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Response to Hurricane Disasters

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Hurricane season is the time of year when the tropical ocean waters warm and the atmospheric winds moisten. It is during this period that the eastern seaboard and gulf coast communities of the United States hope for a quiet season while governmental agencies prepare for the worst. Unlike natural disasters such as earthquakes and wildfires, the destructive paths of hurricanes can be predicted to some degree. Preparedness and adherence to recommended evacuation orders can and do save lives. Like other disasters, however, nature is an unpredictable force that can result in significant destruction, injury, and loss of life [1]. Systems at multiple levels, not the least of which is medical, may be stressed and must execute well-designed and practiced plans to function optimally. Plans are built on experience and on what to expect. For medical systems, these plans include the prehospital emergency medical systems, hospitals, and individual physicians. Although medical needs can vary as much as the strength of the storm, similarities exist across all windstorms. Knowledge of and preparation for these needs are what build effective plans.

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What is a hurricane?

A hurricane is a tropical storm with winds that have reached a sustained speed of 74 miles per hour (mph) or more. Hurricane winds blow in a large spiral around a relatively calm center known as the "eye." The eye is generally 20 to 30 miles wide, and the storm may extend outward 400 miles. As a hurricane nears land, it can bring torrential rains, high winds, and storm surges. A single hurricane can last for more than 2 weeks over open waters and can run a path across the entire length of the eastern seaboard. August and September are peak months during the hurricane season, which lasts from June 1 through November 30.

Windstorms are classified by category based on the speed of the sustained winds (Saffir-Simpson Hurricane Scale). Tropical depressions are organized systems of clouds and thunderstorms with a defined circulation and maximum sustained winds of 38 mph or less. A tropical storm is an organized system of strong thunderstorms with a defined circulation and maximum sustained winds of 39 to 73 mph. Intense tropical weather systems with a well-defined circulation and maximum sustained winds of 74 mph or higher become hurricanes. Hurricanes are called typhoons in the western Pacific, whereas similar storms in the Indian Ocean are called cyclones.

Although the most destructive hurricanes affecting the United States form in the Atlantic Ocean, hurricanes can also form in the Gulf of Mexico, the Indian Ocean, the Caribbean Sea, and the Pacific Ocean. Hurricane winds in the Northern Hemisphere circulate in a counterclockwise motion around the hurricane's eye, whereas hurricane winds in the Southern Hemisphere circulate clockwise. Natural phenomena that affect a storm include temperature of the water, the Gulf Stream, and steering wind currents. Powered by heat from the sea, storms are steered by the easterly trade wind, the temperate westerlies, and by their own ferocious energy. Around their core, winds grow with great velocity, generating violent seas. Moving ashore, they sweep the ocean inward while spawning tornadoes and producing torrential rains and floods. In addition to the violent winds, the storm surge, which generates subsequent flooding, is the major source of destruction on land.

Although the damage inflicted by a hurricane differs with the terrain it encounters, the structural integrity of the buildings hit, the population density, the tide levels at the time of landfall, and the potential property damage and flooding expected along the coast can be estimated. Category 1 storms, with winds of 74 to 95 mph, produce no real damage to building structures; damage is limited primarily to unanchored mobile homes, shrubbery, and trees. Some coastal road flooding and minor pier damage may occur. Category 2 storms (winds 96–110 mph) result in some roofing material, door, and window damage. Considerable devastation to vegetation, mobile homes, and piers can be expected. Coastal and low-lying escape routes flood 2 to 4 hours before the arrival of the center of the storm, and small craft in unprotected anchorages break their moorings. Category 3 hurricanes (winds

111–130 mph) cause some structural damage to small residences and utility buildings, with a minor amount of curtainwall (non–weight-bearing panels suspended on the exterior of multistory structures between supporting columns) failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures, with larger structures damaged by floating debris. Terrain lower than 5 feet above sea level may be flooded 8 miles or more inland. As the winds increase to 131 to 155 mph (category 4), more extensive curtainwall failures occur, with some complete roof structure failure on small residences. Major erosion of the beach and major damage to lower floors of structures near the shore can be expected. Terrain lower than 10 feet above sea level may be flooded, requiring massive evacuation of residential areas as far as 6 miles inland. Top-level hurricanes (category 5: sustained winds >155 mph) produce complete roof failure on many residences and industrial buildings. Some complete building failures, with small utility buildings blown over or away, can be seen. Major damage occurs to lower floors of all structures located less than 15 feet above sea level and within 500 yards of the shoreline, which may require massive evacuation of residential areas on low ground within 5 to 10 miles of the shoreline.

