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US Navy Ship-Based Disaster Response: Lessons Learned

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Abstract

Purpose of Review The US Navy has a long history of responding to disasters around the globe. US Navy ships have unique characteristics and capabilities that determine their capacity for a disaster response. This paper discusses common considerations and lessons learned from three distinct disaster missions.

Recent Findings The 2010 earthquake in Haiti had a robust response with multiple US Navy ship platforms. It was best assessed in three phases: an initial mass casualty response, a subacute response, and a humanitarian response. The 2017 response to Hurricane Maria had a significant focus on treating patients with acute needs secondary to chronic illnesses to decrease the burden on the local healthcare system. The COVID-19 response brought distinctive challenges as it was the first mission where hospital ships were utilized in an infectious disease deployment.

Summary The first ships to respond to a disaster will need to focus on triage and acute traumatic injury. After this first phase, the ship's medical assets will need to focus on providing care in a disrupted health care system which most often includes acute exacerbations of chronic disease. Surgeons must be ready to be flexible in their responsibilities, be competent with end-of-life care, and negotiate technical and cultural communication challenges.

Keywords Disaster medicine · Military surgery · Military ships · Hospital ships · Humanitarian surgery · Military medicine

Introduction

The US Navy has a long history of responding to a wide range of disasters from natural to man-made, the first being the USS Jamestown, crewed by civilian mariners bringing much needed supplies to Ireland during the potato famine in 1848 and most recently during the COVID-19 pandemic [1]. The Department of State is the lead United State Government (USG) agency for disaster response and requests for assistance to the US Navy can include medical care and evacuation, delivery of needed essentials such as water, food, and medicine, engineering support for repair or reconstruction, and emergency power and water generation. Upon any given day, the US Navy has approximately 100 ships dispersed throughout the world's oceans geographically poised to respond to natural disasters around the world [2]. Response to a disaster typically occurs in five phases which begin with assessment and planning and end with transition and redeployment. The end-state goals are immediate life-saving care or equipment transfer and transition to local responsible authorities in a peaceful state [3].

While the hospital ships, USNS Comfort (T-AH 20) and USNS Mercy (T-AH 19), are the most readily thought of in a humanitarian disaster response, multiple shipboard platforms have the capability to move patients from shore to ship and perform damage control surgery. The class of ship with the most robust casualty receiving and treatment

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are Landing Helicopter Dock (LHD) platforms. Although the configuration of each ship can be different, in general, these platforms have 2 operating rooms (with flexible capability up to 6 operating rooms), 14 intensive care unit level beds and 45 surgical ward beds. Additionally, these platforms have packed red blood cells (PRBC) and fresh frozen plasma (FFP) storage capacity, can receive patients by sea or air evacuation, and have intrinsic radiology, pharmacy, laboratory, preventive medicine and biomedical repair capabilities [3, 4]. Mobile surgical teams, whether Fleet Surgical Teams (FST) or Expeditionary Resuscitative Surgical System (ERSS), can augment these platforms to increase damage control surgery capability.

There are other combatant naval ships with operating rooms such as aircraft carriers (CVN-Carrier, Aircraft, Nuclear) and Landing Helicopter Assault (LHA) which have intrinsic surgical capability and the landing platform docks (LPD) which do not have organic surgical capability. Like the LHD platform, LHA and LPDs do have PRBC and FFP storage capacity. However, aircraft carriers rely on the ship's walking blood bank (WBB) program to gain access to blood products. When fully staffed, the hospital ships, which are purely noncombatant ships, have 12 operating rooms, 80 intensive care beds, up to 1000 minimal care beds, and have robust blood storage, pharmacy, laboratory, and radiology (including CT scanner) capabilities. Hospital ships receive casualties by rotary wing [3, 4].

While humanitarian civic assistance (HCA) missions and disaster relief (DR) missions are often grouped together strategically, medically they are often two very different missions. HCA missions are usually elective, preplanned evolutions designed to improve international partnerships, promote global stability and security, maintain the operational readiness of military personnel, and facilitate interoperability with host and partner nations during a crisis. Disaster relief missions are often unpredictable and often US Navy surgical teams with different capability and capacity are the first to respond. With the understanding of the assets and capabilities of the US Navy in disaster response, the purpose of this review is to describe the firsthand surgical experiences and lessons learned responding to three different disasters: the 2010 earthquake in Haiti, Hurricane Maria in 2017, and the COVID-19 Pandemic in 2020 are presented. US Navy ship responses to disasters are summarized in Table 1.

