Impact of a Major Hurricane on Surgical Services in a University Hospital

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Hurricane Hugo struck Charleston, South Carolina, on September 21, 1989. This report analyzes the impact this storm had upon surgical care at a university medical center. Although disaster planning began on September 17, hurricane damage by high winds and an 8.7-foot tidal surge led to loss of emergency power and water. Consequently, system failures occurred in air conditioning, vacuum suction, steam and ethylene oxide sterilization, plumbing, central paging, lighting, and refrigeration. The following surgical support services were affected.

In the blood bank, lack of refrigeration meant no platelet packs for 2 days. In radiology, loss of electrical power damaged CT/MRI scanners and flooding ruined patient files, resulting in lost information. In the intensive care unit, loss of electricity meant no monitors and hand ventilation was used for 4 hours. In the operating room, lack of temperature and humidity control (steam, water, and suction supply) halted elective surgery until October 2. Ground and air transportation were limited by unsafe landing sites, impassable roads, and personnel exhaustion.

Surgical planning for a major hurricane should include 1) a fail-safe source of electrical power, 2) evacuation of as many critically ill patients as possible before the storm, 3) cancellation of all elective surgery, and 4) augmented ancillary service staffing with some, although limited, physician support.

HURRICANE HUGO struck the coast of South Carolina on the night of September 21, 1989. The surgical services at the Medical University of South Carolina, located in the coastal city of Charleston, were affected for a period after the storm. The purpose of this report is to point out the problems we experienced in maintaining our surgical services. We hope that our successes, as well as our mistakes, will benefit other medical centers faced with similar storms in the future.

Background

Hurricanes represent the planet's most violent form of weather (Funk, B. Y., National Geographic, 1980; 158: 346–67). As explained by Eliot, these storms form when air warmed by the surface of tropical oceans rises creating an area of low pressure. North of the Equator and as a result of the Earth's rotation, prevailing winds in these storm systems spiral counterclockwise toward the center of the low pressure region. This process perpetuates itself, causing ever stronger winds (Eliot J, *Into the Eye of David.* National Geographic, 1980; 158: 368–71). The storm system is referred to as a hurricane when sustained winds reach 74 miles per hour (mph). Hurricanes are often hundreds of miles in diameter, and winds become increasingly destructive toward the center of the storm. The "eye" of a hurricane is an area of calm in the center of the storm into which the associated winds spiral. Winds approaching the coast push water ahead of them, resulting in flooding well above normal tide levels. This phenomenon is referred to as a tidal surge. Thus, the two major destructive forces are high winds and flooding. Hurricanes are classified by their windspeeds and the degree of flooding according to the Saffir/Simpson Scale (see Table 1).

Hurricane Hugo was a Class IV hurricane with sustained winds of 135 mph and gusts exceeding 180 mph. The maximum tidal surge was in excess of 15 feet. Although reports vary substantially, it has been estimated that this storm spawned as many as 200 tornadoes in the greater Charleston area. Destruction ex-

Presented at the Annual Meeting of the Southeastern Surgical Congress, Atlanta, Georgia, May 31–June 3, 1992.

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TABLE 1 *The Saffir/Simpson Hurricane Scale*

Storm Class	Sustained Wind Velocity (mph)	Tidal Surge (ft)
I	74–95	4–5
II	96–110	6–8
III	111–130	9–12
IV	131–155	13–18
V	>155	>18

tended over much of North and South Carolina, and the eye of the storm passed directly over the city of Charleston and the Medical University Hospital. This storm's most destructive winds and highest tidal surge were to the North of the eye, thus sparing the city the hurricane's worst destruction. Sustained winds in the city approached 100 mph with substantially stronger gusts and 8.7 feet of flooding at the hospital. Total estimated damage in South Carolina alone exceeded $6 billion, making Hugo the most expensive storm in American history.

Preparations

Although never explicitly expressed at the time, three goals for the surgical services at the Medical University Hospital were paramount. First, we wanted to assure the safety of our hospitalized patients. The second goal was to assure that our regional Level 1 Trauma Center would remain open. Finally, we wanted to assure an ample, well-functioning staff despite any problems that might be encountered.

Patient Safety

Storm preparations began on September 17, 1989, when it became apparent that a powerful storm that had formed off the coast of Africa would strike the coast of the eastern United States. Once it was clear that this storm, now dubbed Hurricane Hugo, would strike in the vicinity of Charleston, efforts to decrease the hospital's patient census were initiated. Beginning 36 hours before the hurricane's effects were felt, admissions were limited to emergencies only. On the morning of September 21, this policy was amended so that no patient would be admitted without the consent of the hospital's medical director. Patients in the hospital were reviewed and any patient deemed ready for discharge was sent home. We did not, however, evacuate any patients to another hospital nor did we cancel any surgical procedures on patients already in the hospital before hurricane preparations began.