Prestorm medical issues

With current-day communications, an approaching storm should be a surprise to no one. The National Hurricane Center, located in Miami, Florida, tracks storms from their inception, and has performed well in predicting the power and anticipated landfall location of most recent storms. With these predictions comes the ability to prepare, which for most involves the accumulation of supplies (water, food, flashlights, batteries), the securing of property (debris removal and placement of hurricane shutters), and evacuation. An adequate supply of prescription medications and supplies (syringes for diabetics, dressings for those who have recent wounds) must be anticipated and obtained. For those planning to weather the storm at home, placing these supplies in a safe room (away from windows and outside doors) should be done. Adequate supplies of fuel for personal vehicles and generators (in the event of power loss) need to be obtained before the storm arrives. These activities, representing only a partial list of the immediate preparation required, produce a very stressful environment.

As anxiety levels mount, errors occur that can lead to medical emergencies. Hurricane shutters can cause serious injury. These shutters are made of aluminum with very sharp edges and, in bulk, can be very heavy. Falling shutters have resulted in extensive lacerations and even death from head injuries. As people rush to accomplish their goals, motor vehicle accidents are also a concern.

As the storm approaches, emergency medical support disappears. Helicopters are typically grounded when wind speeds approach 45 mph. Operation of high-profile ground ambulances becomes risky at wind speeds of

45 mph, and dispatch of fire suppression units may terminate at wind speeds of 55 mph. Persons who have serious illness and injuries at this point become nontransportable.

Weathering the storm

The excitement of increasing winds and rain can be quickly replaced by substantial concern when that rain becomes torrential and the winds rattle structures. Fear that those structures may fail begins to mount. As power lines are downed, communication with relatives and news agencies is lost, and protective structures are left in darkness. Structures built to hurricane standards often do well; however, for structures not typically in hurricane-prone areas and those not built to the stringent standards of hurricane building codes, structure failure can occur. Total roof failure exposes those inside to flying debris. Many have been injured or killed when falling trees struck and collapsed houses. Reports of people wishing to go outside to experience the storm and being struck by flying debris (often with fatal results) are frequent.

Poststorm problems

As the storm passes, a sense of relief is quickly followed by one of awe or one of despair at first sight of the resulting damage. Here is where the real medical problems begin.

Power outages may be limited to neighborhoods or entire counties, lasting hours to months. With the lack of power comes the loss of refrigeration of food and medications, air conditioners, and lights. Those fortunate enough to have generators (17.5% in Florida following hurricanes Charley, Frances, Ivan, and Jeanne) [1] can spare some of these inconveniences, but generators are a risk unto themselves. Standard generators run on gasoline. Spilling gasoline onto a hot engine while attempting to refill the tank can lead to a burned victim. Despite the seemingly appropriate placement of generators away from living quarters, carbon monoxide is still a cause of fatal and nonfatal poisonings after hurricanes. One hundred sixty-seven such poisonings (including six fatalities) were treated in Florida in the aftermath of the four hurricanes of the summer of 2004 [2]. Although common knowledge might predict otherwise, 5% of those using generators placed them indoors [2]. Fifty-one cases of carbon monoxide poisoning were reported following Hurricane Katrina in 2005 in the states of Louisiana, Mississippi, and Alabama. Burns resulting from alternate sources of heat for cooking, such as barbeques and butane/propane stoves, are also frequent.

Downed power lines are also a source of injury. Contact with any structures charged by these lines leads to electrocution injury. In areas flooded by the storm, those entering the water to work or play are subject to lethal electrocution if that water is energized by a downed power line.