Recent Findings

US Navy Response to the 2010 Haiti Earthquake

On January 12, 2010 at 16:53 local time a 7.0 magnitude earthquake struck 16 miles west of Port au Prince, Haiti. There were an estimated 530,000 casualties with 230,000 killed and 300,000 injured and more than 2 million people were left homeless. The aircraft carrier USS Carl Vinson was on station just three days after the earthquake and assumed medical operations on January 16th during Operation Unified Response (Fig. 1). The amphibious assault and casualty receiving and treatment ship (CRTS) USS Bataan and USNS Comfort arrived January 18, 2010, and January 20, 2010, respectively.

Overall, 60 patients were treated on the carrier, including 29 that arrived in one 5-h period. Thirty-two surgical procedures were performed, 12 were major operations, mostly amputations of infected open fractures and crushed extremities. The WBB was activated 5 times with 17 units transfused.

The sailors, marines, and providers aboard the amphibious assault ship USS Bataan not only cared for patients, but transported 1,000 pallets of relief supplies, triaged approximately 2,000 patients ashore, and immunized nearly 10,000 local nationals. Bataan's crew also removed 150 tons of rubble, built 65 shelters for 130 families, and distributed 500,000 meals. In addition to transporting 524 Haitian patients to and from the USS Carl Vinson, USNS Comfort, and Port-au-Prince hospitals, the ship cared for 97 patients [14].

The USNS Comfort was on station for 40 days. In that time, the providers of the hospital ship admitted 872 patients and performed 927 procedures; in the first 48 h, 85% of triaged patients had orthopedic injuries and 72.2% (669) of surgical procedures were performed on extremities. Of these 872 patients, 27% (237) were pediatric, 44 younger than 1-year, and 179 between the ages of 1 and 16 [8••]. A total of 428 units of blood products were transfused including 399 units of red blood cells, 16 units of fresh frozen plasma, 12 units of platelets, and 1 unit of cryoprecipitate [15].

The magnitude of the 2010 Haiti earthquake was profound not only in terms of the death and destruction, but the near total decimation of the country's limited health care resources. This required all US Navy assets and non-governmental organization (NGO) field medical teams (FMT) to communicate, cooperate, and coordinate the care of patients to get them to the right available resources on scene. As the US Navy was present at the request of the Haitian government, they were able to serve a complementary role across all domains of a disaster response to include on the ground security, and the crew of the Bataan providing shelter, relief supplies, and sustenance to the local population. The USNS Comfort served as a tertiary trauma center for the NGOs on the ground with limited capability and capacity [8••, 16].

Given the impact of the earthquake on Haiti's fragile health care system, the USNS Comfort was required on station for a prolonged period of time beyond just responding to the initial disaster. The USNS Comfort surgical team observed three different phases during the disaster response:

Table 1 Summary of US Navy disaster responses since 2000

Date	Disaster	Location	Operation	Ship/Unit	Response Length	Support provided (Surgeries performed)	Notes
2001	9/11	NYC		USNS Comfort	21 days	624 sick call appts; > 1000 massage therapies, > 800 mental health appts [5]	
2004	Southeast Asia Tsunami	Indonesia	Operation Unified Assistance	USNS Mercy	81 days	137 patients (26% disaster related) Thousands of onshore procedures. Just under 200 admissions + procedures on ship. Key in delivery of crucial supplies [6]	1st time Mercy deployed on a disaster mission
2005	Hurricane Katrina	New Orleans, LA		USNS Comfort, USS Iwo Jima	42 days	Flight coordination, USS Iwo Jima provided comms/logistical support [4, 7•]	Coordinated with numerous national organizations
2010	Haiti Earthquake (2010)	Haiti	Operation Unified Response	USNS Comfort, USS Carl Vinson, USS Bataan	72 days	USNS Comfort: 900 procedures on 454 patients, 32 surgeries (12 major operations) USS Carl Vinson: treated 60 patients USS Bataan: treated 97 patients, transported 524 patients [4, 7•, 8••]	Overall, more than 30 ships responded, many of which military
2011	Fukushima Nuclear	Fukushima, Japan	Operation Tomodachi	20 US Navy ships	28 days	Deliver 260 tons of HA/DR supplies, clear harbor, radiation containment, search and recover bodies. [4, 9]	
2017	Maria	Puerto Rico		USNS Comfort	~42 days	170 surgical procedures, 53 emergent. 1589 patients treated in the casualty receiving area after being screened pier-side in San Juan [10]	
2020	COVID-19	New York City, NY Los Angeles, CA		USNS Comfort, USNS Mercy	~35 days	> 110 operations and procedures. (54% on COVID positive patients) [11, 12]	Responded in < 7 days. No OR personnel tested positive at the conclusion
2021	Haiti Earthquake (2021)	Haiti		Multiple US Navy ships		Provided command and control, supported fueling for flight operations, deployed unmanned aerial systems, aided in food/resource distribution [13]	

