeal airway (OPA) to assist with oxygen delivery. Perform endotracheal intubation if the equipment is available (direct or video laryngoscope). If not available, consider performing surgical cricothyrotomy.[32] Recommend avoiding rapid sequence intubation (RSI) medications, if possible, as this patient could decompensate to the point of cardiac arrest if given strong sedatives and a paralytic. If patient gags or vocal cords are not relaxed enough to allow endotracheal tube passage, give RSI medications (recommend ketamine 1–2mg/kg slow IV push and rocuronium 1mg/kg IV push) with push-dose epinephrine readily available to supplement BP. If surgical airway is performed, use 1%–2% lidocaine for local anesthesia to prevent the patient from reacting.

- Push-dose epinephrine = 1mL from 1:10,000 epinephrine syringe mixed with 9mL of saline from a saline flush. Concentration of epinephrine then becomes 10µg/mL, give pushes of 1mL every 2–5 minutes as needed for hypotension.
- Place the patient on a ventilator using a lung protective ventilation strategy (6mL/kg predicted body weight).[33] Use volume assist control (V-AC) as base standard and start with 100% FIO_2 and positive end expiratory pressure (PEEP) of 5mmHg, with rapid adjustments based on peak inspiratory pressures (PIP) and O_2 saturation.[34] Predicted body weight (kg) calculation:
  - Men = 50 + (0.91 * height (cm) – 152.4)
  - Women = 45.5 + (0.91 * height (cm) – 152.4)
- Use Ketamine push doses for sedation. Use 1–2mg/kg slow IV or IO push, or 300mg IM every 20–30 minutes. Repeat as often as needed.
- Consider using 2–4mg IM or 0.5–1mg slow IV push (over 1–2 min) of Versed (midazolam) can be used for added sedation as required.
- Perform an electrocardiogram, as profoundly hypothermic patients are at high risk for cardiac dysrhythmias.
- Place nasogastric tube (NGT) for gastric decompression and enteral access; place to low continuous wall suction.
- Elevate the head of the bed to 30–45° due to concern for head trauma.
- Perform X-rays of the skull, right humerus, chest, abdominal flat plate, and pelvis.
- Skull X-ray shows no obvious abnormality.
- Right humerus X-ray confirms an angulated midshaft fracture.
- Chest X-ray with significant white opacification of bilateral lung fields concerning for aspiration pneumonitis and possibly ARDS.
- Pelvis X-ray negative for any acute injuries.
- Abdominal flat plate X-ray confirms NGT is in the stomach.
- Place the right humerus into a sling; ensure distal palpable radial pulses.
- Place a urinary catheter to monitor fluid output.

Patient 2's diagnosis includes:

- Accidental hypothermia II (moderate) (Table 1)
- Aspiration pneumonitis
- Closed right humerus fracture
- Closed blunt head injury

Treatment principles include the following:

- Aggressive rewarming through the use of passive external rewarming (warm room and blankets), active external rewarming (Bair Hugger or HPMK), and active internal warming (warm IV fluids). Use invasive warming through the use of warm fluid bladder lavage only if absolutely necessary.
- Place an internal temperature probe if available, such as a urinary catheter or nasogastric tube with built-in temperature probe, or place a separate esophageal or rectal temperature probe. Monitor temperature continuously and rewarm until the patient's core temperature reaches 36°C.
- As this patient has fluid aspiration into the lungs, development of ARDS is likely and managing the ventilator can become very difficult. Attempt maintaining O_2 saturation of 88%–95%. Use 6mL/kg of predicted body weight and slow increases in PEEP to address hypoxia. Follow the ARDSnet recommended FIO_2/PEEP ratios (Table 2).
- Use a minimum PEEP of 5cmH_2O. If O_2 saturations persistently below 88%, consider incremental increases in FIO_2/PEEP ratios as demonstrated in Table 2. For example an increase in FIO_2 of 0.4 to 0.5 may require an increase of PEEP from 5 to 8cmH_2O.
- If available, plateau pressure is the best measure of lung compliance and should be monitored at least every 4 hours. Consider dropping tidal volumes to 1mL/kg if plateau pressure exceeds 30cmH_2O.[35] Use physical exam to monitor O_2 saturation if electronic monitoring is not working due to severe vasoconstriction, look for central and peripheral cyanosis. Consider using the patient's earlobe for electronic O_2 saturation monitoring as this often has higher rates of success when compared to the vasoconstricted extremities.
- Monitor urine output (UOP) closely with a goal of 0.5–1mL/kg/h. Patients with a core temperature <30°C often experience cold diuresis, where they will expel extra urine (>1mL/kg/h) even when not adequately hydrated. This pathology makes it difficult to use UOP as a measure of resuscitation in the initial hours; excess IV fluids will likely be required compared to normothermic trauma patients. Use ultrasound (if available) to assess for inferior vena cava collapsibility and its variation with the ventilatory cycle for relative intravascular volume assessment.[36] The passive leg raise test may help with intravascular volume assessment.[37]
- Use ketamine and Versed (midazolam). Further paralytic use should be avoided after the initial airway control measure, unless it is indicated during MEDEVAC to a higher level of care.

