

# Between the devil and the deep blue sea: A review of 25 modern naval mass casualty incidents with implications for future Distributed Maritime Operations

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**ABSTRACT:**

In the future, United States Navy Role 1 and Role 2 shipboard medical departments will be caring for patients during Distributed Maritime Operations in both contested and noncontested austere environments; likely for prolonged periods of time. This literature review examines 25 modern naval mass casualty incidents over a 40-year period representative of naval warfare, routine naval operations, and ship-based health service support of air and land operations. Challenges, lessons learned, and injury patterns are identified to prepare afloat medical departments for the future fight. (*J Trauma Acute Care Surg.* 2021;91: S46–S55. Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.)

**LEVEL OF EVIDENCE:** Literature Review, level V.

**KEY WORDS:** Mass casualty; military; maritime; burn; surgery at sea.

The United States' experiences in Iraq, Afghanistan, and Syria during nearly 20 years of conflict have demonstrated the paramount importance of readiness, predicting the needs of the current and future battlespace. Anticipating potential power competition from peer and near-peer adversaries, the US Navy performed a Force Structure Assessment in 2016, resulting in the goal to achieve and maintain a fleet of 355 total ships by 2035 and 500 manned and unmanned vessels by 2045,<sup>1</sup> compared with the current fleet of 253 ships and submarines.<sup>2</sup> In 2018, the Chief of Naval Operations provided a mission statement in the opening comments of "A Design for Maintaining Maritime Superiority" (version 2.0): "The United States Navy will be ready to conduct prompt and sustained combat incident to operations at sea. Our Navy will protect America from attack, promote American prosperity, and preserve America's strategic influence. US naval operations—from the seafloor to space, from the blue water to the littorals, and in the information domain—will deter aggression and enable resolution of crises on terms acceptable to the United States and our allies and partners. If deterrence fails, the Navy will conduct decisive combat operations to defeat any enemy." To meet this intent, in

addition to increasing fleet size, the US Navy will "continue to mature the Distributed Maritime Operations (DMO) concept."<sup>3</sup> While still being developed, implicit in the DMO concept is that individual components of the naval force will be more geographically dispersed, with connectivity provisioned by a "comprehensive operational architecture" of new and developing technology to provide sea control over a larger geographic area.<sup>1,3</sup>

Rapid transport has been a hallmark of casualty care in recent land conflicts. It is not uncommon that a casualty will move greater than 8,000 miles in less than 72 hours and be cared for at multiple levels of care with escalating capabilities.<sup>4</sup> In the maritime environment, support of DMO will not fit into the current paradigm of combat casualty care (Fig. 1); prolonged care of casualties and those acutely ill with medical and surgical disease will be necessary not only by surgical teams, but also by Role 1 medical departments led by Independent Duty Corpsman. The requirement for prolonged casualty care is frequently discussed, but rarely necessary; however, DMO will make it an essential capability. The aim of this review is to examine maritime mass casualty incidents (MCIs) to inform and prepare for Naval Health Service Support in the current and future operating environment. By identifying challenges, understanding maritime injury patterns, resource requirements, and studying previous lessons learned we can improve readiness and prepare shipboard Role 1 and Role 2 medical teams for contested and uncontested DMO.

## METHODS

An English Language search was performed using PubMed (MEDLINE), Embase, Ovid Medline, and EBM Review from January 1, 1980, to October 16, 2020, including the terms naval medicine, maritime, blast injuries, disasters, MCI, mass casualty event, burn, burn injury, triage, and the Falklands War. A citation review of key studies and review articles was also performed to

Submitted: January 26, 2021, Revised: February 21, 2021, Accepted: March 10 2021, Published online: March 30, 2021.

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site ([www.jtrauma.com](http://www.jtrauma.com)).

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DOI: 10.1097/TA.0000000000003199

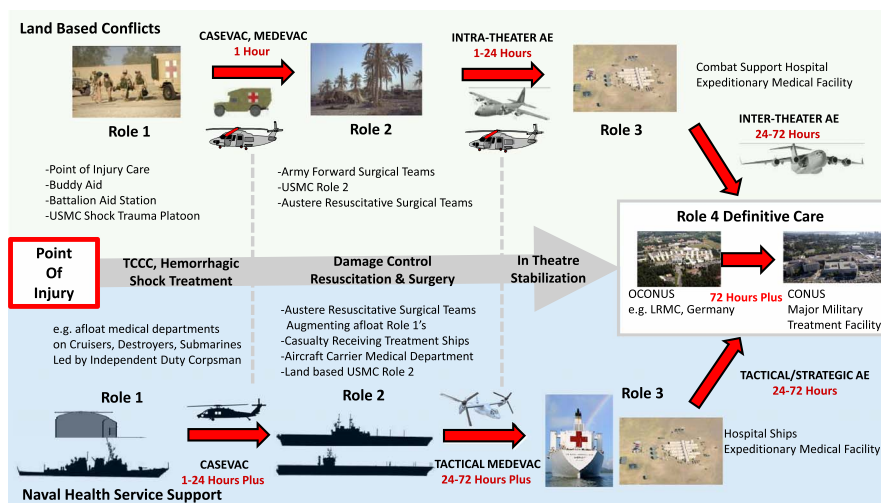


Figure 1. Current paradigm of combat casualty care (adapted from Bailey et al.<sup>4</sup>).

identify additional eligible studies. Inclusion criteria included any article giving a detailed description (crew size, incident details, casualty numbers, injury descriptions, time to evacuation) of single or multiple naval MCIs at sea. Exclusion criteria included MCI that occurred before 1980, those without detailed descriptions and civilian only MCI. Open-access Chief of Naval Operations reports and Navy Judge Advocate General command investigation reports ([https://www.jag.navy.mil/library/jagman\\_investigations.htm](https://www.jag.navy.mil/library/jagman_investigations.htm)) were reviewed using the same inclusion and exclusion criteria. The authors' (M.J.S., J.B.) personal experiences during maritime MCI were also included. The MCI details were abstracted, and unique challenges were identified. Where possible, the percentage of crew who were injured or died was based on the total number of crew at risk of during the event. If the entire ship was at risk (i.e., sunk or fatally damaged), then casualty rates were based on the total crew complement at the time of the event. If only a subset of the crew were potentially at risk, casualty rates were based on only the crew potentially affected by the event, not total ship complement. Total crew complement at the time of the MCI was determined by either the review or if not available it was estimated based on standard US Navy crew complements obtained from the Naval Vessel Register, available at <https://www.nvr.navy.mil/SHIPS.html>. Identified injury types were compared with historical shipboard injury patterns during the World War II.