- Phase 1: Initial mass casualty response consisting of triage and the performance of life and limb saving procedures
- Phase 2: The subacute response, where the care of patients who would have survived the disaster with or without care is optimized
- Phase 3: The humanitarian response, where rehabilitation of the injured and the affected populace can begin [8••]

During phase 1, both the NGOs on the ground and the USS Carl Vinson medical department were in the midst of a mass casualty triage response. During this acute phase, NGOs provided initial acute phase trauma support on the ground, but the care they were able to provide was limited by their resources and level of austerity depending on their field hospital footprint and capacity. Many temporized patients were awaiting definitive care when the USNS Comfort arrived on scene [8••, 16–18].

During the USS Carl Vinson's phase 1 response, the medical department's single surgeon team was stressed during the prolonged medical department's mass casualty responses. An important lesson learned was that unless patient(s) are decompensating or dying the surgical team must pace themselves to ensure crew rest and safe patient care. The USS Carl Vinson surgical team ensured a 2-h break every 12 h and 4-h break every 24 h when they could [19]. Finally, during this phase, expect the unexpected as obtaining accurate patient reports for transferring patients is often difficult as communication may be limited. This is further compounded by language barriers, depending on the host nations' primary spoken language. Rapid identification and utilization of interpreters was essential to improving transitions of care.

During phase 2 of the Haiti earthquake response, the USS Bataan provided optimized care of the local populace through the provision of supplies, vaccines, and shelters [14]. However, it is during this phase that the provision of critical care becomes important particularly in a disaster where multiple extremity crush injuries have occurred. The USNS Comfort internal medicine and critical care team had to stretch their dialysis capabilities for the influx of crush injuries with renal failure that presented during phase 1 and phase 2. The team prioritized dialysis for patients with oliguric renal failure and stabilized hyperkalemia using bicarbonate-based intravenous fluids and standard medical management [20, 21]. Due to a limited supply of dual-lumen catheters, 2 separate central venous sheaths were used for the inflow and outflow, respectively [20].

Transitioning from phase 2 to phase 3 occurs as the mission becomes more akin to an elective humanitarian mission and can be challenging particularly during the disposition of stabilized patients. To be successful, close collaboration and communication with NGOs and the local health system

Fig. 1 A medical response team aboard the Nimitz-class aircraft carrier USS Carl Vinson (CVN 70) transports an injured Haitian woman to an operating room during the response to the 2010 Earthquake in Haiti. The appearance of US Department of Defense (DoD) visual information does not imply or constitute DoD endorsement. Source: Public domain image, not in copyright. Available at: https://commons.wikimedia.org/wiki/File:US_Navy_100121-N-4774B-048_A_medical_response_team_aboard_the_Nimitz-class_aircraft_carrier_USS_Carl_Vinson_(CVN_70)_transports_an_injured_Haitian_woman_to_an_operating_room.jpg

are critical. Finally, when considering definitive surgical care, it is best to meet, but not exceed the local standard of care available before the disaster as these patients are going to follow-up in the local health care system. For example, the USNS Comfort team used plain gauze for dressing as opposed to negative pressure dressings. Plaster casts were used instead of fiberglass to allow removal by water soaking, as cast saws were not universally available in Haiti.