TABLE 2 *ARDSnet FIO_2/PEEP Titration*[35]

Goal O_2 saturation 88%–95%								
Wait 5–10 min before making further adjustments (titrate both at same time)								
FIO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7
PEEP	5	5	8	8	10	10	10	12
FIO_2	0.7	0.8	0.9	0.9	0.9	1.0		
PEEP	14	14	14	16	18	18–24		

*Adapted from JTS Acute Respiratory Failure CPG.

- Maintain a RASS (Richmond Agitation and Sedation Score) of 0, if possible, to assist with neurologic exams (Table 3).[31]

TABLE 3 *Richmond Agitation and Sedation Score*[30]

Richmond Agitation and Sedation Score (RASS)		
Score	**Description**	
+4	Combative	Violent, immediate danger to staff
+3	Very agitated	Pulls at or removes tubes, aggressive
+2	Agitated	Frequent non-purposeful movements, fights ventilator
+1	Restless	Anxious, apprehensive but movements not aggressive
0	Alert and calm	
–1	Drowsy	Not fully alert, sustained awakening to voice >10 seconds
–2	Light sedation	Briefly awakens to voice <10s
–3	Moderate sedation	Movement or eye-opening to voice
–4	Deep sedation	No response to voice, but movement or eye opening to physical stimulation
–5	Unrousable	No response to voice or physical stimulation

*Adapted from the JTS Prolonged Casualty Care Guidelines.

- Monitor serum creatinine and electrolytes closely (every 4 hours at first). Rhabdomyolysis is common in hypothermic patients, particularly with concomitant trauma and is associated with acute kidney injury (AKI). If evidence of rhabdomyolysis, AKI, elevated potassium on a metabolic panel, and/or myoglobinuria without gross hematuria on dipstick urinalysis, continue treating with large volumes of IV fluids (NS preferred over LR in hypothermic patients).
- Keep the patient on the cardiac monitor as dysrhythmia is common. All dysrhythmias require rewarming to treat. Atrial tachycardias do not require medication management. Consider early defibrillation (lower success rates in hypothermia) for unstable ventricular tachycardias as lidocaine and amiodarone are not only hard to find in the tactical or austere maritime environments but also poorly metabolized by the hypothermic liver. Atropine and pacing will also produce unpredictable results in hypothermic patients; consider both for bradycardia, but rewarming is the priority.
- If the patient is hypotensive and not responding to IV fluids, start norepinephrine sooner rather than later, with a goal mean arterial pressure (MAP) >65mmHg. Norepinephrine is preferred to epinephrine in hypothermic patients as it is the least arrhythmogenic.
- Norepinephrine (Levophed) drip range: 2–20µg/min, titrate every 3–5 minutes as needed, reassess BP every 5 minutes while patient is on a pressor.
- Perform hourly neurologic checks for an intubated patient with head trauma. Keep the head elevated to 30–60°. Avoid paralytics as this will hinder exams. Monitor withdrawal/localization in all four extremities and with a pupil exam. Look for worsening neurologic signs such as localization that has changed to withdrawal, new posturing, or Cushing reflex (lower HR, increased BP) before giving 3% hypertonic saline. Use the TCCC recommended dose of a 250-mL bolus given over 20 minutes, repeat every 3 hours until symptoms improve.[38]
- Antibiotics are not necessary for aspiration pneumonia until the patient starts to exhibit infectious symptoms, often 2–3 days after initial insult.
- Extremity injuries take last priority in critically ill patients unless there is neurovascular compromise; if identified during the primary or secondary survey, the limb should be reduced expeditiously. Apply a supportive splint to any concerning area, and attempt to keep the extremity elevated.
- Do not start NGT or IV nutrition until the patient has fully rewarmed. Note: neither enteral or parenteral nutrition formulations are available on an LPD.
- If placing a central line in a hypothermic patient, be very careful not to irritate the myocardium to avoid triggering a fatal arrhythmia. If a provider has the skillset, ultrasound-guided femoral vein access may be ideal to reduce the risk of myocardial irritation.
- If a hypothermic patient goes into cardiac arrest, the priority is to warm the patient as rapidly as possible before discontinuing CPR, even if it takes >1 hour. Recommendations suggest warming at least 5°C above starting temperature, but ideally until they reach 32°C before considering ceasing compressions. Follow Advanced Cardiac Life Support (ACLS) guidelines as normal but realize that defibrillation and epinephrine in hypothermic patients are not as successful; consider spacing them out more than typical to maintain focus on rewarming.[39]

