Injury trends aboard US Navy vessels: A 50-year analysis of mishaps at sea

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BACKGROUND: Maritime activities have been associated with unique dangers to civilian and military sailors. We performed a retrospective cohort study analyzing injury mechanisms and clinical outcomes of casualties onboard US naval ships to determine common injury mechanisms, trends, and outcomes. We hypothesized there would be a downward trend of injuries and fatalities on US naval ships during the study period.

METHODS: All mishaps recorded by the Naval Safety Command aboard active service US naval ships from 1970 through 2020 were reviewed. Only mishaps resulting in injury or fatality were included. Over time, injury mechanisms and casualty incidence rates were trended and compared based on medical capabilities. Ships without surgical capabilities were categorized as Role 1, and those with surgical capabilities as Role 2.

RESULTS: There were a total of 3,127 casualties identified and analyzed, with 1,048 fatalities and 2,079 injuries. The injury mechanisms associated with the highest mortality included electrocution, blunt head trauma, fall from height, man overboard, and explosion. There was a decrease in the trend of mishaps resulting in casualties, fatalities, and injuries over the 50-year study period. The mortality rate for select severe injury mechanisms was higher on Role 1 capable platforms, compared with Role 2 (0.334 vs. 0.250, $p < 0.05$).

CONCLUSION: Casualty incidences decreased over 50 years. However, mortality still remains high for certain mechanisms no matter the operational platform. Furthermore, Role 1 capable vessels have a higher overall mortality rate for severe injuries compared with Role 2. The authors propose training, process improvement, and technology-related solutions to improve outcomes on Role 1 capable naval vessels. (*J Trauma Acute Care Surg.* 2023;95: S41–S49.)

LEVEL OF EVIDENCE: Prognostic and Epidemiological; Level IV.

KEY WORDS: US Navy; maritime injury; military.

Throughout history, seafarers have faced unique dangers,[1–4] and the modern naval warship—part weapons systems, industrial workspace, and aerodrome conducting fixed and rotary aircraft operations—is no exception.[5] While peacetime naval deployments are generally considered safe, modern sailors face the risk of potential injury due to the associated occupational hazards,[6–14] which is significantly increased during naval warfare.[15–18]

Currently, US Navy and Marine Corps operational planning is coalescing around the concept of Distributed Maritime Operations (DMO), where all components of the naval force are geographically separated and isolated across multiple domains within the maritime environment. During DMO, widely dispersed ground forces, air assets, and surface and subsurface naval vessels will be coordinated to provide sea control and sea denial over enormous geographic areas, presenting unique and challenging long-distance considerations for medical planners.[17,19–22] As Navy Medicine supports DMO, it is essential to understand and enumerate common shipboard injury patterns and associated clinical outcomes during naval operations.

To our knowledge, no modern comprehensive analysis of injuries at sea during routine US Navy deployments has been performed and the available literature is limited. Other than publications describing specific mass casualty events,[8,9,15,17,21,23,24] most published data are over 20 years old and limited to isolated deployments.[6,7,14]

Our objective was to analyze the casualties onboard US naval vessels during routine and contingency operations to determine common injury mechanisms, trends, and outcomes to better inform and develop clinical training requirements. Ultimately, our goal is to prepare providers to support current and future DMO, where rapid medical evacuation will not be readily available, and prolonged patient care will be required.[25] To do this, we performed a retrospective cohort study analyzing injury mechanisms and clinical outcomes by platform type. Mortality

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outcomes on platforms with and without surgical capability were also compared. We hypothesized there would be a downward trend of injuries and fatalities on US naval ships during the study period and that mortality outcomes would be improved on ships with an embarked surgical capability.

METHODS

The Naval Safety Command (NSC) database is maintained to "identify, mitigate or eliminate hazards,"[26] and prospectively tracks all mishaps resulting in property or equipment damage, injury, and loss of life. While included in the database, specific injury patterns or clinical outcomes are not routinely tracked. After institutional review board approval, all mishaps included in the NSC database from 1970 through 2020 were retrospectively reviewed. The STROBE guideline was used to ensure proper reporting (Supplemental File, http://links.lww.com/TA/D33).

Mishaps were analyzed for "active service" US naval ships defined as "commissioned" United States Ships (USS) or as "in-service" ships for United States Naval Ship (USNS) vessels, which are comprised of primarily active-duty navy crews versus primarily civilian mariner crews, respectively. All in-port or underway mishaps that resulted in injury or fatality were included, those that did not were excluded. Mishaps occurring on surface and subsurface (submarines) vessels contained the full 50-year period of data, whereas aviation and flight-deck-related mishaps were only recorded starting in 1980.