## RESULTS

Figure 2 shows the PRISMA diagram; after title review, duplicate removal, and abstract review, 54 articles and 15 open access reports underwent full text review. Ultimately, 36 journal articles/reports and 2 MCIs involving the authors (M.J.S., J.B.) were used for data abstraction (Fig. 1). Twenty-five MCIs were identified, including 10 during the Falklands War, and 14 involving the US Navy. A detailed description of each can be found in the Supplemental Digital Content (<http://links.lww.com/TA/B973>).

### Falklands War

The Falklands War was a short (10 weeks) war with a large maritime component between Argentina and the United Kingdom in 1982 over territories in the South Atlantic including the

Falkland Islands; 23 British ships were lost or damaged.<sup>5</sup> Table 1 describes 10 identified maritime MCI: one involving an Argentinian vessel and nine involving UK ships. As 7 of the 10 ships were sunk shortly after attack or were damaged beyond repair Table 1 injury and death rates are based on the total estimated crew complement of each ship. The overall injury rate was 8.6% and mortality was 14.7%, with most dying instantaneously due to explosions, burns, or asphyxiation from smoke inhalation. The bombing of the *Sir Galahad* troop transport resulted in injuries to 50% of those aboard. Of the 169 injured, nearly half (49%) suffered burn injuries, mostly to the face and hands.<sup>6</sup> Of these, 46 required evacuation back to the United Kingdom for further treatment.<sup>7</sup> Most injured during the war were initially cared for on the hospital ship SS Uganda, including 666 "battle related conditions." Of these, smoke inhalation (12%) and hypothermia (10.3%) were common. Of 516 actual "battle casualties," burns affected 21% and penetrating wounds 52.3%.<sup>7,8</sup> As many attacks caused ships to sink or rendered them inoperable, the injured and uninjured survivors were off the ship, en route to further care within minutes to 1 hour except for the HMS Sheffield (4 hours)<sup>9</sup> and the HMS Plymouth (<1.5 hours).<sup>10</sup> The injured from the *Galahad* were receiving treatment on the hospital ship Uganda within 3 hours of injury.<sup>7</sup> Information was not available on ship medical roles of care; however, they all likely had the equivalent of a Role 1 capability.

### Israel Defense Forces Boarding of the Mavi Marmara

Thirteen Israel Defense Forces commandos boarded the civilian vessel Mavi Marmara while it was attempting to break an Israel Defense Forces naval blockade and were attacked by a mob of passengers with various weapons. All commandos survived, but 69% were injured. Of the 700 passengers, 7.6% were injured and 1.3% died. The most severely injured were hoisted up to a helicopter for evacuation, taking up to 40 minutes for five patients. Surgical interventions in survivors after evacuation to local hospitals included craniotomy (2), exploratory laparotomy (5), diaphragm repair (1), bowel repair (2), vascular repair (2), and operative management of long bone (2) and mandible (1) fractures.<sup>11</sup>

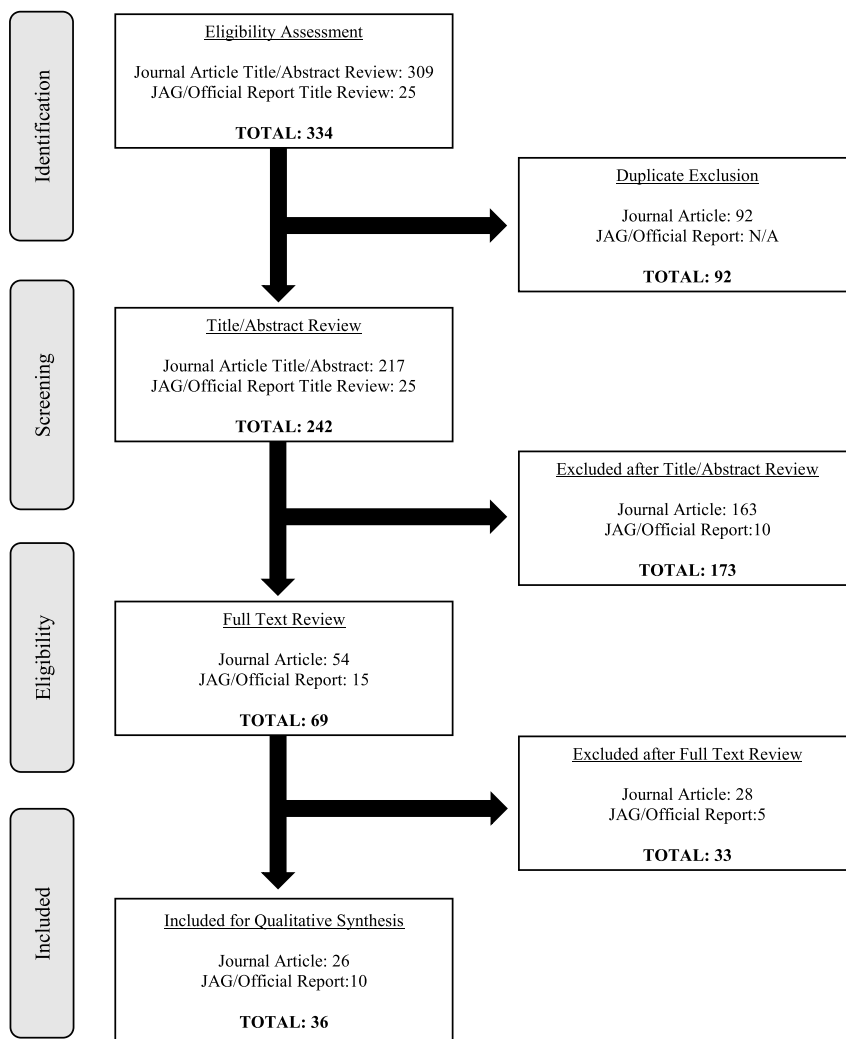


Figure 2. PRISMA flow diagram.