USNS Comfort (T-AH 20) Deployment to Puerto Rico to Hurricane Maria

In September 2017, the category 5 storm Hurricane Maria devastated the Caribbean. It made landfall in Puerto Rico on the 20th. The island territory of the USA was already in the midst of rebuilding after previous storms, and as a result, the local infrastructure and power grid were overwhelmed. The Governor of Puerto Rico estimated the damages at over eight billion dollars shortly after the storm passed. The Federal Emergency Management Administration (FEMA) and Health and Human Services (HHS) requested the Navy to send the USNS Comfort (TA-H 20) with a 250 bed capacity [10]. The ship was ready to deploy within 40 h of activation and set sail on September 29th with 241 clinical and supporting personnel (Fig. 2).

Overall, during the approximately 6-week mission, the surgical mission on board the USNS Comfort during the Hurricane Maria disaster response included 170 surgical procedures of which 53 were considered emergent. This included 75 general surgery cases; 30 orthopedic cases; 29

vascular surgery cases (including 17 amputations), 20 oral surgeries; 11 otolaryngology procedures; and 5 obstetric/gynecology procedures. This came from a combination of 120 patients transported via enroute care teams, and 1589 patients treated in the casualty receiving area after being screened pier side in San Juan [10]. During this mission, the crew cared for 36 ICU patients with an average acute Physiology and Chronic health Evaluation (APACHE) II score of 30. This predicts an overall mortality of 80%. However, the actual ICU mortality for this cohort was only 27% [10]. The ICU was staffed by four critical care specialists including 3 trauma/critical care surgeons and one anesthesia critical care (CC) physician. This was intentional planning by the Director of Surgical Services, who believed that a trauma surgeon's expertise might be needed if large volumes of injured patients were going to be treated. This allowed trauma/critical care surgeons and the critical care anesthesiologist to cover both the ICU and operative cases. In contrast to the Haiti earthquake response, the primary need from local Puerto Rico hospitals after hurricane Maria was to off load their long-term ICU patients in order to make room for more acute patients.

Initially the patients were admitted due to acute exacerbations of their chronic medical conditions, including but not limited to congestive heart failure, chronic obstructive pulmonary disease, myxedema coma, and other chronic illnesses that were stressing the local systems ability to respond to the disaster at hand. It quickly became clear that the underlying medical conditions were unlikely to improve. When families came aboard, many discussions took place regarding goals of care. This is particularly challenging in a setting with communication limitations, language translation barriers, and difficulty locating next of kin as the local population is dispersed geographically during a disaster.

USNS COMFORT (T-AH 20) Deployment to New York City for the COVID-19 Pandemic

The surge of hospitalizations due to COVID-19 in early 2020 prompted an executive order for the two US Navy hospital ships to simultaneously deploy to New York City (NYC) and Los Angeles [22, 23]. Both ships were in scheduled maintenance cycles which meant there was active reconstruction occurring in the casualty receiving area. Within seven days, the USNS Comfort was on its way to NYC. Due to the rapid deployment, the global shortage of medical supplies, unclear mission expectations, and both hospital ships leaving simultaneously, there were equipment and consumable supply challenges.

Although the US military has experience with infectious disease deployments, this was a novel experience for the hospital ships [24]. This made deciding the required personnel for the mission extremely challenging. Initial guidance was that the USNS Comfort would care for COVID-19 negative patients to offload the burden on the strained healthcare systems and so the personnel assigned to the ship was focused on subspecialty and particularly surgical care.

Fig. 2 Sailors treat a patient in casualty receiving aboard the USNS Comfort during the response to Hurricane Maria. The appearance of US Department of Defense (DoD) visual information does not imply or constitute DoD endorsement. Source: Public domain image, not in copyright. Available at: https://commons.wikimedia.org/wiki/File:Sailors_treat_a_patient_in_casualty_receiving_aboard_the_Navy_Hospital_ship._(26289055569).jpg

Once the ship arrived in NYC, there was a rapid change in mission, resulting in taking care of COVID-19 positive patients [25]. The majority of the ship's medical staff were moved into local hotels to decrease risk of infection and the ship was split into "green" and "red" zones with one way foot traffic and each area with enforced hand sanitizer stations. Inpatient wards were separated into COVID-19 positive and negative by separate decks. Although the ship had many ventilators, there was not staffing for the required intensive care nursing and respiratory technicians to utilize all of them. ICU staff worked twelve hours on, twelve hours off for the entire mission. The ship was at 100% capacity for ventilated beds (18) and over 80% for critical care beds (34) once the mission shifted (Fig. 3).