Exact crew manifests for all naval vessels throughout their years of service are not publicly available, so standard crew complements were assumed for all of the USS and USNS ships. Using individual commissioning and decommissioning dates, each ship's years of active service were used to estimate the at-risk period to calculate incidence rates. For each year of the study period, each ship, its years of active service, and estimated standard crew complements were determined using the official Naval Vessel Register (NVR)[27] and the annual reference Jane's Fighting Ships for the years 1970, 1980, 1990, 2000, 2010, and 2019.[28–33] Identified crew complements were also cross-referenced using the unofficial websites Navsource Naval History (https://www.navsource.org) and https://www.navysite.de.

Injury mechanisms were collected for all mishaps meeting inclusion criteria. Each ship was also categorized based on its medical capability as defined by standard US military designations: Role 2 platforms have damage-control surgery and resuscitation capability, whereas Role 1 platforms provide unit-level medical care, self-aid, buddy aid, and tactical combat casualty care (TCCC).[34] For each class of vessel included in the NSC database, a determination was made as to whether the vessel would routinely embark with a damage-control surgical capability or not.

Injuries were defined as all identified naval personnel injured during surface and subsurface vessel mishaps who survived, fatalities were those who did not survive the mishap, and casualties were defined as all identified injuries + fatalities. Using the cross-referenced cumulative standard crew complements of all active service US naval vessels identified for each year of the study, casualty, injury, and fatality incidence rates per 100,000 person-years (100k person-years) in each decade of the study were calculated. Individual mechanisms were then identified and trends per year and decade were calculated. Mortality rate comparisons between Role 1 and Role 2 vessels for the casualty types of "fall and blunt trauma," "fire, burn, smoke, and chemical exposure," "man overboard," and the combination of all three was performed using a two-sample Z-test for proportions; significance was set with an alpha of 0.5. Statistical analysis was performed using Microsoft Excel version 16.54 (Seattle, WA).

RESULTS

A total of 878 injury-related combat and non-combat-related mishaps were identified aboard USS and USNS vessels causing 3127 total casualties, including 2,079 injuries (66.5%) and 1048 fatalities (33.5%). Table 1 lists the 15 most commonly identified non–combat-related injury mechanisms, their associated mortality, and year of most recent occurrence. Excluding self-harm and medical emergencies, injury mechanisms of electrocution, accidental weapons discharge, blunt head trauma, man overboard events, explosion, fall from height (other than man overboard), mass casualty events following collisions, ordinance-related mishaps, chemical exposure, and inhalational injury, blunt torso trauma, and fire or burn-related mishaps resulted in the highest mortality. Of the 223 extremity injuries, 83.8% were to the hand or fingers, and 11.6% to the foot.

Table 2 provides the incidence rate by decade for selected non-combat injury mechanisms sustained on surface vessels and submarines, respectively. Figure 1 demonstrates the total number of surface and subsurface incidents (1970–2020) as they correlated with noteworthy international events and changes in US National Defense Strategy impacting naval operations. Over the 50-year study period, the overall incidence rate for all events decreased; each subsequent year was associated with a 0.5883 decrease per 100 k person-year (r^2 = 0.303). However, between 2000 and 2020 there were casualty "spikes" due to various maritime mass casualty incidents, especially involving collisions. In 2005, the submarine USS San Francisco (SSN-711) collided with an underwater mountain while submerged causing 98 injuries (71.5%) and one fatality (0.007%) from severe traumatic brain injury (TBI) in the estimated crew of 137. In 2017, the USS Fitzgerald (DDG-62) and the USS John S. McCain (DDG-56) with combined crews of 712 Sailors were involved in different collisions with surface merchant vessels resulting in 68 (9.6%) injuries and 17 (2.4%) fatalities. During the study period, there were 14 different collision events identified, injuring 274 total crew with an overall mortality of 41.9% (Table 2).

