

History and Clinical Impacts of Drowning in Amphibious/Water-Based Operations

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ABSTRACT

United States (US) military amphibious operations have played pivotal roles in the success of military conflicts throughout history. Amphibious operations ranging from large-scale assaults, such as the Allied forces invasion of Normandy, to smaller operations, including river crossings, carry an inherent risk for drowning and near-drowning casualties which have historically been associated with substantial morbidity and mortality. Highly trained servicemembers die every year during water operations in both combat and non-combat environments. Drowning incidents result in a series of physiological responses primarily affecting the respiratory, cardiovascular, and neurological systems that ultimately lead to cardiopulmonary arrest. Survivors are at risk for the development of numerous complications including aspiration pneumonia and severe electrolyte derangements that may necessitate advanced medical care which is challenging to provide in austere environments. The management of near-drowning victims is focused on removal from water, respiratory and cardiovascular support, and timely evacuation for further management and monitoring for delayed complications. This review will highlight the history, pathophysiology, and management of drowning casualties in US military operations.

HISTORY OF UNITED STATES MILITARY AMPHIBIOUS OPERATIONS

For centuries, amphibious operations have been monumentally important in wartime. Having a highly functioning military force that is capable of engaging enemies as well as efficiently transport personnel, equipment, munitions and supplies in a water-based environment is essential during wartime. Throughout history, specialized transports have been developed to facilitate that goal. The Continental Marines amphibious landing in the Bahamas during the Battle of Nassau during 1776 marked the United States' first utilization of amphibious warfare.¹ During the Spanish-American War, the United States (US) Marines performed an amphibious invasion of Cuba and captured Guantanamo Bay, an area still controlled by US military forces today.² In 1933, the Fleet Marine Force was created, composed of both US Navy and Marine personnel.³ The Fleet Marine Force subsequently developed the Tentative Landing Operations manual in 1935, which was utilized for training and preparation for future amphibious operations.⁴

Following the onset of World War II (WWII), amphibious operations were key for Allied victories and were utilized widely throughout the African, European, and Pacific theaters of operation. On 6 June 1944, the United States, along with Allied forces, invaded Normandy, France to establish a stronghold in Western Europe known as D-Day. This operation involved the utilization of both sea and air forces

and marked the largest amphibious assault in military history.⁵ Over 160,000 Allied troops landed on the French coastline while utilizing 5,000 ships and 470 amphibious vehicles during D-Day.⁶ Though D-Day was a successful operation and established an Allied stronghold in Europe, it was costly with over 2,500 American casualties.⁷ Beyond D-Day, the US Marines and US Army utilized amphibious operations in the Pacific theater by a process known as "island hopping." These operations involved the rapid insertion of Marine forces on Japanese-controlled islands throughout the Pacific. Significant casualties were sustained during these operations with the invasions of Crete, Peleliu, and Iwo Jima being amongst the deadliest with casualty rates approaching 30%.⁸

While large scale amphibious assaults, such as D-Day and island hopping, were key to allied victories in WWII additional operations crossing smaller water ways to include river crossings were key in troop movements throughout the European and Pacific campaigns. Notably the crossing of the Rhine River where multiple US divisions and British allies crossed at several locations from 22 March to 26 March 1945 during Operations Plunder and Varsity. These river crossing operations were essential in the continued invasion of western Europe and into Germany, with the eventual surrender of Germany on 7 May 1945. During these operations there were approximately 2800 US and 3900 United Kingdom casualties.⁹

Following the Allied victory in both the European and Pacific theaters, the US military was well-versed in amphibious warfare, though the subsequent development of unconventional warfare posed many potential changes to previously learned strategies. In 1950, during the Korean War, General MacArthur and the X Corps (7th Infantry division and 1st Marine division) led a large amphibious assault at the Battle on Inchon to push through the Pusan perimeter into North Korea. After four days of fighting, key objectives were taken, and the operation was considered an overall success.¹⁰ Throughout the remainder of 1950s, several amphibious operations were conducted for withdrawal from this theater.