The quick transition to red zones and green zones and high attention on appropriate hygiene and PPE kept COVID-19 positivity rates in the staff and crew very low. Patients were safely and successfully weaned off ventilators by performing tracheostomies, which had been previously discouraged in the literature as an aerosolizing procedure [26]. The surgical services component of the ship were rapidly flexible, covering down on the intensive care unit, assisting in the care of the medical inpatients, and deploying out to community hospitals to better assist triage and transfers. There were 29 major operative cases performed during this mission, 9 of which were COVID-19 positive patients [11]. The ship cared for 182 patients in total, 70% of which were COVID-19 positive.

One of the main challenges for shipboard medical assistance in a disaster is the difficulty with telecommunication and with the pandemic enforced social distancing and mask

Fig. 3 US Navy doctors, nurses, and corpsmen treat COVID patients in the ICU aboard USNS comfort. The appearance of US Department of Defense (DoD) visual information does not imply or constitute DoD endorsement. Source: Public domain image, not in copyright. Available at: https://commons.wikimedia.org/wiki/File:U.S._Navy_Doctors,_Nurses_and_Corpsmen_Treat_COVID_Patients_in_the_ICU_Aboard_USNS_Comfort_(49826501647).jpg

Fig. 4 USNS mercy sailors transport patient during the COVID-19 response to Los Angeles. The appearance of US Department of Defense (DoD) visual information does not imply or constitute DoD endorsement. Source: Public domain image, not in copyright. Available at: https://commons.wikimedia.org/w/index.php?search=USNS+Mercy+Covid&title=Special:MediaSearch&go=Go&type=image

wearing, this was exaggerated. There was initial confusion from NYC hospitals about the admission criteria for the USNS Comfort which was quickly addressed by forming USNS Comfort liaison teams that traveled to regional hospitals. Additionally, there was miscommunication about expectations of the capacity of the hospital ship. The bed capacity was advertised as 1000, but that includes "walking wounded" bunk beds. With nurse staffing limitations, the ship had a capacity of 154 beds, of which 52 were critical care beds. Future pandemic missions, whether a hospital ship or field hospital, should consider much more robust nurse staffing and particularly critical care nurses, increased pharmacy and laboratory staffing, and consider decreased subspecialized surgical staffing.

Although a cell phone carrier installed relays throughout the ship, critical patient care areas still suffered from poor cellular service. This was particularly poignant in this disaster response as the patients were isolated from family and gravely ill patients were not able to call their families. Another underappreciated need for cell service was internet translation applications as the diverse multicultural population of NYC required translation of multiple languages of which there were not intrinsic assets on the ship.

USNS Mercy (T-AH 19) Deployment to Los Angeles for the COVID-19 Pandemic

For the first time in its history, Medical Treatment Facility (MTF) USNS Mercy (T-AH 19) was activated and deployed for Defense Support of Civil Authorities (DSCA). The ship was activated from the Regular Overhaul (ROH) maintenance period and underway with its full personnel complement within 96 h. Within 5 days, nine operating rooms, one interventional radiology suite, 40 ICU beds, and 250 ward beds were fully equipped and ready to receive COVID-19 negative patients to augment the hospital capacity in Los Angeles (Fig. 4).

During its time in Los Angeles, California, the medical staff of USNS Mercy treated 77 patients with a wide variety of severe illnesses including traumatic injury requiring basic medical/surgical ward care and critical care. The primary diagnoses seen by the medical teams included twenty-six gastrointestinal cases, twelve cardiovascular disease cases, three infectious disease cases, and one dermatologic case. The ICU supported thirteen ventilated patients with multiple medical problems for both medical and surgical patients. The ship had a total of 80 functional ventilators, but the rate-limiting factor was the number of critical care physicians, nurses, and respiratory technicians available to care for critically ill and ventilated patients. Anesthesia technicians augmented the respiratory technicians in order to provide assistance in caring for these patients.

In addition, during this difficult and isolating pandemic, the crew of the ICU provided hospice care with empathy and compassion to three patients and their families. This was particularly challenging as the communication structures were limited to telephone and had no ability to have a direct family presence or even video connection. Surgical sub-specialists in gastrointestinal, orthopedic, urologic, and plastic surgery performed 41 surgical procedures resulting in every patient being discharged with no post-surgical mortality. These patients were typically patients that would require significant medical resources from the referring hospitals.