Noncombat aviation mishaps, fatalities, and injuries (1980–2020) all decreased over the course of the study; each subsequent year was associated with a 0.9168 decrease per 100k person-years (r^2 = 0.3224) (Fig. 2). Supplemental Table 1, http://links.lww.com/TA/D34, shows the incidence rate by decade for non-combat, aviation-related injury mechanisms and their associated mortality. The most common mechanism was blunt injury associated with man-overboard events (259 casualties, 46.3% mortality), closely followed by blunt injury on the flight deck (221 casualties, 27.1% mortality). Ejections were next most common, followed by mid-air collisions and man overboard without a blunt injury component.

TABLE 1. Top 15 Noncombat Surface and Submarine Causes of Injury or Death 1970–2020

Injury Mechanism	Casualties (n)	Mortality (%)	Most Recent Occurrence
Fire/burn/smoke inhalation injury (103 events)	923	13	2018
Man overboard (220 events)	352	71.9	2018
Collision (14 events)	275	40.3	2017
Extremity amputation, crush, or laceration	223	0	2019
Blunt torso/chest trauma	153	26.1	2018
Explosion (16 events)	106	60.4	2003
Chemical exposure/inhalation injury (27 events)	104	27.9	2004
Fall from height (other than man overboard)	75	59.2	2020
Blunt head/neck trauma	34	73.5	2005
Electrocution	32	90.6	2018
Ordinance-related mishap	24	37.5	2004
Eye trauma	17	0	2018
Cardiac arrest	17	100	2015
Suicide	12	91.7	2018
Accidental discharge (gunshot wound)	8	75	2004

Figure 3 shows the total combined number of surface, subsurface, and aviation mishaps by decade displayed independently and with all events combined. The spike in total events between the 1970s and 1980s decades is due to the inclusion of aviation mishaps, which started in the 1980s. In the 1970s, the casualty rate per 100 k person-years was 29.11, which decreased to 9.14 per 100k person-years in the 2010s. Flight deck, surface, and subsurface operational environments saw an overall reduction in the rate of injury and fatalities per 100k person-years during the study period.

Active in commission USS naval vessels were attacked six times over 50 years causing 77 injuries and 57 fatalities; a rate of 2% and 1.5% for the estimated crews, respectively (Table 3). There was a wide range across these events. The USS Tripoli (naval mine strike) had four injuries and no fatalities. Whereas, the 1987 Exocet missile attack on the USS Stark (FFG-31) caused 58 casualties (26.3%), with 21 injuries (9.5%) and 37 fatalities (16.8%). The USS Cole (DDG-667) attack (improvised explosive device) caused 37 injuries (10.9%) and 17 fatalities (5%).

There was a higher overall mortality rate associated with Role 1 platforms compared with platforms that had a Role 2 capability for select injury mechanisms (0.334 vs. 0.250, $p < 0.05$). Mortality increased after falls from height and blunt trauma on Role 2 platforms compared with Role 1 (0.725 vs. 0.330, $p < 0.01$). However, mortality was significantly less on platforms with Role 2 capability for chemical, fire, and burn-related injuries (0.093 vs. 0.190, $p < 0.05$) compared with Role 1. There was no difference in mortality after man-overboard incidents (0.729 for Role 1 vs. 0.647 for Role 2, $p = 0.348$).

DISCUSSION

A naval warship is an inherently high-risk environment with innumerable moving pieces of machinery and equipment that can cause bodily blunt force trauma with seemingly endless hatches to walk through risking injury to hands and fingers, and multiple ladder wells and decks to potentially fall from. While morbidity and mortality from injuries remain high for certain mechanisms independent of operational platform, the NSC can remain confident that its mission of mitigating hazards is being met as overall casualty incidences have decreased over the 50-year study period. However, severe injuries that occur on Role 1 capable vessels have a higher overall mortality than Role 2 vessels.

In addition to chains, heavy ropes, and mechanical equipment, depending on ship class and configuration, forklifts, cranes, and smaller boats may also be found aboard. Smaller warships, such as destroyers (DDG) and cruisers (CG), may operate flight decks for embarked helicopters. Via landing craft and helicopters amphibious warships are designed to transport and deploy assault forces composed of armored vehicles, and trucks. Aircraft carriers conduct continuous launching and recovery of both rotary- and fixed-wing aircraft. Given these dynamic environments, that more mishaps resulting in injury were not identified in the present study is a testament to the culture of safety throughout the United States Navy. While a naval warship has no civilian counterpart, compared with other high-risk civilian occupations the risk of occupational injury to Sailors is relatively low. According to the Bureau of Labor Statistics, the incidence rate of mining-related nonfatal occupational illness and injury was 6.3 cases per 100 full-time workers (100 person-years) in 1994, dropping to 2.1 in 2021. Similarly, for construction (11.8 down to 2.5) and ship/boat building/repairing (27.6 down to 6.4) the incidence rates decreased during the same period. For comparison 6.4 per 100 person-years is equivalent to 6400 non-fatal occupational injuries and illnesses per 100 K person-years.[35,36] While these data are difficult to compare directly to the present study, it speaks to the overall safety of naval deployments and it mirrors our findings of falling occupational injury rates over time. Indeed, this is a nationwide trend, with the Occupational Safety and Health Administration reporting a 66% drop in overall worker death rates since its founding in 1970 through 2020; injury and illness rates were reduced by 75% between 1972 and 2020.[37]