### United States Ship Stark and United States Ship Cole Attacks

Table 2 describes 11 MCI involving U.S. Naval vessels including a terrorist bombing (1), missile attack (1) and 9 non-combat

related MCI. The attacks on the United States Ship (USS) Stark (FFG 31) and USS Cole (DDG 67) resulted the deaths of 9.7% and injured 10.4% of the combined crews (Table 2).<sup>12-17</sup> On the *Stark*, smoke spreading through the ship rendered the small medical

TABLE 1. Characteristics of 10 Falklands War Maritime MCIs

Date	Ship	MCI	Crew	Time on ship (h)	Injured (%)	Death (%)
May 02, 1982	General Belgrano <sup>6,7</sup>	Torpedo attack	1,095	0.34	N/A	323 (29.5)
May 04, 1982	HMS Sheffield <sup>8,9</sup>	Air attack (missile)	281	4	26 (9.3)	20 (7.1)
May 21, 1982	HMS Ardent <sup>6</sup>	Air attack	177	Min.	30 (16.9)	22 (12.4)
May 23, 1982	HMS Antelope <sup>6</sup>	Air attack (bomb)	177	Min.	8 (4.5)	2 (1.1)
May 25, 1982	HMS Coventry <sup>6</sup>	Air attack (bomb)	287	0.34	30 (10.5)	19 (6.6)
May 25, 1982	SS Atlantic Conveyor <sup>6</sup>	Air attack (missile)	33	<0.5	N/A	12 (36.4)
June 08, 1982	HMS Plymouth <sup>6</sup>	Air attack	212	<1.5	5 (2.4)	0
June 08, 1982	RFA Sir Galahad <sup>6-8</sup>	Air attack (bomb)	340	Min.	169 (49.7)	48 (14.1)
June 08, 1982	RFA Sir Tristan <sup>6</sup>	Air attack (bomb)	51	Min.	0*	2 (2)
June 12, 1982	HMS Glamorgan <sup>6</sup>	Land attack (missile)	471	N/A	0*	12 (2.6)
Total			3124		268 (8.6)	460 (14.7)

All casualty rates are based on known or estimated total crew compliment at the time of the incident.  
HMS, Her Majesty's Ship; RFA, Royal Fleet Auxiliary; SS, steamship; Min., minimal; N/A, not applicable.

**TABLE 2.** Characteristics of 11 US Navy Maritime MCIs

Date	Ship	MCI	Location	Crew	Time on ship (h)	Injured (%)	Death (%)	Role of Care
Terrorist or missile attack								
May 17, 1987	USS Stark* <sup>12,13</sup>	Air Missile attack	Persian Gulf	220	2–3	21 (9.5)	37 (16.8)	1
October 12, 2000	USS Cole* <sup>14–17</sup>	Explosion	Yemen	338	1.5	37 (11)	17 (5)	1
Total 558						58 (10.4)	54 (9.7)	
Non-combat-related MCI								
April 28, 1988	USS Bonfish* <sup>18</sup>	Fire	Florida	92	0.5	21 (22.8)	3 (3.3)	1
November 11, 1989	USS* Kinkaid <sup>19</sup>	Collision	Straits of Malacca	340	24–36	16 (4.7)	1 (0.3)	1
April 19, 1989	USS Iowa** <sup>20</sup>	Explosion	Puerto Rico	2534 47**	N/A	0	47 (100)	2
June 20, 1990	USS Midway* <sup>21</sup>	Fire, Explosion	Japan	2533	2.5	3 (0.1)	8 (0.3)	2
October 30, 1990	USS Iwo Jima** <sup>22</sup>	Fire	Bahrain	2468 11**	0.5–2	1 (9)	10 (91)	2
January 08, 2005	USS San Francisco* <sup>23</sup>	Collision	Pacific Ocean	138	24	123 (96.1)	1 (0.7)	1
January 29, 2005	USS Kitty Hawk** <sup>24</sup>	Flight Deck Mishap	Japan	5000 28**	1–3	8** (28.6)	0	2
June 17, 2017	USS Fitzgerald* <sup>25</sup>	Collision	Japan	300	5.7–7.75	3 (1)	7 (2.3)	1
August 21, 2017	USS McCain* <sup>26</sup>	Collision	Singapore Strait	300	3.8	48 (16)	10 (3.3)	1
Total				3789	223 (5.9)	87 (2.3)		

N/A, not applicable.  
\*Casualty rates are based on known or estimated total crew complement at the time of the incident.  
\*\*Casualty rates based on the total number of crew and/or aircrew impacted at the time of the event, not the total crew complement.