Time +90 minutes

Patient 1

Patient 1's vital signs are: HR, 75bpm; BP, 116/72mmHg; RR, 16 breaths/min, SpO_2, 94%; temperature, 35°C. His neurologic status is still normal and has been drinking fluids without difficulty and conversing with people. He is very worried about his fellow Marine. Recommendation: monitor for another 90–120 minutes before anticipated discharge back to quarters.

Patient 2

- Patient 2's vital signs are: HR, 64bpm; BP, 95/55mmHg; RR, 16 (on ventilator); SpO_2, 95%; temperature, 32°C. Ventilator settings are: V-AC, TV, 420mL; fraction of inspired oxygen (FIO_2), 90%; RR, 16; PEEP, 14. The patient is intubated with a 7.5 endotracheal tube (ETT). Large volumes of frothy sputum are present in the ETT, requiring frequent suctioning with in-line cannula. Cumulative IV fluids are 2L NS. Norepinephrine drip infusing through peripheral IV at 5µg/min. UOP is 450mL clear urine (>1mL/kg/h). The patient no is longer paralyzed; neurologic exam reveals pain localization in all four extremities. He has had intermittent monomorphic ventricular tachycardia on the monitor with no change in vital signs and each has been a brief spontaneous self-resolving episode. Lab values are: Sodium (Na) 134, Potassium (K+) 5.6, chloride (Cl) 98, CO_2 17, creatinine (Cr) 1.2, blood urea nitrogen (BUN) 30, glucose (Glu) 65, ionized calcium (iCa) 1.2, (hemoglobin) Hb 12.8, hematocrit (Hct) 41; venous blood gas (VBG): pH 7.16, pO_2 16, pCO_2 36, lactate, 5.2.

Recommended interventions include the following:

- Place an NGT, if one has not already been placed. Connect it to suction and use a low intermittent suction setting.
- Perform telemedicine consultation if available; recommend trauma, critical care, orthopedic, and neurosurgery consultations.[40]
- Start warmed NS at maintenance rate (e.g., 125mL/h); transition to LR once the patient is warmed and lab values normalize.

- UOP is currently >1mL/kg/h, but the patient is still hypothermic. Therefore he may still be experiencing cold diuresis. Continue NS rate as above while monitoring output closely.
- Give 50% dextrose (D50) IV push to due to borderline hypoglycemia and inability to tolerate nutrition.
- Hold chemical venous thromboembolism (VTE) prophylaxis due to unknown status of brain injury; if the patient is hemorrhaging, this intervention could have devastating results.
- Hold gastrointestinal (GI) prophylaxis medication until normothermic.
- Continue monitoring BP every 5 minutes while on vasopressors.
- Perform neurologic exams every 30 minutes.
- Perform routine documentation detailing vital signs at minimum every hour. Also document changes in status or exam. Caregivers should complete full patient documentation.
- Avoid rolling/moving the patient until normothermic to avoid triggering an arrhythmia.

Time: +8 hours

Patient 2's vital signs are: HR, 62bpm; BP, 100/68mmHg; RR, 18 (on ventilator); SpO_2, 86%; temperature, 35°C; RASS, –2. Ventilator settings are: V-AC, TV, 420mL; FIO_2, 100%; RR 18; PEEP, 10 (increased due to worsening hypoxia). Plateau pressures (measured by briefly pausing the airflow at the end of inspiration) are elevated (>30cmH_2O) There is persistent frothy sputum present in ETT, requiring suctioning with in-line cannula. Three liters total of warmed NS is given, still at the 125mL/h maintenance rate. Norepinephrine is discontinued. UOP is 1.4L clear urine. The patient is still localizing pain in all four extremities. He is placed into a coaptation splint with sling per orthopedic surgeon recommendation over teleconference.