To our knowledge, this is the first comprehensive analysis of US Navy shipboard injuries in the operational setting and provides a blueprint of the potential injuries embarked providers will manage during routine operations and gives insight into shipboard injury patterns that may occur during combat operations. The most common non-fatal injuries identified were lacerations, crush injuries, and partial amputations involving the hands and fingers. The nearly 100-fold increase in extremity crush/amputation from the 1970s to 1980s (Table 2) could be due to initial underreporting. Another explanation is the increase in surface ship deployments during the Iran-Iraq war (1980–1988). An analysis of US Navy surgeon case logs during warship deployments from the 1990s through 2017, found that the average General Surgeon operatively managed one to three orthopedic hand injuries per 7-month deployment, but currently receives no formal training in the management of hand and finger injuries in military residencies.[38] Injuries to the hands and fingers can have a profound impact on individual quality of life and overall military readiness. A study of traumatic phalangeal amputations from all military branches

TABLE 2. Noncombat Surface and Subsurface Incidence Rates (100k Person Years) for Severe Mechanisms of Injury by Decade

Surface Ship Injury Incidence (100 K Person Years) Rates by Decade

	1970s			1980s			1990s			2000s			2010s			1970–2020	
Injury mechanism	**#**	**Incidence**	**Mortality**	**#**	**Incidence**	**Mortality**	**#**	**Incidence**	**Mortality**	**#**	**Incidence**	**Mortality**	**#**	**Incidence**	**Mortality**	**#**	**Mortality**
Extremity crush or amputation*	1	0.035	0.0%	87	3.020	0.0%	80	3.534	0.0%	16	0.902	0.0%	16	1.009	0.0%	200	0.0%
All blunt trauma**	84	2.913	22.6%	50	1.736	56.0%	24	1.060	45.8%	13	0.733	23.1%	14	0.883	0.0%	185	33.0%
Collision	77	2.671	63.6%	7	0.243	14.3%	1	0.044	0.0%	0	0.000	N/A	68	4.287	80.9%	153	68.6%
Electrocution	13	0.451	92.3%	10	0.347	100.0%	4	0.177	75.0%	1	0.056	100.0%	2	0.126	50.0%	30	90.0%
Explosion	36	1.249	47.2%	59	2.048	79.7%	0	0.000	N/A	74	4.170	63.5%	0	0.000	N/A	169	65.7%
Fall	21	0.728	100.0%	26	0.903	53.8%	19	0.839	42.1%	7	0.394	28.6%	2	0.126	0.0%	75	60.0%
Fire, burn, smoke	428	14.845	12.6%	317	11.004	7.3%	110	4.859	32.7%	59	3.325	6.8%	2	0.126	0.0%	916	12.8%
Man overboard	129	4.474	86.0%	91	3.159	67.0%	80	3.534	47.5%	23	1.296	60.9%	2	0.126	100.0%	325	69.5%