We anticipated the loss of electrical power during the storm and, as did all hospitals, had permanent emergency generators to provide power to much of the hospital's electrical system. However, as the hurricane approached landfall, strengthening as it crossed the ocean, the predicted maximum tidal surge would have inundated these emergency generators. Anticipating that the permanent emergency generators would be unusable, auxiliary generators were brought in to provide power to the various intensive care units.

Finally, in preparation for the storms arrival, alternate locations for caring for intensive care unit patients were arranged, and food and water were stockpiled.

Maintenance of Trauma Center Function

Because of the severity of the storm, we anticipated that serious injuries were inevitable. Experience in another hospital with two storms of less severity demonstrated statistically significant increases in overall emergency department visits, stings, lacerations, chainsaw injuries, puncture wounds, and burns. Increases, although not statistically significant, were observed in orthopedic injuries, motor vehicle accidents and eye injuries.[1,2] We wanted to have facilities available during the storm itself to treat anyone injured within the medical center complex. Once the storm subsided, we wanted to be prepared to treat any injuries incurred outside the hospital that would benefit from the services of a trauma center.

The anticipated maximum tidal surge would have resulted in flooding of our regional Level 1 Trauma Center's admitting area. Therefore, necessary equipment including oxygen cylinders, sterile procedure trays, gurneys, battery-operated suction devices, monitors, lanterns, flashlights, and extra batteries for this equipment were moved to the second floor of the attached outpatient clinic building. In the event of elevator failure due to loss of electrical power or shaft flooding, it would be necessary to move patients from this area to the operating room two floors above by stretchers made available for this purpose.

As part of the commitment to maintain trauma services, we needed to assure operating room availability. First, a limited number of operating rooms were designated for use. Equipment was moved centrally, away from windows, and essential equipment was plugged into outlets supplied by the primary emergency generators. Extension cords were strung into these rooms from emergency power outlets in undesignated operating rooms to augment the limited emergency electrical supply in the designated suites. Instruments were sterilized and packaged in plastic to prevent contamination.

Assurance of Ample, Well-Functioning Staff

The major objectives in this regard were to assure adequate staffing for preparation and cleanup and to allow those that stayed through the storm the oppor-

tunity to rest and return home as soon as possible after the storm to take care of damage to their own homes. Although this was not mandated by the hospital administration, virtually every department followed a similar formula. The available staff was divided into two groups. One group was kept out of the hospital and instructed to return as soon as conditions allowed. The other group was brought into the hospital before the storm and worked alternate shifts until those in the first group arrived. Arrangements for sleep were made for all of those staying at the hospital.

Effects of Storm on Utilities and Services

Water

We had been assured that water pressure would not be lost in the city. This proved not to be true. While water pumping capabilities were maintained as expected, intakes at local reservoirs were unexpectedly occluded by mud. This resulted in a loss of all water to the hospital until September 24th. It was not until several days later that available water was considered safe to drink.

Electricity

As the storm reached its peak, electrical power to the entire region was lost. Because the eye of the storm passed directly over the city, we didn't experience the maximum tidal surge faced by those to the north of the eye. Although water rose to within 1 foot of the hospital's primary generators, they did not flood as we had feared. Unfortunately, these generators were cooled by the city's water system. When this system failed, these generators failed also. Fortunately, an old, unused artesian well was adjacent to the hospital and was converted to a water source for the emergency generators. All power throughout the hospital was lost for 4 hours during this conversion. The auxiliary generators, which had been brought in before the storm, were located in exposed outdoor locations precluding access to them during the storm. Therefore, the auxiliary generators were not employed.

Health care facilities were a high priority for restoration of electrical power. While the majority of the city remained without electrical power for over a week, with some areas in the affected region waiting over a month, the hospital's power was returned by September 24th.

Communications

Telephone service was continuous throughout this period. Telephone cables in the city were generally underground and thus were not seriously effected. The telephone relays for the hospital communication system were surrounded with sandbags and protected from flooding. The hospital's beeper system, however, was rendered inoperable by the loss of electrical power. This system was not supplied by the primary emergency power system but was restored within a few hours, when a portable home generator was tied in to provide the needed electricity.

Transportation

During the storm, flooding and flying debris made travel extremely dangerous and essentially impossible. The hurricane's winds felled trees and knocked down power lines and utility poles throughout the area. Thus, even after the storm, many roads remained impassable to vehicular traffic and, in some cases, to foot travel. The lack of electricity resulted in failure of stoplights and other road signals. Although road crews began cleaning major thoroughfares immediately, travel remained difficult for some time. In addition to roadway problems, air travel was also affected. The loss of electricity closed the Charleston International Airport because of the loss of runway lighting and communications.