During the Vietnam War, amphibious operations were utilized to locate, destroy, and capture enemy strongholds. A total of 62 amphibious assaults/operations were performed by the US Marine Corps from 1965 to 1969 with variable success as the Viet Cong forces were able to quickly maneuver out of areas to avoid contact with US military forces.¹¹ Setbacks during these operations were secondary to expansive forces that limited mobility, as well as large stockpiling of munitions upon making landfall, making it difficult to keep pace and have direct contact with enemy forces. Both the Army and Navy (Mobile Riverine Force/Task Force 116) played a major role in riverine warfare throughout the Vietnam War.¹² The Navy was integral in transporting forces and supplies along the riverways throughout Vietnam. These forces were subject to mines, ambushes and suicide boat attacks.

Despite difficulties with large scale amphibious operations during the conflicts in Korea and Vietnam, US soldiers faced smaller water-based operations in river crossings. These river operations were necessary for troops to be able to move throughout combat zones, patrol areas, and advance into enemy territory. Although these missions included a smaller number of troops crossing a smaller area of water, platoons faced difficulties with complications of these operations, amounting to US casualties. The river crossing tactics learned during the Vietnam War have been adapted by the US Army and are still utilized for training purposes.¹³ During the Global War on Terror, maintaining control over the major waterways to include the Tigris and Euphrates was pivotal. The Tigris and Euphrates run parallel and end in the Gulf. These rivers traverse through Iraq and into Syria and Turkey. Early in the Iraq war some of the heaviest fighting occurred around the Euphrates River to gain control over the water way. US forces were frequently ambushed, and many casualties occurred defending river crossings and bridges.¹⁴

Currently in the conflict in Ukraine, there have been multiple river-crossing missions reported by both Russian and Ukrainian forces. During the battle of Siverski Donets, Russian forces attempted multiple crossing across the Donets River into the villages of Dronivka, Bilohorivka and Serebrianka, but were ultimately repelled by Ukrainian forces. These recent conflicts continue to show the importance of effective water-based operations and the potential dangers with drowning risks for soldiers.¹⁵

HISTORY OF DROWNING CASUALTIES IN WATER-BASED OPERATIONS

During water-based operations, there is a risk for casualties among military personnel during both combat operations and in training environments. Prior to WWII, there were several instances of non-combat related drownings, ships being lost at sea and presumed wrecked with subsequent drownings of its crew. This includes an estimated 2973 non-combat associated drownings prior to the onset of World War II (Table 1).¹⁶ The most notable occurred on the night of 27 April 1944 when 749 American servicemen died during Exercise Tiger, the rehearsals at Slapton Sands for the D-Day landing on Utah Beach in Normandy.

During D-Day, an estimated total of 2,501 US troops were killed in action. Providing medical aid during the battle of D-Day was challenging, because medics faced direct enemy fire which made treatment of wounded soldiers difficult and dangerous. Given the decisiveness of the battle, with multiple waves of soldiers reaching the beach, transportation of the wounded off the beaches was nearly impossible. There were many reports of troops drowning as they exited

Table 1: Naval and Marine Corps Casualties in Combat and Non-Combat Operations

Time Period	Combat Associated Casualties		Total Combat Casualties	Non-Combat related Drownings
	Navy KIA	Marine KIA		
4/1775 – 12/1941	3719	2791	6510	2973
12/1941 – 06/1950	36960	19746	56706	305
06/1950 - 7/1990	2334	17641	19975	61
8/1990 – 2015	211	1259	1470	51

Casualties: US Navy and Marine Corps Personnel Killed and Injured in Selected Accidents and Other Incidents Not Directly the Result of Enemy Action. (n.d.). <https://www.history.navy.mil/research/library/online-reading-room/title-list-alphabetically/c/casualties-usnavy-marinecorps-personnel-killed-injured-selected-accidents-other-incidents-notdirectly-result-enemy-action.html>. Accessed 7/17/2023.