spaces unusable and additional medical supplies including crystalloid had to be brought from another ship. In both, rapid triage occurred, sometimes in parallel and the injured were evacuated to advanced care within 1.5–3 hours of the attack.<sup>12,13</sup> Of the 21 injured on the *Stark*, two had second- and third-degree burns, five were rescued from the water; the remainder received minor injuries attempting to save the ship.<sup>13</sup> On the *Cole*, the flight deck<sup>13</sup> was utilized for initial triage and 37 survivors had the following injuries: long bone fractures (four open, two closed), concussion (5), subdural hematoma (1), rib fracture (3), clavicle fracture (1), complex ligamentous knee injuries (3), first and second degree burns of the face or extremity (4), tympanic membrane rupture (16), soft tissue injuries requiring antibiotics for cellulitis (25), inhalation injury (4), orbit fracture (1), mandible fracture (1), pulmonary contusion (1), and pulmonary blast injury (1).<sup>15–17</sup> Of the 16 deaths, two were officially categorized as potentially survivable: one died within minutes of injury from a depressed skull and basal skull fracture with subarachnoid hemorrhage; the other died from likely hemorrhagic shock 8 hours after the attack and after initial exploratory laparotomy, splenectomy and hepatorrhaphy at a local Aden hospital. The crew

member with the severe traumatic brain injury (TBI) likely would not have survived even though it was categorized as potentially survivable. It is unknown if the primary cause of death was from the TBI, or from a lack of an life-saving airway intervention.<sup>14,15</sup>

### US Navy Noncombat MCIs

Of the nine noncombat MCIs (Table 2), four involved fire or explosions, four involved a collision with another vessel or object, and one was from a flight deck mishap (Table 2).<sup>18–26</sup> The USS *Kinkaid* collision also resulted in a shipboard fire, but the USS *Fitzgerald* and USS *McCain* collisions did not.<sup>19,25,26</sup> The USS *Kitty Hawk* MCI is unique because a mishap occurred during an F-18 fighter jet aircraft carrier landing; an arresting wire broke causing a lower-extremity traumatic amputation on one of the flight deck crew and injured several others.<sup>24</sup> There were approximately 5,000 embarked crew at the time, but only 28 people could have been impacted by the mishap; 2 air crew and 26 flight deck crew. For the *Iowa* and *Iwo Jima* MCI, casualty rates are based on those impacted not the total crew complement. The total number of crew impacted by fire on the USS *Midway* is not known. It took 20 hours until all fires were

**TABLE 3.** Rotary Crash MCI Managed Aboard Casualty Receiving and Treatment Ships

Date	Ship	MCI	Location	Rotary Crew	Time on ship* (h)	Injured (%)	Death (%)	Role of Care
April 20, 1989	USS Belleau Wood	CH-53 Helicopter Crash	Korea	36	2–3	14	22	2
				CH-53				
2017	USS Bataan <sup>29,30</sup>	Blackhawk Helicopter Crash	US 5 <sup>th</sup> Fleet AOR	6	38–42	6	0	2
August 5, 2017	USS Bonhomme Richard	V-22 Osprey Crash	Australia	26	1	23	3	2
Total				68		43 (63.2)	25 (36.8)	

AOR, area of responsibility.

completely out, therefore casualty rates are based on the entire crew complement. Of all nine noncombat MCIs, there were 87 deaths (2.3%) and 223 injuries (5.9%). Of the 87 deaths, 55 (64%) were immediate from explosion or fire, 17 (19.8%) from drowning, 5 (5.8%) from complications related to massive burn injuries, 3 (3.5%) from asphyxiation secondary to smoke inhalation, and 2 (2.3%) from blunt TBI. Although one of the injured with TBI from the USS San Francisco submarine collision survived 24 hours until medical evacuation, ultimately the patient never regained consciousness and died.<sup>23</sup> The gun turret two explosions on the USS Iowa resulted in 47 nearly instantaneous deaths: 12 from blunt force injury, 30 from thermal related injuries, and 5 from both.<sup>27</sup>

Of the available information regarding the 223 injuries, 21.5% were minor soft tissue injuries or minor burns related to fuel exposure, 5.8% were from TBI, 4% were burn-related injuries, 4% were various fractures, and 1.8% were from aspiration of fuel or sea water (Table 2). The collision of the submarine USS San Francisco with a mountain rising from the ocean floor resulted in injuries to approximately 90% of its crew; 43 injuries were documented, 80 were not and classified as “other minor” (Table 2).<sup>23</sup> Of the 11 US ship MCIs, 7 had Role 1 medical capabilities, 4 had Role 2 surgical capabilities and time to evacuation to a higher level of care ranged from 0.5 hours to 24 hours to 36 hours. The most extended times for evacuation from the ship were on the *Kinkaid* (24–36 hours), *San Francisco* (24 hours), *Fitzgerald* (5.7–7.75 hours), and the *McCain* (3.8 hours), all in the US Indo-Pacific Command area of responsibility.<sup>19,23,25,26</sup>

### US Navy Rotary Wing MCI Cared for on Casualty Receiving Treatment Ships

Three MCIs involving rotary wing mishaps, where casualties were transferred to Casualty Receiving Treatment Ships (CRTS), were identified involving 68 total aircrew (Table 3).<sup>28–31</sup> Of these, 36.8% died in the mishap and 63.2% survived. For two of the rotary mishaps, the crash happened on land and patients were transferred to the CRTS (USS Belleau Wood and USS Bataan); initial casualty care occurred on land and en route to the ship. On the USS Belleau Wood (LHA-3), the ship’s surgeon received 15 patients within 30 minutes of the crash and supervised treatments. At the crash scene, the General Medical Officer (nonsurgeon) performed an emergency cricothyroidotomy on one severely injured Marine. Unfortunately, this patient died upon arrival to the CRTS. Of the 14 survivors, the ship’s surgeon

performed bilateral lower extremity escharotomies in four patients with full thickness burns and diagnostic peritoneal lavage in two, in this pre-ultrasound era. Of note, additional medical supplies and crystalloid had to be flown in from nearby ships. All survivors underwent MEDEVAC to the Army’s 121st Evacuation Hospital in Seoul within 2 hours to 3 hours of arrival to the ship. The USS Bonhomme Richard received 23 casualties after an MV-22 Osprey collided with a nearby ship. Patients were first triaged on a Role 1 capable ship and then transferred to the *Bonhomme Richard* for further treatment. One patient was severely injured with an open fracture of his lower leg which was quickly evacuated to Australia for further treatment. The MCI on the USS Bataan (LHD-5) has been described elsewhere<sup>29,30</sup> but, notably, all 6 casualties received 55 units of blood products, of which 39 units were from the ship’s walking blood bank (WBB). In addition, all patients required prolonged stabilization at sea; 4 underwent MEDEVAC to Landstuhl Regional Medical Center (LRMC) 38 hours after arrival, and 2 after 42 hours. All patients survived.<sup>29,30</sup>