Subsurface (submarine) injury incident rates (100k person years) by decade

	#	**Incidence**	**Mortality**	**#**	**Incidence**	**Mortality**	**#**	**Incidence**	**Mortality**	**#**	**Incidence**	**Mortality**	**#**	**Incidence**	**Mortality**	**#**	**Mortality**
Extremity crush or amputation*	0	0.000	N/A	5	3.284	0.0%	14	11.425	0.0%	2	2.281	0.0%	2	2.264	0.0%	23	0.0%
All blunt trauma**	9	6.615	22.2%	2	1.314	0.0%	1	0.816	0.0%	1	1.140	100.0%	0	0.000	N/A	13	23.1%
Collision	14	10.290	0.0%	0	0.000	N/A	0	0.000	N/A	107	122.033	9.3%	0	0.000	N/A	121	8.3%
Electrocution	1	0.735	100.0%	1	0.657	100.0%	0	0.000	N/A	0	0.000	N/A	0	0.000	N/A	2	100.0%
Explosion	0	0.000	N/A	0	0.000	N/A	1	0.816	0.0%	0	0.000	N/A	0	0.000	N/A	1	0.0%
Fire, burn, smoke	1	0.735	0.0%	3	1.971	100.0%	2	1.632	0.0%	0	0.000	N/A	1	1.132	0.0%	7	42.9%
Man Overboard	5	3.675	100.0%	21	13.795	42.9%	0	0.000	N/A	1	1.140	100.0%	0	0.000	NA	27	55.6%

*Excludes extremity lacerations.

**Combines all blunt trauma to the head, neck, or torso

#, number of casualties; N/A, not applicable.

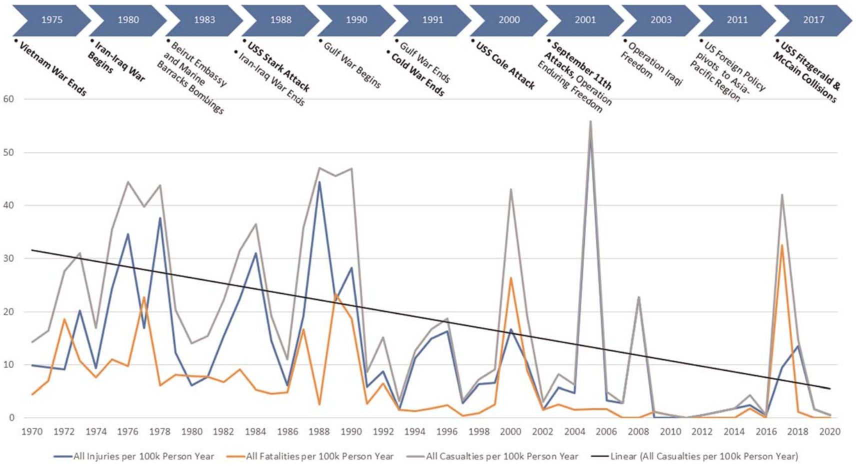

Figure 1. Surface and submarine casualties 1970–2020 by clinical outcome.

found that 6% went on to medical separation.[39] This is significant, and given the frequency of extremity injuries and amputations in this study, focused training on common injuries encountered in the deployed maritime environment including both operative and nonoperative treatment and improvement of functional outcomes should be implemented.

While only 14 injury-causing collision events were identified, they caused significant damage to naval warships resulting in large numbers of injuries and fatalities. Not accounted for in the NSC data are those casualties that have occurred aboard civilian vessels involved in collisions with naval vessels. For example, the 2001 collision between the submarine USS Greenville (SSN 772) and the Japanese fishing trawler Ehime Maru resulted in 9 deaths (26%) of the 35 embarked crew.[40] The USS Fitzgerald and USS John S. McCain collisions with large civilian commercial ships are illustrative of the devastating impact of collisions on naval warships. Both involved significant breeches of the ship's hull below the waterline; 10 USS McCain Sailors and seven USS Fitzgerald Sailors died from drowning. In these two collisions, 20% of the 85 casualties died in the mishap. Three USS Fitzgerald Sailors suffered some type of TBI. Other injuries among survivors included seawater or fuel aspiration, extremity fractures, lacerations, and chemical burns. Fire can also occur after collisions. The 1989 collision of the USS Kinkaid (DD-965) with a civilian vessel caused a berthing area to flood with seawater and a fire in the starboard torpedo magazine.[17]

Depending on injury mechanism, mortality rates of 13% to 90.6% were identified (Table 1). The clinical skillsets required to manage these injured and critically ill patients include non--operative and operative management of traumatic injuries, burns, electrocution, smoke inhalation, and TBI. Knowledge of critical care principles in an under-resourced environment is necessary to meet each of these clinical challenges. This also holds true for naval warfare-related injuries; the attacks on the USS Stark and USS Cole injured 21% (112) of the combined crew, killing 48% of those injured. Of the 58 survivors, 6.9% suffered penetrating wounds, 15.5% burns, 24.1% fractures, 17.2% TBI, 10.3% asphyxiation/inhalation, and 8.6% immersion/hypothermia-related injuries.[17] The most recent examples of large-scale modern naval warfare during a peer/near-peer conflict occurred during the 10-week-long Falklands War in 1982 between Argentina and the United Kingdom. Of the 516 battle casualties (land and sea), 52.3% suffered penetrating wounds, 21% burns, 15.5% asphyxiation/inhalation, and 13.4% immersion/hypothermia injuries.[17,41,42]