Repeat lab values are: Na, 141; K, 5.0; Cl, 102; CO_2 19; Cr, 1.2; BUN, 30; Glu, 110; iCa, 1.2; Hg, 11.2; Hct, 37; VBG: pH, 7.30; pO_2, 30; pCO_2, 39; lactate, 2.7.

Recommended interventions include the following:

- As the patient is continuing to over-diurese (>1mL/kg/h) and body temperature has almost normalized, maintenance fluids can start to be slowed with continued close monitoring of UOP and vital signs.
- The patient's ARDS is worsening as evidenced by the low oxygen saturation as with worsening lung compliance (elevated plateau pressures). Increase PEEP to 12; note: some ventilators may not exceed PEEP of 15cmH_2O. Continue close monitoring of ventilatory status with plateau pressures every 4 hours and VBGs every 6 hours (if available); monitor O_2 saturations and ventilator alarms.
- Continue to hold VTE and GI prophylactic medications. Continue to hold nutrition.
- Perform routine nursing care:
  - Monitor vital signs and perform neurologic exams every hour now that the patient has stabilized and the vasopressor has been discontinued.
  - Continue suctioning the ETT as necessary.
  - Maintain an elevated head of bed between 30–60°.
  - Continue diligent documentation, including hourly intake and output (I&Os).
  - Perform oral care for an intubated patient every 4 hours.
  - Once warmed, the patient should be rolled every 2 hours with padding placed over bony prominences to prevent skin breakdown.

Time: +24 hours

The patient still requires high FIO_2 and continues to produce significant frothy sputum, but his neurologic status is stable and UOP has slowed. Medical staff are informed that evacuation of the patient is still 24–36 hours away.

The patient's vital signs are: HR, 78; BP, 98/68mmHg; RR, 18 (on ventilator); SpO_2 88%; temp: 37°C; RASS –1. Ventilator settings: V-AC; TV, 420mL; FIO_2, 100%; RR, 18; PEEP, 15 (increased again due worsening hypoxia from severe ARDS). There is persistent frothy sputum in ETT, requiring frequent suction with in-line cannula. IV fluid and rate is room temperature LR at 125mL/h (changed due to normothermia). Cumulative IV fluid input is 5,875mL. Cumulative UOP is 1.9L yellow urine. Cumulative ETT output is 2.6L pink frothy sputum. Cumulative NGT output is 800mL. No bowel movement has occurred. Patient still localizing in all four extremities on neurologic exam. Repeat lab values are: Na, 144; K, 4.6; Cl, 104; CO_2, 20; Cr, 1.3; BUN, 30; Glu, 110; iCa, 1.2; Hg, 11.0; Hct, 36; VBG, 7.28; pO_2, 22; pCO_2, 49; lactate, 1.8.

Assessments indicate that the patient neurologic exam findings are unchanged and he has been resuscitated appropriately. He is diagnosed with severe ARDS.

Recommended interventions include the following:

- The severity and associated mortality of ARDS is commonly estimated by determining the ratio of PaO_2/FIO_2.[41] Arterial blood gas is not available on an LPD. However, the ratio of peripheral oxygen saturation (SpO_2) to FIO_2 can help estimate PaO_2/FIO_2 ratios to help determine severity of ARDS (Table 4). SpO_2/FIO_2 ratios of 235 and 315 correlate with PaO_2/FIO_2 ratios of 200 and 300, respectively.[42] This patient currently has an SpO_2/FIO_2 ratio of 88 which is significantly less than 235, and thus he likely has severe ARDS based on the available information. In this austere maritime environment, proning, consideration of dexamethasone, and euvolemia should all be considered.[43] Paralysis has previously been shown to have a mortality benefit in ARDS, but a recent 2019 study showed no significant mortality benefit.[44] Critical care and trauma surgery telemedicine consultation is recommended to discuss the following ARDS treatment strategies[43]:
  - Proning: 16/8 hour prone/supine ratio. This is time- and labor-intensive but has a demonstrated mortality benefit.[45]
  - IV dexamethasone 10mg twice daily for 5 days, followed by IV 10mg daily for 5 days.[46]
  - Continuous neuromuscular blockade (paralysis) may improve lung compliance, facilitate ventilator synchrony, and decrease metabolic demand. However, paralysis will significantly limit neurologic exams in patients with evidence of traumatic brain injury. If possible, discuss with an intensivist or trauma/critical care surgeon via telemedicine consultation.
  - Continue to monitor hourly output; the patient is normothermic and can now be expected to produce normal UOP of 0.5mL/kg/h.
  - Initiate GI prophylaxis: IV Protonix (pantoprazole) if available; otherwise use oral ranitidine or omeprazole down NGT.
  - Enteral nutrition could be considered at this time. If a patient is being considered for possible initiation of