Table 4 compares shipboard injuries of survivors from the Falklands War, the *Stark* and *Cole* attacks and the nine noncombat MCI to shipboard injuries from 1944–1945 sustained on US Naval ships who survived disposition during World War II.<sup>32</sup>

#### Box 1 Identified Challenges Associated with Maritime MCIs.

- Maritime MCIs are complex and dynamic, especially those threatening the survival of the ship. Casualty triage and life-saving interventions will be performed in parallel to ship damage control, fighting fires, preserving watertight integrity, and ensuring ship stability.
- Additional casualties may result from necessary damage-control interventions to save the ship. This must be included in the resources required and underscore the importance of all personnel knowing how to perform basic life-saving interventions.
- The primary triage area or medical spaces may be unusable secondary to fires, smoke or structural damage. Parallel triage and treatment performed by nonmedical providers may be required in multiple areas of the ship.

**TABLE 4.** Modern MCI Related Injuries Compared to US World War II Injuries

Injury Type	World War II (32) (n = 4529)	Falklands War (n = 516)	USS Stark and USS Cole (n = 58)	Noncombat Mishaps (n = 223)
Penetrating	39.2%	52.3%	6.9%	—
Burns	26.1%	21%	15.5%	4%
Soft tissue injuries	7.6%	—	41.4%	21.5%
Fractures	6.8%	—	24.1%	4%
Concussion/TBI	4.5%	—	17.2%	5.8%
Asphyxiation/inhalation	1.1%	15.5%	10.3%	—
Amputation	0.6%	—	0%	0.5%
Immersion/hypothermia	0.2%	13.4%	8.6%	—
Aspiration (fuel or sea water)	—	—	—	1.8%
Other minor	—	—	—	35.9%

- Communication both within the ship and outside of the ship may be disabled, complicating triage, delivery of medical supplies, and MEDEVAC.
- Maritime MCIs can be associated with blunt-force trauma (blasts, collisions) resulting in TBI, long-bone fracture, solid-organ injury, and penetrating fragment wounds. Fires can result in burns and smoke inhalation requiring crystalloid resuscitation, definitive airway management and mechanical ventilation. Submersion can result in hypothermia, and sea-water or fuel aspiration.
- Most deaths from maritime MCIs are due to fire, explosion or loss of hull integrity with drowning; they can occur rapidly or instantaneously.
- Shipboard medical supplies may be destroyed or rapidly exhausted during MCIs.
- MEDEVAC can be time consuming if rotary wing assets are unable to land on the ship.
- Failure to re-triage casualties may result in loss of life from previously unidentified or evolving injuries and complications related to delayed MEDEVAC.
- Role 1 shipboard medical departments do not have organic en route care capabilities, stored blood products aboard or a WBB capability.
- If the operational environment allows, casualties from off-ship MCI should be taken to ships with a surgical capability to avoid delay of potential life-saving interventions.
- During routine operations, maritime surgical platforms are usually embarked with only one surgical team; therefore, more than one urgent surgical patient can rapidly result in a MCI.
- All providers, involved in primary assessment of injured patients, including corpsmen, must have formal training in performing and interpreting the Focused Assessment Sonography for Trauma ultrasound examination to perform appropriate triage and prolonged care.

Box 1 summarizes the unique challenges associated with maritime MCI identified during full text review.

## DISCUSSION

An MCI occurs when any number of casualties overwhelms available resources. In civilian or military settings, MCIs challenge every level of the system of care. Maritime MCIs, particularly those threatening ship survival, add multiple layers of unpredictability resulting in unique challenges. We reviewed 25 MCIs involving naval vessels over 40 years representative of modern naval warfare, routine naval operations, and ship-based Role 2 health service support of air and land operations. Of the survivors from naval warfare, approximately one quarter of the injuries included burns and fractures; 20% included TBI, and up to 10% involved inhalation injury. Less common were immersion and hypothermia. Mishaps secondary to collisions, fires or explosions resulted in similar injury patterns (Table 4). Most deaths during maritime MCI occurred nearly instantaneously or rapidly from blast effects related to explosions, flash fires, smoke inhalation or drowning after loss of hull integrity, underscoring the importance of rapid triage and identification of those with survivable injuries.

### Unique Challenges Associated With Maritime Mass Casualty Events

Box 1 lists various challenges associated with maritime MCIs to inform operational readiness. Maritime MCIs require unique clinical and tactical skills to decrease preventable deaths because, the ships' survival (and therefore the clinical care platform) may be threatened by fires, explosions, smoke, or flooding. Analogous to the care-under-fire principles of Tactical Combat Casualty Care (TCCC), providers and the ship's crew have to perform both tactical and clinical damage control. Initial triage and lifesaving interventions have to be performed while fighting fires, preserving watertight integrity, and ensuring ship stability and survival. Maritime MCIs are rare and unpredictable; therefore, primary medical or triage spaces may be rendered unusable and often out of necessity parallel triage efforts will be conducted; underscoring the importance of tactical and clinical capabilities for all ship's crew. Communications may be inoperable complicating triage and treatment, and delay