During routine or contingency operations, deployed shipboard providers must be clinical experts in providing trauma,

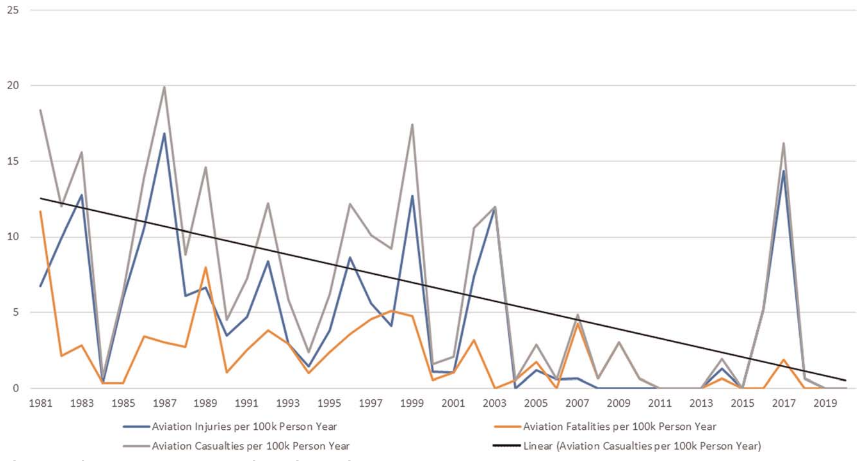

Figure 2. Aviation-related casualties 1980–2020 by clinical outcome.

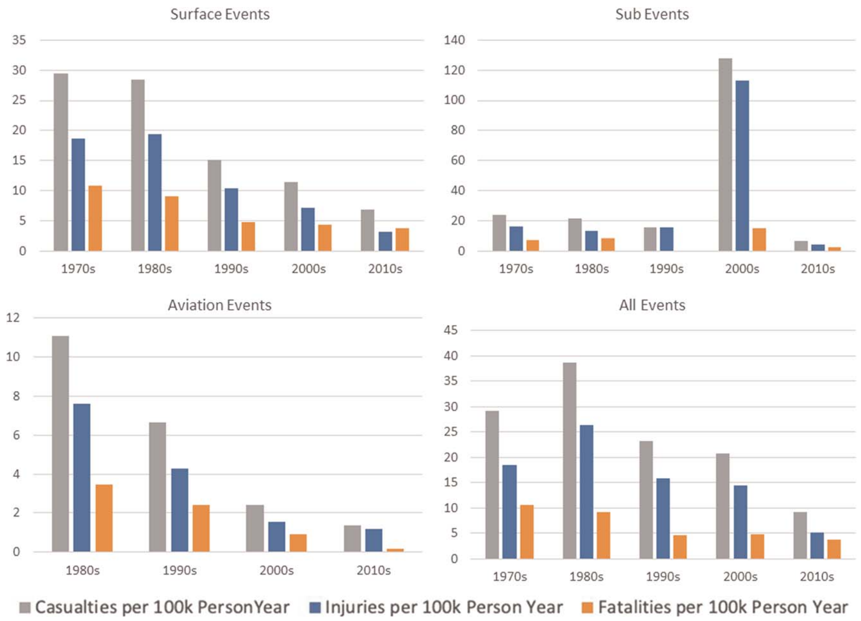

Figure 3. Surface, submarine, and aviation-related casualties by decade and clinical outcome.