Casualties: U.S. Navy and Marine Corps Personnel Killed and Wounded in Wars, Conflicts, Terrorist Acts, and Other Hostile Incidents. (n.d.). Naval History and Heritage Command. Retrieved July 17, 2023, from <https://www.history.navy.mil/research/library/online-reading-room/title-list-alphabetically/c/casualties1.html>

their amphibious vehicle into the water which was thought to be due to the combination deep water and heavy gear. Soldiers on Omaha Beach had to wade through neck deep water for nearly 100 meters secondary to difficulty clearing beach obstacles which limited the ability of the amphibious vehicles making it to land.¹⁷⁻¹⁹ Deaths solely due to drowning were not documented. Famously, one D-Day soldier saved the lives of many drowning soldiers, PVT Carlton William Barrett waded through the shoreline to assist wounded and drowning soldiers. He refused to remain pinned under enemy fire and continued to carry casualties to an evacuation boat just off the shoreline. For his brave actions, he was awarded the Congressional Medal of Honor. After WWII, recommendations for the evacuation of wounded personnel during amphibious warfare titled “Medical Services in Amphibious Operations” was published by the US Navy in Sept 1945.²⁰

Although water-based military operations increase the risk of drowning, it is an infrequent cause of death for service-members overall. Following WWII, the continued risk of drowning has been a factor in all major conflicts, as well as military training. During the Vietnam conflict, there were 1,207 documented deaths by drowning or suffocation.²¹ During the more recent 1st and 2nd Gulf Wars, there have been multiple cases of casualties occurring secondary to vehicular-related drowning. According to the Armed Forces Institute of Pathology records, there were 71 cases of drowning among US service members deployed to Iraq from 2003 to 2005, all of which involved motor vehicles being submerged or partially submerged in water. This occurred largely due to vehicle rollovers into rivers and/or streams secondary to improvised explosive devices (IED’s). Risks associated with casualties from vehicle-related drownings included lack of wearing a seatbelt and nighttime conditions.²² From 2005 to 2014 there were 1193 reported incidents of drowning/near-drowning with 162 deaths (Table 2). Additionally, from 2013 to 2017 there were a total of 359 incidents of drowning episodes (Table 3).

Table 2: Incidents and death rates of active-duty service member drownings from 2005-2014

Branch	Total	Deaths
Army	359	62
Navy	342	46
Air Force	239	29
Marine Corps	186	25
Coast Guard	67	None

Adapted from MSMR, June 2014 Update: Accidental drownings, active component, U.S. Armed Forces, 2005–2014

An article published in 2010 documented several cases of US military personnel treated following drowning or near drowning at Landstuhl Regional Medical Center (LRMC) in

Landstuhl, Germany.²³ Eight service members were treated following drowning events in Iraq with an overall mortality rate was 37.5%. While drowning casualties are noted to be rare in combat operations, there have been many cases of military personnel drowning during training operations as well as off-duty activities. In those military personnel who die from drowning in non-combat operations, over 30% of episodes occur surrounding alcohol use.²⁴ Additional data was published from Tripler Army Medical Center who documented 62 cases over a 10-year period.²⁵

Table 3: Incidents of drowning episodes of active-duty service members from 2013-2017.

Branch	Total Incidents
Army	125
Navy	95
Air Force	63
Marine Corps	76

Adapted from MSMR, September 2018, Accidental Drownings and Near Drownings, Active Component, U.S. Armed Forces, 2013–2017

PATHOPHYSIOLOGY OF DROWNING

Drowning is the process of experiencing respiratory impairment secondary to submersion, where the airway is below the surface of the liquid, or immersion, where the airway is above the surface of the liquid. Specifically drowning results in death from hypoxemia and asphyxiation and subsequent cardiopulmonary arrest. In near-drowning episodes, an individual experiences a submersion or immersion episode and survives for at least 24 hours, while not necessarily succumbing to injuries.²⁶ Submersion/immersion incidents cause physiologic responses in the cardiovascular, pulmonary, and neurological systems. In most instances, drowning/near drowning occur in colder water than physiologic body temperature (sub-thermoneutral) that may lead to a cold shock response.