TABLE 4 *ARDS Severity Using Berlin Criteria and SpO_2/FIO_2 Ratio*[40–42]

Severity	PaO_2/FIO_2 ratio	SpO_2/FIO_2	Associated mortality risk
Mild	$200<PaO_2/FIO_2 \le 300$ (PEEP $\ge$5cmH_2O)	$235 < SpO_2/FIO_2 \le 315$	27%
Moderate	$100<PaO_2/FIO_2 \le 200$ (PEEP $\ge$5cmH_2O)	$SpO_2/FIO_2 < 235$	32%
Severe	$PaO_2/FIO_2 \le 100$ (PEEP $\ge$5cmH_2O)	N/A	42%

*Adapted Ranieri et al., Rice et al., and Grasso et al.

nutrition, recommend telehealth consult with intensivist, internist, or nutritionist if available. Note: neither enteral or parenteral nutrition formulations are available on an LPD.
  - The patient still has severe ARDS and requires continued close monitoring of plateau pressure every 4 hours and VBGs every 6 hours (if available).
  - VTE prophylaxis decision should be made in conjunction with neurosurgery or trauma surgery consultant via telemedicine, if available; otherwise, continue to hold but attempt using lower extremity compression devices if available.
- Continue routine nursing care as previously described:
  - If proning, ensure bony prominences are padded to prevent skin breakdown.

Time: +48 hours

The patient has continued to require high levels of FIO_2 and PEEP. After critical care telemedicine consultation with instruction, both proning protocol (16/8h prone/supine ratio) and IV dexamethasone were initiated. Repeat chest X-ray demonstrates persistent whiteout of bilateral lung fields. He developed a fever at hour 40 but vital signs have otherwise remained stable and no vasoactive medications have been required. Patient has improved neurologically and will now open his eyes spontaneously.

Vital signs are: HR 88bpm; BP, 96/60mmHg; RR, 20 (on ventilator); SpO_2, 90%; temperature 39°C; RASS, 0 to +1. Ventilator settings are: V-AC; TV, 420mL; FIO_2, 70%; RR, 18; PEEP, 15. There is persistent frothy sputum coming out of the ETT, requiring suctioning with in-line cannula. SpO_2/FIO_2 is 129. IV fluid and rate is LR at 50mL/h. Cumulative IV fluid input is 7,555mL. Cumulative UOP is 2.7L light yellow urine. Cumulative ETT output is 4.1L pink frothy sputum. Cumulative NGT output is 1,200mL. No bowel movement has occurred. The patient is following simple commands and opening eyes. Repeat lab tests are not performed.

Assessment reveals that the patient's improved neurologic status is reassuring. New fever is concerning for aspiration pneumonia with saltwater species being a concern, particularly Vibrio species.[2,47] Persistent sputum production and respiratory status is consistent with severe ARDS.

Recommended interventions include the following:

- Draw blood and sputum cultures if able to be performed. Note: not possible on an LPD.
- Start antibiotics, recommend IV ertapenem for broad-spectrum coverage and high likelihood of availability. Also recommend adding IV or oral doxycycline (same bioavailability) for *Vibro* and other seawater species coverage.[47]
- Increase sedation, consider adding a secondary drip agent such as Versed or fentanyl to assist. The rationale for this is a more alert patient will likely demonstrate worse ventilator compliance and potentially worsen their respiratory status, something this patient will not tolerate well due to his ARDS. If respiratory status deteriorates further, consider adding a paralytic while increasing sedation after telemedicine consultation.
- Continue GI prophylaxis.
- VTE prophylaxis decision again should be made in conjunction with trauma or neurosurgery consultant via telemedicine, if available.
- Continue routine nursing care.