Clearing and repairing the damage to one's property can be arduous work. As noted, hurricanes occur during the summer months when the heat and humidity are at their highest. Many people are not accustomed to heavy workloads in these environments and, as a result, suffer heat disorders. Cardiac events also increase in frequency. Roof and tree damage leads to people climbing to heights not frequented by most. Falls from roofs and ladders are commonly seen in the aftermath of a storm. For some, only a home remedy is required, but for others, the injury is a significant laceration, fracture, or worse, brain injury or other form of life-threatening internal injury.

The debris after a hurricane is frequently in the form of shrubbery and fallen trees. Clearing these often requires knives, handsaws, machetes, and chain saws. Many people rent chain saws but have little or no experience using them. As one might imagine, a spectrum of lacerations, some quite severe, results from the use of these tools.

Preparation is key

Preparation is the key to minimizing injury and death from the destructive forces of a hurricane; however, as witnessed in the days surrounding the approach of Hurricanes Katrina and Rita toward the cities within Louisiana and Texas, and Hurricane Wilma in Florida during the summer of 2005, preparation can be formidable on a public health level. Evacuation plans must include those unable to evacuate themselves, including the healthy who do not have personal transportation and the residents and patients of nursing homes, group homes, hospices, and hospitals. Despite mandatory evacuation orders by local officials to those in predicted high-risk areas, a significant percentage of these residents do not heed these orders. As a result, call volumes for prehospital providers increase markedly. Although some patients acquire only minor injuries, many suffer chronic problems and have nowhere to go. The elderly are deposited in hospital emergency departments by family members, expecting a safe refuge—all this at a time when the hospitals themselves may be trying to evacuate. As seen during the hurricanes of 2005, many nursing homes had evacuation plans that included agreements with transportation companies, but because those companies had contracted with several nursing homes simultaneously, they did not have the capability of evacuating all of the patients in time.

Hospital disaster plans usually include a plan to discharge or transfer less acute patients to nonaffected facilities. Critical patients, however, are frequently not able to be transferred due to their acuity, and are rightfully left in place. Hurricanes can bring storm surges, heavy rains, and flooding, and hospitals with ground-based helipads are unable to evacuate patients by air if those helipads are under water. Most hospitals have ground-level or basement emergency generators that can similarly flood and become nonoperational. Although the Joint Commission for the Accreditation of Health

Care Organizations requires that hospitals have fuel for those generators, no minimum amount is specified. The American Institute of Architects guidelines state that hospitals should have a minimal storage capacity to permit continuous operation for at least 24 hours [3] in accordance with National Fire Protection Association (NFPA) 99, NFPA 101, and NFPA 110. Florida Building Code specifies a requirement for a fuel supply stored on-site to fuel generators for 100% load for 72 hours of actual demand load for all patient areas (Florida Building Code Section 419.4.2.9.2) for nursing homes (Florida Building Code Section 420.3.25) and hospitals (Florida Building Code Section 419.3.18). (NFPA 110 Section 2-2.3 requires a Class 48 generator, defined as having a fuel tank size of 48 hours, with an additional 33% over the 48 hours required as per Section 3-4.2.3. This requirement equates to 64 hours of fuel, but for simplicity, 72 hours is the standard). What if evacuation resources are not available until after that fuel is exhausted? Some health care facilities in New Orleans following Hurricane Katrina had accumulated a supply of food and water but had stored them in basement facilities, only to have them destroyed by floodwaters [4]. Even generator power can fail, leaving ventilators that lack backup batteries without a power source and, therefore, nonoperational. The usual 1:2 ICU nurse-to-patient ratio suddenly becomes unmanageable when ventilated patients require human-assisted ventilation with bag-valve-masks.

Special needs, hospice, nursing home, and hospitalized patients should probably be evacuated in larger storms, but many older adults requiring no special needs choose to remain in the area. During and after the storm, however, barriers to medical care for pre-existing needs can prove fatal [5]. Food, water, and medications can be destroyed in the storm, and isolation because of flooding or area destruction can prevent access to medical care. Because hurricanes tend to be summertime events, excessive heat can prove to be fatal in those who have frail health. As seen in Hurricane Katrina, even those in a normal state of health can succumb to the high temperatures produced in attics during attempts to escape rising floodwaters.