**TABLE 5.** Tactical Combat Casualty Care Responder Levels<sup>32</sup>

Responder Level	Provider Type	TCCC Task/Skill Examples
Tier 1	All service members	<ul style="list-style-type: none"> <li>– TCCC</li> <li>– Care under fire/threat</li> <li>– Tactical evacuation care</li> </ul>
Tier 2	Combat lifesaver	<ul style="list-style-type: none"> <li>– All tier 1 skills</li> <li>– Tactical evacuation care</li> </ul>
Tier 3	Combat medic/hospital corpsman	<ul style="list-style-type: none"> <li>– All tier 2 skills</li> <li>– Lifesaving interventions to include triage, junctional tourniquet application, use of airway adjuncts, cricothyroidotomy, oxygen administration, shock and burn resuscitation, fracture management</li> </ul>
Tier 4	Combat paramedic/provider (including physicians and IDC)	<ul style="list-style-type: none"> <li>– All tier 3 skills</li> <li>– Advanced lifesaving interventions such as endotracheal intubation and tube or finger thoracostomy</li> </ul>
ARC	Team-based capability	<ul style="list-style-type: none"> <li>– REBOA insertion and device management, Foley catheterization, urine output monitoring, ultrasound FAST examination</li> </ul>

IDC, Independent Duty Corpsman; REBOA, resuscitative endovascular balloon occlusion of the aorta; FAST, Focused Assessment Sonography for Trauma.

patient evacuation, highlighting the need for a prolonged casualty care capability on each ship.

Current Navy operational doctrine at sea mandates dispersed Battle Dressing Stations (BDS) throughout the ship to allow for simultaneous tactical response, triage, and clinical care. The medical department acts as the primary BDS and each BDS is manned by organic ship's company including providers and nonproviders. The provider's initial actions are dictated by the ship's nonmedical damage-control team including the specific route through the ship to retrieve casualties, when they can be evacuated, and which BDS they should be brought to. Mass casualty drills are performed regularly to maintain readiness in parallel triage and basic clinical care with emphasis on initial wound management. While Navy medical personnel are routinely required to have TCCC training at various points during their careers, currently it is not routinely required while assigned to a shipboard medical platform. Table 5 reviews the five TCCC responder levels, provider types and associated TCCC skills.<sup>33</sup> While the Department of Defense has mandated All Service Member (Tier 1) TCCC, it has not been completely adopted or required for nonmedical crew while assigned to the surface and sub-surface Fleet. Prior to the attack on the USS Cole, the ship's medical team provided a 1-day first responder training for all new crew members focusing on the historic "Gitmo 8" wounds including treating extremity fractures, abdominal evisceration, electrical shock, amputation, smoke inhalation, sucking chest wounds, jaw fractures and burns. After the Cole attack, crewmembers indicated that this, along with stretcher-bearer training, was helpful during casualty management. But, there was a lack of mass-casualty training for corpsmen.<sup>34</sup> In 2015, the Gitmo 8 were revised and included the management of hypothermia, heat stress and lacerations, tourniquet use in amputations with massive hemorrhage and penetrating wound management. Recently, there have been efforts to routinely teach TCCC-Tier 3 skills to all shipboard corpsman and TCCC-Tier 4 skills to shipboard IDCs (Table 5); however, this has not been universally implemented, and is not current Fleet doctrine. For example, the use of tranexamic acid for hemorrhage and more recently TBI is a principle of TCCC,<sup>35</sup> yet it is not doctrinal, nor is it available on afloat Role 1 platforms at the time of this writing. This review demonstrates the paramount importance of optimizing the management of hemorrhage and TBI during maritime MCIs. At a minimum, solo shipboard IDCs should be provided with formal Tier 4 TCCC training allowing them to train their corpsman Tier-3 TCCC skills and the rest of the ship's crew Tier-1 skills.

The availability of clinical experiences that prepare afloat medical teams to care for multiple casualties during MCI is a major readiness gap identified in this historic analysis. Those most affected are IDCs leading Role 1 medical departments. While trauma training and skills sustainment gaps for military providers is a current and frequent discussion point within the Department of Defense, often the need for clinical burn experience is rarely considered.

### Back to the Future: Implications for Future DMO

While the casualties from the Falklands War are likely representative of the types of injuries encountered in a future contested DMO, the time to definitive care is not. During the Falklands War, most patients were en route to definitive

treatment and surgical care within 90 minutes or less of injury (Table 1).<sup>7,9</sup> Similarly, after the Cole and the Stark attack, casualties were en route to definitive care between 1.5 hours and 3 hours after injury, initial triage and treatment. After ship evacuation, Cole casualties were initially cared for at local hospitals with minimal blood bank stores until a French surgical team arrived approximately 8 hours after the attack to evacuate 11 of the most severely injured to Djibouti, about a 47-minute flight away. No information about blood products transfused is available. Notably, no blood products or WBB capability were available on the Cole. This currently remains the case as the WBB is not considered an operational requirement for US Navy Role 1 afloat medical departments.<sup>36,37</sup>