Effects of the Hurricane and of Loss of Utilities and Public Services on Surgical Capabilities

Operating Room

Contamination of the operating suite was a major problem. Loss of water, and therefore steam, in the operating room suites resulted in loss of instrument sterilization capability. The operating room air conditioning and dehumidification system failed, resulting in a loss of temperature and humidity control. The air handlers were disabled by the loss of electrical power, and the loss of water disabled the vacuum system. The lack of running water made the usual surgical scrub impossible. Therefore, bottles of water were used by those surgeons performing the few emergency procedures done in the period immediately after the hurricane.

Contamination problems were amplified when wind-driven rain, passing directly through the brick and mortar of the hospital's outer walls, flooded many of the operating rooms. Once power was restored to the air conditioning and dehumidifiers, the serious degree of contamination required that all rooms be completely cleaned with disinfectant solutions. All air handler filters were changed and all rooms were disinfected again. Cultures were then taken and incubated. These requirements resulted in an inability to perform all but emergency procedures until October 2

Surgical, Neurosurgery, Burn, and Cardiothoracic Intensive Care Units

While efforts to decrease the patient census in the entire hospital worked to some degree, the intensive care units remained nearly full at the time of the storm. Problems were magnified when an entire wall of windows shattered in the pediatric intensive care unit several floors above the surgical units. Patients from this unit were evacuated to any available space in the other intensive care units. The total failure of electrical systems required that patients requiring mechanical ventilator support be hand-ventilated with bag–valve devices for the 4 hours required to restore power from the primary emergency generators. All monitoring capabilities were lost during this interval The only available light was that provided by flashlights and candles.

Trauma Admitting Area

At the peak of the storm, the inner walls of our relocated trauma admitting area began to vibrate violently, generating concern among hospital engineers that the building was in imminent danger of collapse. The area was abandoned until the eye of the hurricane passed over the hospital. At that time, equipment necessary for treating in-house injuries was moved into administrative areas located well inside the main hospital building. When the entire storm had passed and it was clear that the hospital itself had experienced minimal flooding, the trauma admitting area was reopened in its original locational and functioned with battery-powered equipment and available emergency power.

Surprisingly, few patients were seen in the few days immediately after the storm. The majority of hurricane-related injuries occurred during efforts to make repairs and clean up damage caused by winds and flooding throughout the region.

Surgical Wards

Although the patient census in these units was significantly reduced, the remaining patients were severely ill or in the immediately postoperative stage and many had chest tubes or other mechanical devices in place. When the hurricane's winds began breaking windows throughout the hospital, patients were moved from their rooms into the hallways. Unlike outlets in the patient's rooms, the electrical outlets in the hallways were not supplied by the emergency generators. Thus, even before the primary emergency generators failed, equipment did not function. In addition, such equipment was in short supply because most was being utilized in the intensive care units. When all power was lost, flashlights and candles, which were a serious fire threat, provided the only available light.

After the storm, supply shortages became a significant problem. The hospital's warehouse is far removed from the hospital and road conditions limited the movement of supplies. The loss of power to the laundry facility resulted in a shortage of linens. Soiled sheets could not easily be replaced, which posed a potential threat of wound infection and skin breakdown. In addition, the loss of air conditioning, combined with the tropical heat and humidity associated with the storm, was unbearable for the patients and the staff.

Radiology

The damage to radiologic services was the worst in the hospital. Flooding of an adjacent building destroyed one computed tomography (CT) scanner and the electronic components of a magnetic resonance imaging scanner. A second CT scanner, while still somewhat functional, was damaged by power surges as well as by the heat and humidity caused by the loss of the air-conditioning system. After many breakdowns and attempted repairs, this CT scanner ultimately required replacement. These losses hampered our ability to evaluate our patients expediently until mobile scanners were made available more than a month later. In addition, more than 20,000 outpatient x-ray files, many less than a year old, were destroyed by flooding. This potentially caused problems in our ability to observe a great number of patients radiographically.

Blood Bank

The blood bank had few significant problems. Dry ice brought in before the storm minimized the loss of blood components due to loss of refrigeration. However, platelets could not be preserved and were unavailable until normal refrigeration was restored 2 days later.

Emergency Medical Services (EMS)

During the hurricane itself, local EMS agencies were unable to function because of dangerous conditions on the area's roads. Once the storm subsided, EMS experienced a substantial increase in call volume. Emergency medical technicians worked long shifts with little break. Long hours and medic exhaustion made long-distance ground transport difficult, and an increased call volume compounded this problem. Taking an ambulance out of service for one long-distance transport made EMS services less available to the many needing them in the immediate area.