Although hospitals are on the high-priority list for restoration of support, lower-profile hospices, assisted living facilities, and skilled nursing facilities are often delayed in regaining necessary power and supplies. Outpatient dialysis centers are another significant area of need. Most hospitals are not equipped to handle a large number of chronic dialysis patients if the outpatient centers should become nonfunctional. For this reason, if advance warning is available, these patients should be dialyzed at their respective centers before the event occurs and be prepared to not be dialyzed for up to 3 days after; adherence to a proper emergency renal diet is necessary [6]. All Medicare-certified outpatient dialysis centers are required to have at least one backup facility [7], and this information must be passed on to the patients. Similar arrangements need to made for chemotherapy patients and other chronic needs patients. Oxygen supplies for health care facilities and those on home oxygen must also be kept current.

Coordination of the poststorm medical needs response should occur through the local and state Emergency Operations Centers. Emergency Support Function (ESF) 8 is the designated group within the disaster response organization responsible for this coordination and should be updated regularly with the functional status of all health care facilities within the affected areas. These facilities include all emergency medical services ground and air systems, bed surge capacities of hospitals, burn beds, acute care beds, skilled nursing and assisted living facilities, and a listing of all blood centers, dialysis centers, and outpatient chemotherapy and radiation centers.

Anticipation of blood needs is yet another task for hospitals. One of the many challenges facing resumption of clinical surgical services is blood product availability. All community-wide blood drives are usually suspended, which means that all blood products need to be delivered from remote locations. This delay in delivery is especially problematic for platelets, which have a shelf life of only 5 days.

Local and state disaster response

As outlined previously, hurricanes may pass into the history books as nothing more than a stressful threat or as the most devastating natural disaster in United States history. The degree of poststorm response is dictated by the degree of destruction.

Area hospital emergency rooms can quickly become busy. In the early hours and days after the storm, many of the visits are for injuries. In the authors' experience, these patients can be taken to areas of the hospital other than the emergency room (for instance, the recovery room if elective surgical cases are suspended) in an effort to offload the increasing surge on the emergency department. Because hospital registration is often the bottleneck to rapid care, wounds can be triaged and addressed first by surgeons brought in specifically for this reason, patients can be given a supply of antibiotics, and registration can be handled as the patients exit the area. In any large-scale disaster, medical care must be streamlined and sometimes inventive.

Medical licenses are issued by the state, which should allow personnel to practice anywhere within that state. The limitations to outside physician and nursing assistance, therefore, are at the individual hospital level. Emergency suspension of the requirement of hospital privileges allows personnel from unaffected areas to fill positions in the hospital temporarily vacated by medical personnel whose own lives have been disrupted by the storm. This waiver allows for the reopening of hospitals and much needed medical care in the immediate vicinity of the affected area.

Knowledge of the operational status of near and distant area facilities allows for expedited transfer or transport of patients to functional medical care facilities. Figs. 1 and 2 from the Department of Health and Human