burn, and critical care including initial resuscitation and ongoing stabilization in the maritime environment for prolonged periods. In a review of naval mass casualty incidents, those injured were transferred off the damaged ships within minutes to up to nearly 8 hours after injury.[17] Rapid medical evacuation off ship will not likely be possible in a future peer adversary conflict. During future multidomain, large-scale combat operations over large geographic areas, the US Military and allies are unlikely to have the freedom of maneuver, communication, and air superiority characterized by the last 20 years of war. Instead of evacuating patients in a matter of hours, shipboard medical departments will have to manage critically ill or injured patients for up to 4 days to 7 days[17,21,22] requiring clinical skill sets beyond TCCC for Role 1 teams and the damage-control surgery and resuscitation capabilities of maritime surgical teams. Role 1 providers will need to be proficient in Prolonged Casualty Care (PCC) principles, including advanced airway management, correcting reversible causes of shock beyond hemorrhage (e.g., sepsis, and oral and intravenous burn resuscitation), and basic critical care nursing skills.[43] In this potential future scenario, maritime surgical teams will need to provide more than damage-control techniques prior to evacuation; different, more complex, and definitive surgical management strategies may be required. For the most severely injured, a comprehensive understanding of supporting organ system failure, particularly respiratory failure, in austere environments will be a critical capability requirement. Said another way, maritime surgical teams must be experts in providing austere critical care for prolonged periods; a skill set not routinely required of these teams during the last 20 years of war.

Compounding these issues is that many General Surgeons may be ill-equipped to manage the injuries identified in this study without better resources and clinical training. Navy General Surgery education and pre-deployment training should change clinical rotations to enhance the exposure of residents and staff surgeons to expected types of injuries focusing on the management of trauma, burn, and critical care in austere environments. Currently, most maritime surgical team providers do not receive experience managing burn or critical care patients beyond their residency rotations. The average surgical resident receives variable exposure to surgical critical care and burns. An analysis of 7,299 graduating surgical residents applying for board certification, found that during residency the mean exposure to burns is 0.8 months and 3 months for surgical critical care.[44] Given the well-documented decreasing surgical workload

TABLE 3. Known Attacks on United States Navy Vessels, 1970–2020

Year	Ship	Mechanism	Estimated Compliment	Injured (%)	Fatal (%)
1972	USS Goldsborough (DDG-20)	Coastal Artillery Fire	354	2 (0.56)	3 (0.8)
1987	USS Stark (FFG-31)	Air Missile Attack	220	21 (9.5)	37 (16.8)
1988	USS Samuel B. Roberts (FFG-58)	Naval Mine	330	10 (4.9)	0
1991	USS Princeton (CG-59)	Naval Mine	330	3 (0.9)	0
1991	USS Tripoli (LPH-10)	Naval Mine	2,358	4 (0.17)	0
2000	USS Cole (DDG-67)	Improvised Explosive Device	338	37 (10.9)	17 (5)
		Total	3,805	77 (2)	57 (1.5)

at all military hospitals,[45] it is hard to imagine any provider maintaining a robust critical care experience if they are only sustaining clinical skills at their assigned hospital.

A provider unique to the Navy and Marine Corps is the Independent Duty Corpsman (IDC); who is at the tip of the trident (or spear) leading medical care in the DMO environment. The gap in IDC clinical skills sustainment is even greater compared with Medical and Nursing Officers. IDCs receive no regular clinical experience or specific training beyond primary care and TCCC to prepare them to perform PCC and other advanced resuscitative and procedural skills. Current Fleet strength (fiscal year 2023) consists of 242 active surface and subsurface USS vessels; 20 (8.3%) routinely provide a Role 2 capability.[27] Of the 222 Role 1 capable platforms, approximately 90% have an IDC as the senior medical provider; the other 10% have a General Medical Officer who has often completed only an internship. While IDCs have routine access to physicians for guidance, communication is not always available. Of the 14 at-sea collisions identified, 40.3% of casualties died (Table 1); in 10 (71%) the Role 1 medical department was led by an IDC performing the initial triage and resuscitation. This highlights the importance of IDCs within the maritime trauma system and the crucial need for the implementation of advanced training, including ongoing clinical sustainment experiences relevant to injuries encountered in the deployed maritime environment.

Maritime whole blood availability aboard all US naval vessels is another gap when considering the need for prolonged holding at sea during sustained combat operations. At the time of this writing, only 8.7%[21] of all active surface and subsurface vessels have stored frozen red blood cells and plasma available. The 11 Role 2 capable aircraft carriers only have a walking blood bank (WBB). However, a recent policy was initiated to mandate 5 units of low-titer whole blood available during deployments. Including aircraft carriers and amphibious warships (with stored blood products), only 17.4%[42] of all active USS vessels are WBB capable. None of the IDC-led medical departments including destroyers, cruisers, and submarines are WBB capable; whole blood resuscitation in hemorrhagic shock is foundational to both TCCC and PCC. Furthermore, both prehospital blood transfusion and within minutes of injury in combat casualties are associated with improved 24-hour and 30-day mortality, highlighting the need for more comprehensive blood product availability in the deployed maritime environment.[46]