Just as the shipboard injuries encountered during modern naval warfare are similar to World War II injuries (Table 3), we must look through the "retrospectroscope" to understand the challenges shipboard providers might face in future contested DMO environments. The US Navy's experience evacuating casualties in the Pacific theater of operations during WWII is the most recent historical example of a contested DMO conflict. US Navy doctrine at the time was for casualties to receive definitive surgical treatment within 12 hours of injury.<sup>38</sup> To do this, nonhospital ships, such as destroyers and tank landing ships (LST) were augmented with surgical teams because hospital ships were often targeted for attack. During the initial amphibious invasions a "scoop and sail" tactic was used.<sup>39</sup> Casualties at the beachhead would be triaged and placed on empty LSTs after delivering materiel and troops. Surgical casualties would be re-triaged aboard the LST and sent to ships with a surgical capability for initial definitive care. Eventually these patients would be transferred to hospital ships some distance away and often days later. Initially, hospital ships were primarily used to shuttle patients to shore-based medical facilities.<sup>38,39</sup> However, toward the end of the Pacific campaign, hospital ships were closer to the point of attack; during amphibious assaults, patients were rapidly triaged from the beachhead to a hospital ship for definitive care,<sup>39</sup> similar to the Falklands War. This practice was continued during the Korean conflict, Vietnam War and the 1990s Gulf War.<sup>39</sup> However, in the current routine and future contested DMO environments, this practice is not an option. While infrequent, Role 1 medical departments can have a significant casualty burden when mishaps occur during routine operations. During DMO, these ships will be geographically dispersed resulting in much longer casualty holding times than identified in this review. Given the technological advances of current peer advisories, hospital ships will likely be targets during contested DMO. Therefore, the "scoop and sail" evacuation tactics used during the early phases of the WWII Pacific campaign will likely be used in the future maritime and littoral battlespace. Similar to WWII, austere maritime surgical teams are now augmenting afloat Role 1 medical departments during routine DMO.

Tremendous lessons have been learned over the last 20 years of sustained conflict in Iraq, Afghanistan and Syria; however, in preparing Naval Health Service Support for contested and noncontested DMO, some aspects of the care continuum are not directly relevant to naval warfare. The most obvious difference is the archetype of combat casualty care operations on land, with air superiority, rapid transport and ability for rapid resupply. During the recent conflicts, expeditionary surgical teams

were usually within 30–60 minutes from point of injury. These austere Role 2 teams routinely performed damage-control resuscitation and surgery, followed by rapid transfer to Role 3 hospitals staffed with critical-care teams led by surgeon and nonsurgeon fellowship-trained intensivists (Fig. 1).<sup>40</sup> After further intensivist lead stabilization, including advanced airway and respiratory support, in-theater extracorporeal membrane oxygenation (ECMO) and continuous renal replacement therapy (CRRT) and often additional surgical intervention, the most critically ill of these patients were transported out of theater to the LRMC Role 4 within 72 hours to 96 hours of injury via US Air Force Critical Care Air Transport Team (CCATT).<sup>41–43</sup>

One of the most notable aspects of these conflicts is that casualty volumes were overall low. While only one to two severely injured patients could result in an MCI, this was secondary to resource constraints and the small medical footprint of the expeditionary teams which heavily rely on rapid transport to the next level of care. While multiple casualty events with over 20 patients certainly occurred, this was not a frequent occurrence. When preparing for the future operating environment, either on land or sea, large volumes of casualties should be expected and the trauma system prepared to manage large scale combat operations.

In a potential future contested DMO conflict with a near-peer adversary within a large geographic space like the Pacific, US Forces will unlikely have air superiority making rapid transport, which the current deployed trauma system has heavily relied on, less feasible. Casualties will likely be cared for on US aircraft carriers and amphibious CRTS with robust Role 2 surgical and critical care capabilities or by austere surgical teams embarked on smaller vessels not designed for patient holding. Furthermore, because of tactical risks, hospital ships will unlikely be close to active combat engagements. In this system, shipboard medical departments will need to manage critically ill casualties potentially for 2 days to 5 days prior to MEDEVAC to a Role 3 hospital. Comparing this to the medical requirements in a noncontested (and thereby fully resourced and with rapid evacuation capability) DMO, the 2017 USS Bataan MCI used three different surgical teams and the entire shipboard medical contingent to successfully treat six critically ill casualties requiring a total of 55 units of blood products. Considering the Bataan's relative geographic isolation, casualties remained on board for longer than the current land trauma system paradigm (Fig. 1), but were still evacuated to LRMC in less than 2 days.<sup>29,30</sup> In future DMO environments, providing prolonged maritime care including surgery, burn and hemorrhagic shock resuscitation, as well as ventilator or TBI management, will likely be required of shipboard medical departments.

The US Navy is currently developing a Role 2 "ambulance" ship concept, much smaller than current Role 3 hospital ships, to evacuate shipboard casualties during DMO based on the catamaran hulled Expeditionary Fast Transport ship. If developed, it will be designed, manned and equipped to perform expeditionary triage, resuscitation, emergency surgery, and essential post-operative care of patients during evacuation from the DMO environment to higher levels of care.<sup>44</sup> The future DMO conflict will also likely require aeromedical evacuation out of the maritime theater. Currently the US Navy does not have its own CCATT capability. A V-22 Osprey critical care aeromedical transport capability mirrored after the Air Force's fixed wing CCATT, that can rapidly augment maritime platforms with

a surgical or critical care capability, or evacuate critically ill and injured patients off ship may be necessary in the future contested DMO environment.

One of the most critical elements of the maritime trauma system is the role of the IDC and the crucial need for them to be well trained, and that training sustained with ongoing clinical experience. Once IDC's are in their fleet assignments, their jobs are largely administrative and any clinical experience they have taking care of the ship's crew is focused on necessary preventative medicine, primary care and disease nonbattle injury. This is the consequence of relative peacetime operations, but drastically effects readiness for potential future DMO. Furthermore, they receive no inpatient, trauma, critical care or burn clinical experience in these billets prior to deployments. This challenging readiness paradox could result in unnecessary preventable deaths during maritime MCIs. Table 2, demonstrates that 7 of the 11 MCIs were on Role 1 platforms where the senior medical provider is an IDC. Given the large casualty volumes in these documented MCIs resulting in injuries of up to 90% of the crew and a 1% to 17% mortality rate depending on the incident, this is a massive burden of clinical care for any medical provider. Whether in a contested or noncontested DMO environment, these IDCs will have to perform several days of prolonged care for patients with complex injuries such as burns, inhalation injury and TBI; underscoring the critical requirement for IDCs to receive clinical sustainment training in advanced airway, ventilator and TBI management, and burn and hemorrhagic shock resuscitation.