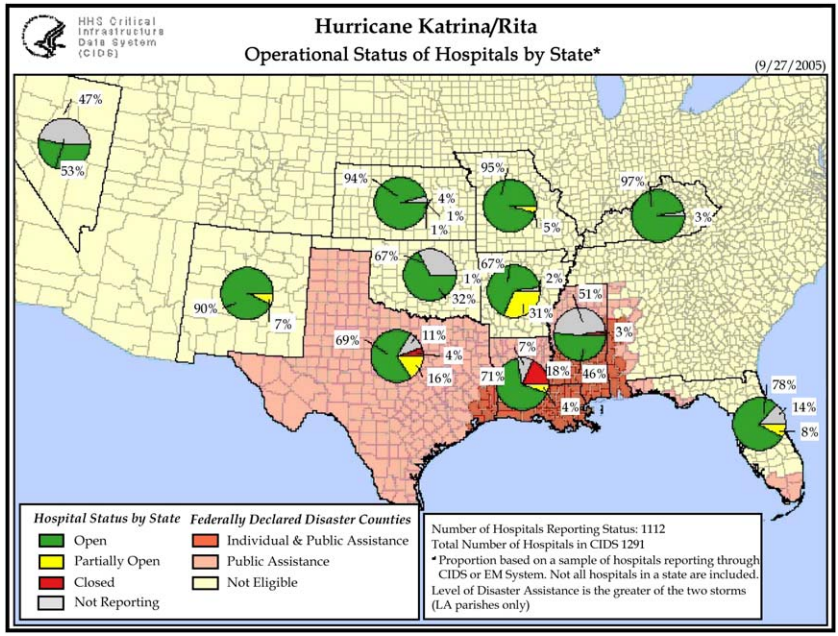

Fig. 1. Operational status of hospitals by state following Hurricane Katrina/Rita. (*From* US Department of Health and Human Services, Washington, DC.)

Services Critical Infrastructure Data System demonstrate the local, state, and national availability of medical care for hurricane victims following Hurricane Rita in 2005. A means of rapidly assessing the needs of the affected area also allows proper resource deployment and use [8].

Federal disaster assistance

In December 2004, the National Response Plan (NRP) [9] became operational, with a 4-month phase-in period, after which the previous Federal Response Plan, the US Government Domestic Terrorism Concept of Operations Plan, and the Federal Radiological Emergency Response Plan became obsolete. This document, based on the National Incident Management System, provides a framework within which disaster response can operate at all levels (local, state, tribal, federal, private sector, and nongovernmental organizations) and is designed to function in an all-hazards environment. With this plan comes definitions of roles and responsibilities of key authorities.

Although hurricanes allow for more planning and preparation than other natural disasters, much of the initial poststorm response lies in the hands of local authorities who are usually first on scene. This response includes an initial damage assessment, the subsequent restoration of power outages,

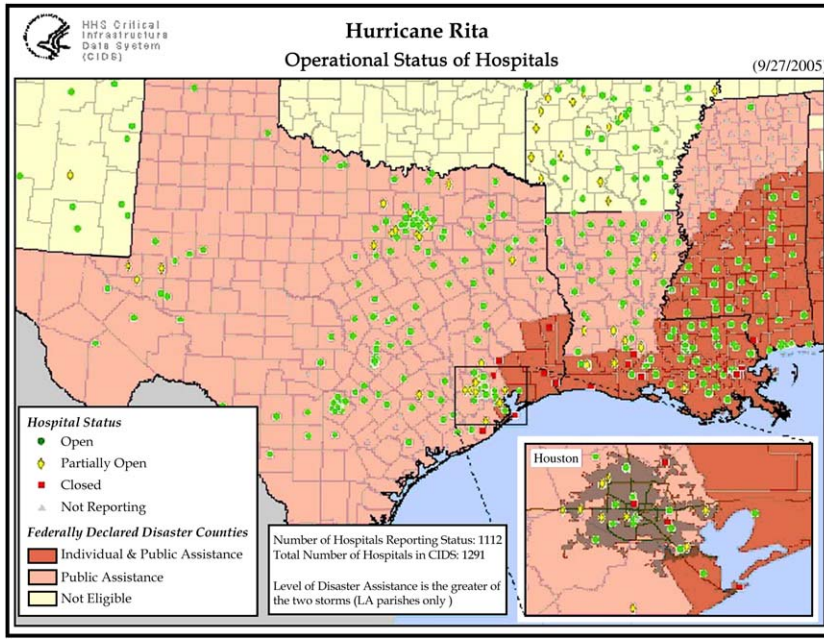

Fig. 2. Operational status of hospitals during Hurricane Rita. (*From* US Department of Health and Human Services, Washington, DC.)

the clearing of roads to allow the safe movement of traffic and rescue personnel, and the establishment of a law enforcement presence to prevent unlawful acts. In the event that local resources are overwhelmed, state assistance is requested. As outlined in the NRP, the governor, as the state's chief executive officer, is responsible for coordinating the state's resources "to address the full spectrum of actions to prevent, prepare for, respond to, and recover from incidents in an all-hazards context" [9]. If and when it becomes clear that state assets have been exceeded or exhausted, federal assistance can be requested by the governor. The process for this request and assistance is outlined in the Robert T. Stafford Disaster Relief and Assistance Act [10]. This federal assistance can be extensive and can include medical care.