Integral to the success of USNS Mercy's mission was a first-ever healthcare DSCA partnership between the military and civilian leadership in Los Angeles, California. At the mission outset, an Advance Echelon (ADVON) team

along with the THIRD Fleet Surgeon and DSCA Planner met with the Governor's Office of Emergency Services. Working closely with State leadership, the ADVON team successfully assessed the needs of the State and laid the groundwork for how patients would be screened and admitted to the USNS Mercy during its mission in Los Angeles County.

Ultimately, medical staff orchestrated a system enabling regional hospitals to contact a central location to screen COVID-19 negative patients for suitability for admission. They screened 139 patients and facilitated the physician-to-physician handoff of 77 complex surgical, medical, and critically ill patient admissions. The liaison team was instrumental in coordinating the use of Los Angeles County patient transportation assets and seamlessly facilitated all transfers and discharges of patients receiving care.

The USNS Mercy admitted only COVID-19 negative patients. In order to ensure the ship remained COVID free, a significant majority of the crew (> 98%) were transferred to two hotels in Los Angeles where they remained isolated when not working on the ship.

Conclusion

For natural disasters, such as the 2010 Haiti Earthquake and Hurricane Maria, the US Navy response involved much more than the provision of medical care (Table 1). The initial medical response during a disaster response is focused on surviving patients often with limb-threatening traumatic injury which present typically within the first week. The most common injuries tend to be fracture and open wound/soft tissue injury, making up a total of 68% of injuries [27••]. Each case study emphasized the post-acute period where routine health issues become predominant as local health care remains disrupted. As this review discusses, the type of US Navy ship that will first respond to a disaster is non-medical, so afloat medical departments should be prepared for general and orthopedic trauma and the need for blood resuscitation. All surgical teams should review and practice their WBB screening procedures and policies, including those teams with a robust blood storage capacity such as an LHA or LHD. Furthermore, if able to before deployment, ensure the ship's crew are pre-screened in accordance with WBB policy.

Communication, in general, is often more difficult when using ship-based assets. Essential interpreter services, which were highlighted in the Haiti, Puerto Rico, and NYC cases, need to physically be present on the ship as phones are not readily available in patient care areas. Due to lack of cell service reception and limited phone lines, communication between ship and shore needs special consideration. Many reports have mentioned initial confusion about how to transfer patients to the ship once it has responded.

The hospital ship, with its dedicated medical staff and unique intrinsic capabilities, has a rapid activation, often leaving within five days, but will take longer to reach the disaster. In 2017, the USNS Comfort departed 9 days after Hurricane Maria struck. In 2010, the USNS Comfort arrived 8 days after the Haiti Earthquake. For sites within the Pacific, transit time is longer. The USNS Mercy departed 10 days after the 2004 tsunami devastated the Indian Ocean and arrived 5 weeks later [28]. Although this response time has been criticized, it is imperative to note the ship can arrive and immediately be prepared to receive patients and more importantly, carries with it a massive pharmacy, blood bank, CT scanner, full laboratory and pathology services, and multiple ORs complete with extensive supplies. There is no local dependence for housing, freshwater, or food, nor biohazard waste management. In this, these platforms are well capable of providing care for chronic disease. Each case study emphasized the post-acute period where routine health issues become predominant as local health care remains disrupted [29, 30].

During a disaster response, the need to both prevent and treat acute renal failure and hyperkalemia cannot be understated, particularly after a disaster resulting in multiple extremity crush injuries such as the Haiti earthquake. Field hospitals and austere role 1 and role 2 platforms should attempt to prevent pre-renal acute kidney injury with appropriate blood based or isotonic intravenous (IV) crystalloid resuscitation as indicated. Solutions containing potassium such as Lactated Ringers should be avoided particularly if giving prophylactic crystalloid without knowing blood electrolyte data [21, 29, 30]. Patients should be monitored for the development of compartment syndrome, and prompt surgical treatment initiated when identified. If deploying on a platform that provides renal replacement therapy, anticipate the need for this capability and plan accordingly for the supplies and personnel required *before* deployment [29, 30].