The Medical University of South Carolina operates an emergency aeromedical transportation service. Before the hurricane, the helicopter, along with a complete crew, was moved 100 miles inland. By 7 AM on September 22, the helicopter had returned to Charleston.

However, loss of communications, due to the widespread power outages, lack of ground lighting, and the danger of downed power lines, minimized its usefulness for scene trauma flights. Inclement weather in the days after the storm further compromised the helicopter's ability to function and essentially eliminated the helicopter as an effective means of patient transport. Together, the loss of the airport, which prevented fixed-wing transportation and the unavailability of ground EMS units for long-distance transport made evacuation of patients very difficult after the storm. One intubated severely injured patient, who required a CT scan of the head because of a possible closed head injury, was transferred more than 100 miles in the back of a National Guard jeep because of these difficulties.

Discussion

How did the Medical University perform in terms of meeting prehurricane goals? Staffing of the various nursing units and essential ancillary services was not a significant problem. The staffing plan adopted almost universally throughout the hospital proved to be quite adequate. The major problem in supporting the staff was providing sufficient food, water, and sleeping arrangements. The loss of air conditioning, with its resultant heat and humidity, as well as a lack of running water, which prevented washing and rendered bathroom facilities inoperative, was quite uncomfortable for those who worked during, and immediately after, the storm.

With the exception of a brief period at the height of the storm, we were able to maintain a functional trauma center throughout this period. Unquestionably some compromises in our usual standard of care were required but, in general, we remained capable of functioning as a regional trauma center for any patient that could be brought to us. Our experience suggests that during the peak of a storm of this magnitude, transportation to a trauma center is impossible. Efforts should be aimed, instead, at providing care for any in-house injuries that occur.

Assuring patient safety proved to be a problem. No patient died or, to the best of our knowledge, had a serious complication as a direct result of Hurricane Hugo. While this is, to some extent a result of prestorm planning, much credit must go to the ingenuity and dedication of the hospital staff. In some ways, luck also played a role. The city of Charleston and the Medical University Hospital did not experience the full force of the storm. Had the eye of the hurricane passed 25 miles south of the city, we would surely have faced many more serious problems.

We can make several recommendations based on the problems we encountered during Hurricane Hugo:

1) *Electrical power must be as fail-safe as possible.* The most serious problems with patient safety were related to the loss of electrical power. Since the storm, our emergency generators have been converted to a self-contained coolant system similar to an automobile radiator system, making them independent of outside water sources. These generators are still potentially susceptible to flooding. During the hurricane, the tidal surge of 8.7 feet came within 1 foot of these generators. Had we experienced the tidal surge of more than 15 feet experienced to the north of the city, we would have lost all power in most of the hospital for several days at a minimum. At best, this would have caused a further disruption of surgical services, and in all likelihood, would have cost the lives of some of our surgical patients. Because our primary emergency generators cannot easily be moved to a higher level, it may some day be necessary to rely on temporary auxiliary generators. These must be positioned in sheltered accessible locations well above any potential flooding so that they can be operated during a storm.

2) *Critically ill patients should be evacuated before a storm whenever possible.* Although the overall census of patients on the surgical services was reduced in the 2 days before the hurricane, those still in the hospital were either critically ill or in the immediate postoperative period. The loss of power in our intensive care units posed a grave threat to patients on ventilators as well as to those requiring intensive hemodynamic support. The transportation problems that developed as a result of the hurricane made evacuation after the storm nearly impossible.

3) *Only emergency, life-saving surgical procedures should be performed in the period immediately proceeding any storm of this caliber.* Although we admitted no new surgical patients, surgery continued on patients who were already in the hospital. This left a group of acute postoperative patients in the hospital. Many of these could, and perhaps should, have been discharged and operated on at a later date.

4) *Minimize the number of physicians and the number of people not directly providing patient care in the hospital* We found that there was substantially less need for attending physicians than we anticipated. The surgical residents were able to provide care for, and were familiar with, the patients of many attending physicians. The attending staff, on the other hand, added little to the care of patients other than their own and, by their presence in the hospital, placed an additional burden on the hospital's resources. We could have functioned quite well with a limited number of attending physicians working closely with and serving as a resource for those residents willing to stay through the

storm. Although administrators were of great importance after the storm, with the exception of those involved in maintaining essential hospital services, such as the hospital engineers, they added little during the storm itself. This excess in personnel provided an additional burden on an already stressed system.

Conclusion

A hurricane as ferocious as Hurricane Hugo can have a significant impact on a hospital's ability to perform surgery. Careful planning is essential to assure patient safety and efficient staff function while maintaining those services essential to the community.

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