Within the NRP are 15 ESFs. These ESFs, in their partial or full activation, provide a coordinated assistance mechanism for local, state, and tribal governments for recovery from any and all disasters. Two of these 15 ESFs provide medical assistance. Activation of ESF 9 (Urban Search and Rescue) mobilizes elite teams trained in the specialized area of heavy structure collapse. These teams provide primarily search and rescue capabilities but include a component of medical personnel for the treatment of rescued victims; however, their supplies and capabilities are limited. Within ESF 8 (Public Health and Medical Services) is the National Disaster Medical

System and the network of Disaster Medical Assistance Teams (DMATs). These DMATs consist of medical personnel from all areas of emergency medical care, including physicians, nurses, radiology and respiratory therapy technicians, and laboratory personnel. These teams deploy with their personnel and equipment and are capable of independent function as a field hospital in a parking lot or in filling personnel positions in existing hospitals. These teams were used extensively in the hurricanes of 2004 and especially in those of 2005. Over 64,000 patients were treated by the deployed DMAT teams in the 6 weeks following the landfall of Hurricanes Katrina and Rita in 2005 [11]. Military assets have also been successfully deployed following major storms [12] and can provide supplies, air support, manpower, and law enforcement resources.

The future

Every disaster carries with it new challenges that have never been seen or perhaps never been considered. As such, every disaster provides a teaching environment from which we can and should learn. Hurricane Katrina provided a significant classroom from which we can change future policy.

Few disasters in the United States have brought the infrastructure of an entire city to its knees as occurred in New Orleans in the summer of 2005. Few have produced the numbers of victims of that storm. A considerable amount of time and brainpower has been devoted over the years to preparing for disasters, but more postincident planning should be stressed. Although communication has long been a recognized problem in the postdisaster setting, transportation becomes a formidable issue in a large-scale disaster that affects thousands and eliminates the basic support structures. Before and after a storm, huge numbers of people must be evacuated by public and private transportation. Even those who heed evacuation demands find themselves caught in interminable traffic jams. Effective plans that allow for proper evacuation must be developed, and adequate numbers of vehicles used for postevent evacuation must be rapidly mobilized.

After victims are removed from immediate danger, they are frequently deposited in areas while awaiting definitive evacuation. Mass care of these potential thousands must be prepared for. Casualty collection points must be identified before the event and must be staffed and equipped properly with basic-needs medical care. These collection points can range in function from treatment areas to morgues. Mass casualty triage must be used effectively. Although most physicians are accustomed to treating the most severely sick and injured first, it is difficult for this practice to happen in these settings. Those in need of advanced medical care may fall into triage categories in which care will not be rendered, and physicians must be trained to deal with this scenario. Shelters should be identified for prestorm evacuees and the potential hundreds or thousands displaced from their homes after the storm.

Summary

The preparation and rebuilding in the wake of a devastating hurricane can be a challenge at all levels. The summer of 2004 proved how frequently these preparations might need to happen, and the hurricanes of 2005 demonstrated how extensive these preparations should be and the cost of inadequate preparation. Medical care is a very large component of the disaster plan for hurricanes and must include not only supplies but also personnel. Personal and professional limitations can impede the response of valuable personnel to distant sites, but one must remember that the local response falls in the hands of those first on site (ie, those who reside in the area). Proper planning and effective drills can mitigate the extent of damage to structures and human life, and when deemed necessary, effective evacuation of at-risk areas is crucial. In the end, nature is much too powerful a force for us to fight—we can only be prepared to respond to and bend with the potentially devastating forces directed our way.

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