Time: +60 hours

The patient has maintained respiratory status with sedation. Vital signs otherwise remain stable and the patient has not experienced further fevers. The medical team is informed that MEDEVAC is available in 4 hours. The patient is to fly by rotary wing to Adak, Alaska, where an Air Force Critical Care Air Transport Team (CCATT) with Extracorporeal Membrane Oxygenation (ECMO) capability will meet him and fly him to the civilian level 1 Trauma Center in Anchorage, an approximate 4-hour flight away.

Recommendations to prepare the patient for MEDEVAC include the following:

- Make copies of all documentation and lab reports to send with the en route care (ERC) team.
- Place eye (glasses/goggles) and ear (earplugs) protection on the patient.
- Reinforce all tubes and lines with tape.
- Ensure all fluids and medication bags are labeled.
- Label all lines using a strip of tape approximately 6 inches from the IV site. Indicate exactly what dose/concentration the medication or type of fluid that is infusing.
- Empty the urinary catheter bag.
- Consider administering 4mg IV ondansetron (Zofran) prior to flight to help with motion sickness.
- Consider administering a paralytic as the ERC team is about to take off; this will prevent the patient from fighting the ventilator en route.
- Review the medication administration record with ERC team.

Discussion

This case highlights the importance of all maritime operational forces maintaining high levels of diligence in training for both traumatic and non-traumatic medical emergencies. Box 1 lists the JTS CPGs and readily available resources used to make recommendations for the patients in this scenario.

BOX 1 *Readily Available Drowning, Hypothermia, and Critical Care Management Resources*

- Tactical Combat Casualty Care (TCCC) Guidelines[20] – available at: https://books.allogy.com/web/tenant/8/books/b729b76a-1a34-4bf7-b76b-66bb2072b2a7/
- Prolonged Casualty Care Guidelines[30] – available at: https://jts.health.mil/assets/docs/cpgs/Prolonged_Casualty_Care_Guidelines_21_Dec_2021_ID91.pdf
- Drowning Management[3] – available at: https://jts.health.mil/assets/docs/cpgs/Drowning_Management_27_Oct_2017_ID64.pdf
- Hypothermia Prevention and Treatment[17] – available at: https://jts.health.mil/assets/docs/cpgs/Hypothermia_Prevention_Treatment_07_Jun_2023_ID23.pdf
- Acute Respiratory Failure[34] – available at: https://jts.health.mil/assets/docs/cpgs/Acute_Respiratory_Failure_23_Jan_2017_ID06.pdf
- Airway Management in Prolonged Field Care[31] – available at: https://jts.health.mil/assets/docs/cpgs/Airway_Management_in_Prolonged_Field_Care_01_May_2020_ID80.pdf
- Telemedicine Guidance in the Deployed Setting[39] – available at: https://jts.health.mil/assets/docs/cpgs/Telemedicine_Deployed_Setting_19_Sep_2023.pdf
- Documentation In Prolonged Field Care[47] – available at: https://jts.health.mil/assets/docs/cpgs/Documentation_Prolonged_Field_Care_13_Nov_2018_ID72.pdf
- Management of Drowned Patient[2] – available electronically through Naval Medical Center San Diego Library Services
- Management of hypothermia and immersion injuries[16] – available electronically through Naval Medical Center San Diego Library Services
- Acute Respiratory Failure and Ventilator Management Afloat[42] – available electronically through Naval Medical Center San Diego Library Services
- Maritime Prolonged Casualty Care[48] – available electronically through Naval Medical Center San Diego Library Services
- Infectious Disease Pearls for Maritime Surgical Teams[46] – available electronically through Naval Medical Center San Diego Library Services

Patient 1 did not experience any trauma, likely helping contribute to the lack of severe hypothermia and fluid aspiration. He was able to be treated conservatively using oral hydration and passive warming methods, with active body warmers only being used to expedite his improvement. When at all possible, this method of treatment should be used, as any more invasive medical treatment increases the risk of potential morbidity and mortality.

Patient 2 suffered some type of traumatic brain injury without evidence of skull fracture, a closed long bone fracture of the upper extremity, and aspiration pneumonitis with subsequent severe ARDS from drowning. The humerus fracture did not alter the course of the patient's care significantly, but the concern for a possible head injury was considered early in the patient's care, and serial neurologic monitoring was performed. The patient experienced what is very common in these types of situations, severe ARDS secondary to what was probably a large amount of seawater aspiration and concomitant hypothermia. The hypothermia resolved appropriately after simple measures, such as drying the patient and using a forced air warming blanket. The course of slowly worsening hypoxia and lung compliance resulting in extremely high levels of FIO_2 and PEEP is not unexpected in these patients, but the mortality risk was very high in this hypothetical patient—at least 42%—using the Berlin criteria estimated the PaO_2/FIO_2 ratio, using SpO_2/FIO_2 ratios as surrogate. Given the traumatic mechanism and the barotrauma, pneumothorax must always be a concern, particularly with a rapid change respiratory status.