In the present study, mortality for all mishap and naval warfare casualties was significantly higher on Role 1 capable vessels. While it would be easy to attribute this difference to Role 1 provider clinical training and experience, all collisions and the USS Stark and USS Cole attacks occurred on Role 1 vessels; mishaps characterized by a high number of significantly injured casualties. There was no difference in mortality after man overboard events on ships with surgical capability compared with those without, highlighting the injury mechanism severity. Unsurprisingly the mortality after falling from height was higher on Role 2 capable vessels because these ships tend to be much larger with greater heights to fall from. The mortality was higher for chemical, fire, and burn-related injuries on Role 1 capable vessels. There is no way to know if these patients would have survived had they been on Role 2 capable ships, but it does highlight the need for both training and clinical skills sustainment experiences to prepare IDCs to care for these types of patients for prolonged periods.

There is precedent for enhanced Role 1 provider training and whole blood availability. Equivalent to the modern IDC, World War II saw the deployment of "pharmacist mates" on submarines serving as the "medical officer, the dentist, the nurse, and the chaplain all rolled into one."[47,48] On small surface warships such as destroyers, they routinely managed all aspects of shipboard WBBs, collecting whole blood just prior to naval engagements and resuscitating injured casualties. While these sailors did not possess medical degrees, they were trained to provide the surgical management of appendicitis, initial traumatic injury care, whole-blood resuscitation, and prolonged casualty care. A commitment to training the modern Role 1 provider in a similar manner as their 1940s predecessors may result in better clinical outcomes.

Military medicine has begun focusing to improve mentoring technologies available to the deployed provider. While some resources are available to help deployed maritime providers,[43,49] as Navy Medicine prepares for DMO and PCC contingencies, enhancing their communication capabilities is an opportunity to augment deployed clinical capabilities. In the experience of one author, deployed in the 7th Fleet area of responsibility, an IDC had to rely on asynchronous email to communicate concerns of a patient with a potential necrotizing soft tissue infection. Telephonic communications were not available, and the IDC used email to send pictures, and await recommendations from the surgeon hundreds of miles away on another ship. By improving communications beyond those currently available, the clinical capability of deployed assets can be enhanced. However, during a peer-peer conflict characterized by restricted bandwidth and an emphasis on the minimization of electronic signatures by the fighting naval force, routine synchronous communication will unlikely be available, requiring asynchronous mentoring technologies. A focus on developing technologies to promote synchronous and asynchronous virtual, mixed, or augmented reality technologies will allow for the mentorship of IDCs or other non-surgically trained providers during DMO.

This study has inherent limitations. As it is a retrospective review of a non-clinical database, underreporting data or incorrectly characterizing injuries to the NSC either intentionally or unintentionally by non-medical personnel submitting the data are both possible. Hassel et al.[50] has shown a previous trend of underreporting maritime accidents to databases, and it is reasonable to extrapolate their findings to naval injuries at sea, particularly any minor injuries. As there is no way to determine specific underway periods for each vessel, the at-risk period used to calculate incidence rates was determined by each ship's total years of active service, potentially falsely lowering calculated incidence rates. However, depending on the ship, many sailors live aboard when in port, and some of the mishaps identified occurred in port. The NSC database of aviation-related mishaps was significantly different from the surface and submarine mishap databases. This is significant as less information with fewer descriptions of injuries was available.

Navy Medicine must understand the risks our Sailors and Marines face while at sea to improve survivability after injury during current and future DMO. Therefore, the authors recommend that the NSC, in partnership with Navy Medicine and the Joint Trauma System, routinely track injury and illness at sea with clinical outcomes to continually improve Sailor and Marine survivability and enhance the lethality of the Naval force. The combination of improved remote mentoring technologies, relevant clinical experience, and robust at-sea injury data will allow for the continuous process improvement of shipboard safety parameters and optimize the clinical training and capabilities of forward-deployed Independent Duty Corpsmen, Medical Officers, and surgical teams.

AUTHORSHIP

M.D.T. participated in the study concept. D.A.B., M.C.V., and M.D.T. performed the literature search and primary data collection, designed the study, interpreted the data, drafted the article, and performed critical revisions. J.K. performed data and statistical analysis. R.M., K.D.C., and T.D.E. participated in data interpretation and critical revisions.

DISCLOSURE

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