Another lesson relearned from multiple past wars is the need to use blood, in particular whole blood, to resuscitate a hemorrhaging casualty and decrease preventable death rates. Resuscitation strategies have come full circle as we relearned the need for rapid access to blood in order to decrease battlefield mortality.<sup>45–48</sup> The reintroduction of cold-stored low-titer O+ whole blood (LTOWB) has not only clinical but logistical advantages in the forward deployed environment.<sup>46–49</sup> Walking blood banks can collect type specific or LTOWB that is transfused immediately to a casualty; over 10,700 units of whole blood have been transfused during the recent conflicts in the Middle East. Amphibious CRTS have a large supply of stored blood and a robust WBB capability.<sup>29,30,46</sup> Similarly, aircraft carriers also have a WBB capability, but do not routinely carry stored blood. As the US Navy implements the DMO doctrine, austere maritime surgical teams are increasingly augmenting Role 1 shipboard medical departments. While these Role 2 teams are equipped with a limited supply of component blood products, Role 1 shipboard medical departments are not trained or equipped to perform a WBB; a capability required to save the lives of surgical casualties. The casualties from the USS Cole and USS Bataan demonstrate the lifesaving need for a whole blood capability.<sup>15,29,30,37</sup> Changes in Navy doctrine, organization, policy and training to support a shipboard Role 1 WBB capability are needed to prepare for future DMO and potentially decrease preventable deaths.

This report has several limitations inherent to literature reviews. It is not a comprehensive: only those MCI available through literature review and open access resources were reviewed. While general injury types were identified, some specifics and amounts of blood products transfused were not available for most MCI; nor were long term patient outcomes. However, to the best

of our knowledge, this is the most comprehensive review of modern naval MCI characterizing injury types and specific challenges associated with these complex and dynamic events.

## Recommendations

To better prepare shipboard medical teams providing Naval Health Service Support for current operations and for future contested DMO, the authors provide the following near and long-term recommendations.

### Near Term

1. Develop and implement a WBB capability across all Role 1 surface medical departments.
2. Doctrine, policy and training should require Role 1 shipboard medical teams to be current and competent in TCCC; Tier 4 training for IDCs and Tier 3 training for corpsman (Table 5).
3. Successful shipboard triage during maritime MCI requires all nonmedical crew members to be current and competent in TCCC for all service members (Tier 1 TCCC).
4. Role 1 and Role 2 providers should routinely receive Advanced Burn Life Support or equivalent and prolonged operational critical care training tailored to the types of casualties likely to be encountered during maritime MCI; including specific skill sets such as airway and ventilator management, resuscitation, sedation, and critical care procedural skills.
5. Update Authorized Medical Allowance Lists so that tranexamic acid is available on all Role 1 maritime platforms, as current TCCC guidelines recommend its use in hemorrhagic shock and TBI.

(Since the drafting of this manuscript, aspects of short term recommendations 1, 2, 3 and 5 are being evaluated through Navy Medicine's Operational Clinical Community)

### Long Term

1. Sustainment and generalization of a WBB capability across all Role 1 surface medical departments.
2. Surgeons, fellowship trained intensivists and expeditionary physicians embarked on maritime Role 2 platforms should be trained and equipped to provide Advanced Resuscitative Care (ARC) including resuscitative endovascular balloon occlusion of the aorta.<sup>46</sup> One severely injured casualty can quickly overwhelm surgical resources as most Role 2 platforms usually have one surgical team embarked during routine operations. Therefore, ARC training, as well as current clinical trauma experience, is required for successful casualty management.
3. In addition to clinical skills sustainment opportunities, Role 1 and Role 2 maritime teams should have consistent exposure to trauma and burn care to maintain clinical currency and competency either at military treatment facilities or by leveraging military and civilian partnerships.
4. Conduct a comprehensive review of shipboard medical materiel, particularly Role 1 platforms, to ensure it is appropriate for TCCC, burn care, shipboard and battlefield nontrauma injuries, post trauma critical care complications and prolonged maritime care scenarios.
5. Study the need and feasibility of developing a US Naval (Navy or Marine Corps) modular maritime rotary wing

critical care transport capability for advanced maritime MEDEVAC or rapid augmentation of shipboard Role 1 and Role 2 teams during DMO. Scalable, modular capabilities should include ARC, burn, surgical, and critical care.

## CONCLUSION

During routine operations or naval warfare, modern Naval MCI are complex and dynamic events, where shipboard personnel often have to perform parallel triage and treatment while simultaneously trying to save the ship. Blunt, burn, blast, asphyxiation and drowning mechanisms of injury are commonly encountered during maritime MCI. Future US Navy DMO will likely require Role 1 and Role 2 shipboard medical platforms to care for these patients for prolonged periods of time, potentially several days, atypical of the US military's experience in recent conflicts. Several recommendations are made to optimize patient outcomes during maritime MCIs, including implementing TCCC, Advanced Burn Life Support, and trauma and critical care training and clinical skills sustainment experiences for providers and implementing a WBB capability (including tranexamic acid) across all maritime Role 1 platforms.

### AUTHORSHIP

M.D.T. participated in the study concept and design, data collection and analysis, article preparation and critical revision. J.G., M.S.T., L.C.C. participated in the article preparation and critical revision. M.J.S., J.B., M.C. participated in the mass casualty description from personal experience; critical revision of article. J.L., M.V. participated in the literature review and critical revision of article. J.A.A. participated in the study concept and design, data collection and analysis, critical revision of article.

### DISCLOSURE

The authors declare no funding or conflicts of interest. The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, the Department of the Army, the Department of Defense, or the US Government. Copyright statement: I am a military service member of the United States government. This work was prepared as part of my official duties. Title 17, U.S.C., §105 provides that copyright protection under this title is not available for any work of the US Government. Title 17, U.S.C., §101 defines a US Government work as a work prepared by a military Service member or employee of the US Government as part of that person's official duties.

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