Cold shock response is the physiologic response to sudden immersion/submersion into cold water (<91.4°F/33°C). This response usually occurs in the first few minutes of immersion. The initial response causes hyperventilation (associated with the gasp reflex) as well as peripheral vasoconstriction and tachycardia. This physiologic response augments cardiac output though may induce cardiac arrhythmias which can lead to cardiac arrest. If the individual is not removed from the cold-water hypothermia may result with subsequent bradycardia and ventricular arrhythmias.²⁶⁻²⁸

Acute pulmonary edema can rapidly occur in those experiencing submersion into water, such as cases of drowning/near-drowning, as well as swimming or diving associated pulmonary edema.²⁹ This occurs secondary to inhalation of water resulting in lung damage with

resultant ventilation-perfusion mismatching and hypoxia. Laryngospasm and forceful ventilatory efforts against a closed glottis can result in mechanical damage, as well as contribute to acute lung injury and pulmonary edema.³⁰ The aspiration of either fresh water or sea water causes resultant dilution and damage to pulmonary surfactant leading to disruption of the alveolar capillary membrane with development of alveolar edema. This resultant acute lung injury and pulmonary edema leads to the development of severe hypoxemia and acute respiratory distress syndrome (ARDS).³¹

In immersion victims, “circum-rescue collapse” may occur; which is defined as an acute drop in blood pressure after removal from water. This is thought to occur by several potential mechanisms. One theory suggests the water produces an increased hydrostatic pressure causing additional return of blood flow to the head, which is augmented by peripheral vasoconstriction as described above. Once removed from the water, the lack of increased hydrostatic pressure leads to venous pooling of blood followed by decreased venous return, and subsequent decreased coronary perfusion with resulting arrhythmia and cardiac arrest.³²

Victims are noted to swallow water during the drowning/near drowning which can increase risk of vomiting and further aspiration during resuscitation.³³ Swallowing of sea or fresh water may also cause severe electrolyte disorders including hypokalemia, hypernatremia, and/or severe metabolic acidosis. Hypobicarbonaemia resulting in severe metabolic acidosis is likely the result of hypoxia and shock.³⁴⁻³⁵

If immersion victims survive the initial incident, there is potential for increased risk of aspiration pneumonia. A 1997 review article found that most common organisms involved in aspiration pneumonia are associated with either normal flora or bacteria originating in the aquatic environment the aspiration event occurred [36]. The organisms that caused aspiration pneumonia in this review were varied though notably were aerobic gram-negative bacteria, including *Aeromonas spp.* However additional gram positive (*Streptococcus pneumoniae*, *Staphylococcus aureus*) as well as fungal species (*Aspergillus spp.*) were isolated. A study performed of drowning victims in the Seine River showed increased rates of multi-drug resistance isolates in respiratory samples in drowning victims. Most notably *Aeromonas spp.*, *Haemophilus spp.*, or multiple organisms were isolated. In this study, amoxicillin-clavulanate was used as initial empiric antimicrobial therapy in seventeen of the twenty-one cases. Six of the seventeen patients grew bacterial species that were resistant to the amoxicillin-clavulanate empiric treatment (4 *Aeromonas spp.* and 2 *Pseudomonas aeruginosa*).

A more recent 10-year descriptive ICU cohort evaluation performed at two intensive care units in France evaluated the rates of aspiration pneumonia in near-drowning patients.