At a more robust tertiary care hospital, a patient with this severe lung injury would almost certainly require more advanced ventilatory modes, bronchoscopy with bronchoalveolar lavage, and possibly ECMO. ARDSnet lung protective strategies are critical to supporting this lung injury until evacuation is possible, while avoiding further complications such as barotrauma and pneumothorax.

Proning was used in this scenario. It should be noted that on an LPD there are no nurses of any kind, nor physicians with any significant critical care experience. The two physicians in this scenario are likely aware of the mortality benefit of proning in ARDS,[46] but this practice is time- and labor-intensive and these maritime caregivers should discuss the procedure with experienced critical care nurses and physicians via synchronous or asynchronous telemedicine modalities before proceeding.

Cardiopulmonary arrest was not experienced in the above cases but should be considered as it requires significant nuance in the hypothermic patient. Due to multiple anecdotal cases of neurologic preservation even after prolonged unconscious (and likely time in arrest) periods in water, particularly colder water, CPR should be continued until patients warm at minimum to an increase in 5°C, but ideally until they reach 32°C. Previous literature has shown that cerebral oxygen consumption decreases 5% for every 1°C drop in body temperature. Many medications, and even defibrillators, will not work until the patient is at least 30°C.[3] The American Heart Association (AHA) recommends attempting one defibrillation for patients <30°C in pulseless ventricular tachycardia or ventricular fibrillation, and if it does not work to cease further attempts until the patient is warmer than 30°C.[48,49]

Another notable pathology not experienced in the above cases but should be considered by any provider caring for a large volume fluid aspiration patient is the potential for electrolyte shifts and disturbances. It typically does not occur except in locations with very high levels of electrolytes, such as the Dead Sea. Hypercalcemia and hypermagnesemia are the two electrolyte disturbances that may require treatment, making both mandatory testing parameters when available.[50] Hyponatremia has been postulated as a major concern after significant freshwater aspiration, and while studies have shown patients are in fact hyponatremic after such an incident, it is often more mild than anticipated, and patients have rarely experienced hyponatremic seizures or other sequelae.[51] Furthermore, regardless of either fresh water or salt water aspiration, drowning survivors typically are unable to aspirate enough water to cause electrolyte disturbances.[2,3]

This scenario has several training, skills sustainment, and medical supply implications. If an Independent Duty Corpsman embarked on smaller naval vessel, such as a destroyer, cruiser, or submarine, has to manage a patient with severe ARDS, he or she is unlikely to survive unless rapidly evacuated to a higher level of care. While there were two physicians able to care for these scenario patients, neither was residency trained. While the Navy is currently changing this paradigm, where the SMO on an LPD is a residency trained physician, typically Internal Medicine or Family Medicine, they would be unlikely to have significant critical care experience beyond their initial exposure in residency training. While an ultrasound was available, no maritime caregiver currently receives routine pre-deployment ultrasound training, and therefore its ability to aid in treatment and diagnosis is limited by the user's experience. Other procedural skills needed (or potentially required) in this scenario that non-residency trained physicians have little to no experience in (depending on the specialty) include endotracheal intubation, cricothyroidotomy, and ultrasound-guided central venous catheter placement. Likely none of the LPD caregivers have the requisite critical care nursing experience to manage this patient, highlighting another critical pre-deployment training gap.

Conclusion

As mentioned in preceding sections, prevention is the best way to treat both drowning and hypothermia. Preparation for such incidents is imperative before any operational undertaking or ship underway period. This preparation should include material procurement, medical skill acquisition, particularly regarding airway management, and medical planning for every possible scenario that military personnel could encounter. Zero preventable deaths is the gold standard in operational medicine, and inadequate preparation comes at the cost of human lives. This hypothetical drowning scenario highlights the critical care and PCC skills required to support a patient with aspiration, hypothermia, and ARDS.

Author Contributions

MDT conceived the study concept. KDL developed the scenario. KDL and MDT performed the literature review and drafted the original manuscript. KDL, VHD, JJB, and MDT participated in critical revisions.

Disclaimer

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