Depending on the environment, platform, patient holding times, and evacuation capabilities, peritoneal dialysis (PD) may be considered in austere settings, particularly for those platforms that don't have the ability to provide traditional renal replacement therapy [29, 30]. However, it does require peritoneal catheter placement and large volumes of appropriate sterile dialysate [29, 30]. The Joint Trauma System, "Hyperkalemia and Dialysis in the Deployed Setting" clinical practice guideline describes the indications for acute PD in austere deployed environments, the repurposing supplies for PD catheter use and creating field-expedient PD fluids from both Normal Saline and Lactate Ringers. [21] Often, the length of disaster relief missions can be unpredictable, being prepared to provide PD may be necessary. Surgeons providing disaster relief are integral to the provision of PD and should be prepared for this contingency depending on the platform and mission. [29, 30]

During the recurrent HCA hospital ship-based missions, the surgical care is limited due to either mission time constraints or the inability to provide appropriate long-term care when the ship leaves. The primary mission in an acute disaster is to assist the affected population *now* by supporting an overwhelmed healthcare system based on what it *needs* which can be unknown until arrival. Local healthcare systems tend to be overwhelmed and the standard of care may need to be adjusted due to the loss of infrastructure, lack or loss of expertise, or the sheer volume of patients exceeding the system's capacity. Therefore, greater risk acceptance may be required depending on surgical team capability and capacity. While every opportunity to maintain US standards of care should be made, this is not always possible and crisis standards of care need to be considered and evaluated carefully. Often, complex pathology that would be too risky to attempt during an elective HCA mission will be appropriate to attempt in a disaster, because no alternatives are available. However, every effort needs to be made before leaving to ensure long-term follow-up is taken into account [12, 31, 32].

While an analysis of the overall COVID-19 response is beyond the scope of the present article, based on the rapid change in mission in NYC and the relatively few patients cared for on the USNS Mercy, the role of the hospital ship in responding to a pandemic has limitations. While the hospital ship did provide additional critical care level beds, ventilators, and supplies, the staffing was not such to provide the maximal capacity of the ship and local hospitals may have been better served by teams to augment capacity within the local hospital system. As demonstrated by the various disaster responses explored here, what is clear is that surgical teams need to be flexible when they respond. What is needed by local communities during disaster responses may change rapidly or be unpredictable depending on the type of disaster and the healthcare infrastructure of the community or nation receiving assistance.

From triage officers to managing critically ill patients, surgeons have demonstrated the flexibility needed in disaster response. Even during chronic care phases, it has been imperative for surgeons to assist in all aspects of care from bedside procedures to palliative cancer surgery. End-of-life care is another commonly underappreciated aspect of disaster response that often falls to the surgical services on the ship. As evidenced by the hospital ship experiences in Puerto Rico and Los Angeles respectively, providing dignified end-of-life care during disaster responses provides immeasurable value to the system, patients, and their families. If during a crisis response the local system cannot support these discussions and/or the time needed to address these issues, they still need to be completed and are integral to the ethical practice of critical care medicine and surgery.

In addition to the provision of dignified end-of-life care, surgical teams may also be faced with challenging ethical dilemmas during all phases of disaster response [12, 31, 32]. While it is beyond the scope of this article to review the principles of bioethics during a disaster response, US Navy surgical teams must be prepared [12, 31, 32]. In the initial phases, the goal of triage is to do the most-good for the most number of patients. Sometimes triage during a disaster response is challenging for providers who are acclimated to non-austere standards of health care [12, 31, 32]. A priori triage protocols should be developed and a determination of what kind of patients your team will be able to care for based on your resources. Enroute to disaster response, teams should review bioethical principles and prepare all members of the team for difficult decisions. Furthermore, as conditions during the disaster response change, ethical and triage protocols should be continually re-evaluated.

It is important to note that the ship-based disaster responses are only a small part of a complex mostly civilian-led response. This paper reviews the diverse acute and long-term medical capability for disaster response on US Navy ships as well as common lessons learned for planning for future disaster missions.

Declarations

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Disclaimer The opinions or assertions contained herein are the private ones of the author/speaker and are not to be construed as official or reflecting the views of the Department of Defense, the Uniformed Services University of the Health Sciences or any other agency of the U.S. Government.

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