³⁷ This study showed that wild-type *Enterobacter* species were the most common bacterial species isolated from respiratory cultures. Though rates of aspiration pneumonia in near drowning cases vary, empiric antibiotic therapy generally is not indicated, though those at risk (contaminated environment, volume of aspiration, associated aspiration of gastric contents) should be monitored and treated as clinically indicated.^{38,39}

TREATMENT OF PULMONARY/CRITICAL CARE COMPLICATIONS IN AMPHIBIOUS OPERATIONS

Early guidelines for the management of drowning were published by several military authors.⁴⁰ The most recent clinical practice guidelines (CPG) published by the DoD Joint Trauma System include recommendations for the management of drowning and were last updated in October 2017. The CPG generally outlines four phases of treatment including: rescue and in-water resuscitation, initial resuscitation on land, advanced prehospital care, and hospital care.⁴¹ Summary recommendations were published in Military Medicine in 2018 with additional guidelines in Wilderness Medicine.^{42,43}

Pre-Hospital Care:

Pre-hospital treatment involves care in the water, initial resuscitation on land, and continued management enroute to hospital services. The first goal is safely removing the patient from water, which poses a risk for rescuers. The current CPG focuses on both rescuer and patient safety. Recommendations focus on gentle removal of patients given rough handling can cause lethal arrhythmia in hypothermic patients. Once safely removed from water, immediate assessment of the airway, breathing and circulation is recommended, as well as initiating transport services for higher levels of care. General recommendations for respiratory support include supplemental oxygen, bag valve mask ventilation, and non-invasive or invasive mechanical ventilation if needed and available. Close monitoring for vomiting and subsequent aspiration is recommended in patients receiving chest compressions. Patients should quickly be transferred to higher level of care, especially those who experience cardiac arrest, require rescue breathing, and/or advanced respiratory support. Near drowning victims should also be aggressively warmed if hypothermic and require close cardiac monitoring. Once in the hospital setting treatment should focus on respiratory and cardiovascular supporting and rewarming strategies.

Oxygenation/Ventilation:

Generally, an oxygen saturation of >93% or PaO₂ of 60-80 mmHg is considered normal. Patients with persistent hypoxemia despite supplemental oxygenation or those with respiratory failure should receive invasive mechanical ventilation.⁴⁴ If victims require invasive mechanical ventilation, goal of limiting barotrauma should be instituted. In those

who develop adult respiratory distress syndrome (ARDS) ($\text{PaO}_2/\text{FiO}_2 < 300$), clinicians should opt for lung protective ventilation per the ARDSNet protocol. Permissive hypercapnia to pH of 7.2 should be instituted in patients with moderate to severe ARDS to minimize subsequent barotrauma and volutrauma. In patients with severe ARDS and continued clinical worsening despite maximal ventilator support extracorporeal membrane oxygenation (ECMO) may be considered, although outcomes with ECMO have not been well defined in this population. Some data suggest the early initiation of ECMO may be beneficial in appropriate patients.⁴⁵

Rewarming:

Providers should aim to aggressively rewarm patients. Victims with mild hypothermia may receive passive rewarming with warm blankets and environment. Those with moderate hypothermia (temperature of 30-34 degrees Centigrade) require additional support with heating blankets, heated air devices or warm intravenous (IV) fluids. In severe hypothermia (<28 degrees Centigrade), aggressive measures such as peritoneal lavage, esophageal rewarming tubes, or ECMO may be considered.

Cardiovascular Support:

Mean arterial blood pressure (MAP) should be normalized with a goal MAP > 65 mmHg. IV fluid resuscitation should be instituted for hypovolemic patients. If persistent hypotension occurs despite adequate fluid resuscitation, vasopressors should be initiated to maintain adequate tissue perfusion. In near-drowning victims with reduced cardiac activity, inotropic agents may be indicated. In victims with near drowning secondary to traumatic injuries, blood products may be the initial resuscitation fluid of choice given risk of hemorrhagic shock. In patients with severe hypothermia, bradyarrhythmias and electrolyte disturbances have been noted and should be normalized. Rewarming and aggressive electrolyte repletion is indicated along with continuous cardiac monitoring.

Aspiration Pneumonia:

In patients with increased risk or clinical signs of infection, respiratory cultures should be obtained, and empiric anti-microbial therapy may be reasonable. Currently, there is insufficient data to support the use of bronchoalveolar lavage (BAL) for diagnostic evaluation of underlying aspiration pneumonia, though it may be appropriate in certain situations. Bronchoalveolar lavage may be used to further evaluate underlying causative organism for drowning-associated pneumonia, though results may be difficult to interpret, and aspiration of fresh/sea water could be misinterpreted as a true infection versus contaminate.⁴⁶ Depending on severity of illness broad spectrum antibiotics may be considered versus antibiotics based on facility antibiogram or based on known pathogens ubiquitous with the water source where the drowning event occurred.

Management Difficulties in Combat Associated Drownings:

Overall, the optimal treatment of near drowning victims is made more difficult by combat operations. Initially removing casualties may be more difficult if it occurs in connection with direct enemy fire. Additionally, a significant portion of drowning casualties during OIF and OEF occurred in motor vehicles, which complicates extraction. Specific training provided by the DoD has been implemented to improve egress time from damaged vehicles. Given some drowning casualties occurring in vehicle rollovers secondary to IED explosions, traumatic brain injury or other traumatic injuries may further complicate vehicle extraction.

If successful removal of near-drowning victims from the water source has occurred, the next difficulty is successful evacuation from the combat theaters in austere environments. The more recent conflicts in the Middle East involved population-centric counterinsurgency allowing for nearly complete air superiority and aggressive MEDEVAC abilities. However, a large-scale combat operation with contested air superiority would pose difficulties with MEDEVAC capabilities and would likely necessitate prolonged field care of casualties.^{47,48} This type of combat operation would make invasive medical therapies such as prolonged mechanical ventilation, cardiovascular support with vasopressors, or ECMO capabilities difficult.

Comparison of Civilian/Humanitarian Missions to Military Operations

Though military combat operations are unique to active-duty service members, drowning is not. According to the CDC, there are estimated 4000 unintentional drowning deaths per year throughout the United States. This averages roughly 11 drowning deaths per day. With regards to non-fatal drownings, this estimate doubles to approximately 8000 per year, 22 nonfatal drownings per day. Per CDC, drowning is the leading cause of death of children aged 1-4 and second leading cause of unintentional death in children ages 5-14. Of those that die from drowning, 80% are male, which is though secondary to many factors including increased exposure to water, risk-taking behaviors, and alcohol use.⁴⁹ Participants of water-based sports including triathletes are at increased risk of drowning. According to one study which evaluated drownings in athletes, approximately 52 triathletes died while competing.⁵⁰ These deaths are thought to be secondary to swimming in turbulent water, as well as accidental head trauma and/or panic resulting in hyperventilation and subsequent water inhalation.

In 2005 Hurricane Katrina devastated the US Gulf Coast, with approximately 1500-1800 fatalities reported. Approximately 40% of these deaths were related to drowning as water levels rose to nearly 20 feet. A massive number of casualties along with infrastructure damage made evacuation and treatment of these victims challenging.⁵¹ Similarly

in October 2012, Hurricane Sandy overwhelmed the Atlantic coast. Approximately 117 deaths were reported the majority of which were secondary to drowning. During times of natural disasters there are similar difficulties in the management of drowning victims when compared to combat operations. These include reduced ability to remove victims from water, difficulties with the transportation of drowning victims, providing essential medical equipment, and overwhelming medical teams.^{52,53}

CONCLUSION

With the importance of water-based operations throughout the U.S. Armed Forces, drownings/near drownings will continue to occur, especially in combat operations near or in water-based environments. Drowning/near drowning during combat operations complicates management by limiting victim extraction and evacuation to higher levels of care. Optimizing the management of this population includes prompt removal from water, respiratory/circulatory support, rewarming, and expedient evacuation to higher levels of care.

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