Received: 16 April 2021 | Revised: 7 November 2021 | Accepted: 17 November 2021

DOI: 10.1002/emp2.12632

JACEP OPEN — WILEY

REVIEW ARTICLE

Disaster Medicine

Hospitals as disaster victims: Lessons not learned?

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Prior presentations: Xth Mediterranean Emergency Medicine Conference, Dubrovnik, Croatia, September 2019.

Funding and support: By *JACEP Open* policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article as per ICMJE conflict of interest guidelines (see www.icmje.org). The authors have stated that no such relationships exist.

Abstract

Objective: Hospitals are a key component to disaster response but are susceptible to the effects of disasters as well, including infrastructure damage that disrupts patient care. These events offer an opportunity for evaluation and improvement of preparedness and response efforts when hospitals are affected directly by a disaster. The objective of this structured review was to evaluate the existing literature on hospitals as disaster victims.

Methods: A structured and scoping review of peer-reviewed literature, gray literature, and news reports related to hospitals as disaster victims was completed to identify and analyze themes and lessons observed from disasters in which hospitals are victims, to aid in future emergency operations planning and disaster response.

Results: The literature search and secondary search of referenes identified 366 records in English. A variety of common barriers to successful disaster response include loss of power, water, heating and ventilation, communications, health information technology, staffing, supplies, safety and security, and structural and nonstructural damage.

Conclusions: There are common weaknesses in disaster preparedness that we can learn from and account for in future planning with the aim of improving resilience in the face of future disasters.

KEYWORDS
disaster preparedness, hospital damage, hospital infrastructure

1 | INTRODUCTION

The Centre for Research on the Epidemiology of Disasters in Brussels, Belgium, defines a disaster as "a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering."[1] Hospitals and health systems are key components of emergency preparedness and response and are vulnerable to the effects of disasters. A disaster may be the consequence of an internal derangement in function (ie, electrical failure) or the consequence of external forces (ie, flooding from a hurricane). Natural disasters, such as hurricanes, tornadoes, earthquakes, and wildfires, are increasing in frequency and can damage hospital infrastructure, disrupting care for both current patients and disaster victims.[2–4] Other crises, such as blackouts, acts of terrorism, internal fires, radiation exposures, or chemical spills, may leave hospital infrastructure intact but may create an unsafe environment for patient care, thus requiring mass mobilization and evacuation of the facility.[5]

In the United States, the Centers for Medicare and Medicaid Services requires all hospitals and health care facilities to develop emergency plans using an all hazards approach in 4 areas: risk

Supervising Editor: Juan March, MD.

assessment and planning, policies and procedures, training and testing, and communications plan.[6] A 96-hour operational plan should be in place for health care organizations to elucidate capabilities and limitations to make effective decisions under emergency conditions.[7] The emergency preparedness and response literature is growing and reflects an expanding interest in and evolution of the science of hospital preparedness.[8–17] Although there are general themes described in the literature from specific hospitals that have experienced disasters that disrupted normal operations and patient care,[18–28] and although there is literature describing how hospitals should prepare for and respond to internal and external disasters, to the best of our knowledge there are no structured reviews on this topic. The objective of this paper is to provide a structured, detailed review and description of the common themes and lessons from disaster events that directly affect hospitals and health systems via damage to physical infrastructure or degradation of resources, thereby disrupting the basic function of patient care.

2 | METHODS

2.1 | Search strategy and selection criteria

We performed a structured, scoping review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) methodology.[29] A medical librarian performed a structured literature search on MEDLINE/PubMed databases in July 2019 and again in May 2020 (due to increased focus on disaster preparedness related to the COVID-19 pandemic) to identify peer-reviewed literature with one or more preidentified search terms. Multiple individual keyword and MeSH term searches were performed with multiple search strings deployed using Boolean operators. MeSH terms were expanded for use as keywords. Keywords used in 2019 included hospital(s), surge capacity, disaster medicine, disaster planning, structure collapse, triage, patient care, disaster preparedness, targets, and benchmarks. MeSH terms used in the search included terrorism, disaster planning, hospital(s), mass casualty incidents, resource allocation, surge capacity, civil defense, disasters, and natural disasters. Keywords used in the search in 2020 included COVID, SARS-CoV-2, and resilience. MeSH terms used in the search included bioterrorism, chemical terrorism, warfare, disease outbreaks, pandemics, coronavirus, and coronavirus infections. The database search was limited to literature written in English, with a data range from 1946 to May 2020. Duplicate publications were excluded.

The structured literature search was supplemented by manually searching reference lists of identified manuscripts for relevant publications. Selected references identified by hand searching were further hand searched to identify any additional publications. Qualitative synthesis of the results was completed by 2 authors (EMM, CKK). An additional search was conducted in the gray literature and media reports to supplement the peer-reviewed literature search. There was no funding source for this study.

2.2 | Inclusion criteria

Articles identified in the structured literature search were included if published between 1946 and May 8, 2020, written in English, and had an abstract available. If no abstract was available, the article was hand searched and the complete article obtained if possible. The remaining articles were then screened by title and abstract, and eligible papers were included for review.

2.3 | Exclusion criteria

Articles identified in the structured literature search that were excluded were those identified as duplicate articles, articles not related to hospitals as disaster victims, and solitary abstracts.

3 | RESULTS

The literature search identified 257 publications in English. Three duplicate articles were excluded.

The secondary search of references yielded 109 additional publications for a total of 366 publications. Most publications related to natural disasters such as hurricanes and earthquakes, but other disasters such as internal fires, acts of terrorism, and blackouts, were also identified. Articles were then categorized by year of publication, article methodology, type of disaster, and literature review (literature search completed in July 2019, May 2020 or hand search). Articles were then analyzed by year of publication (Figure 1), disaster type (Table 1), and

TABLE 1 Types of disasters

Type of disaster	Number of publications
Blackout	3
Chemical, biological, radiological, nuclear, and explosives	19
COVID-19	40
Cybersecurity	4
Earthquake	21
Environmental	8
Flood/tsunami	7
Hurricane/tropical storm	66
Internal structural	10
Other	160
Terrorism/mass casualty incidents	15
Tornado	3
Volcano, sand/dust storm	2
Wildfire	5
Total	363

Number of publications identified in peer-reviewed and gray literature, by the type of disaster described within the publication.

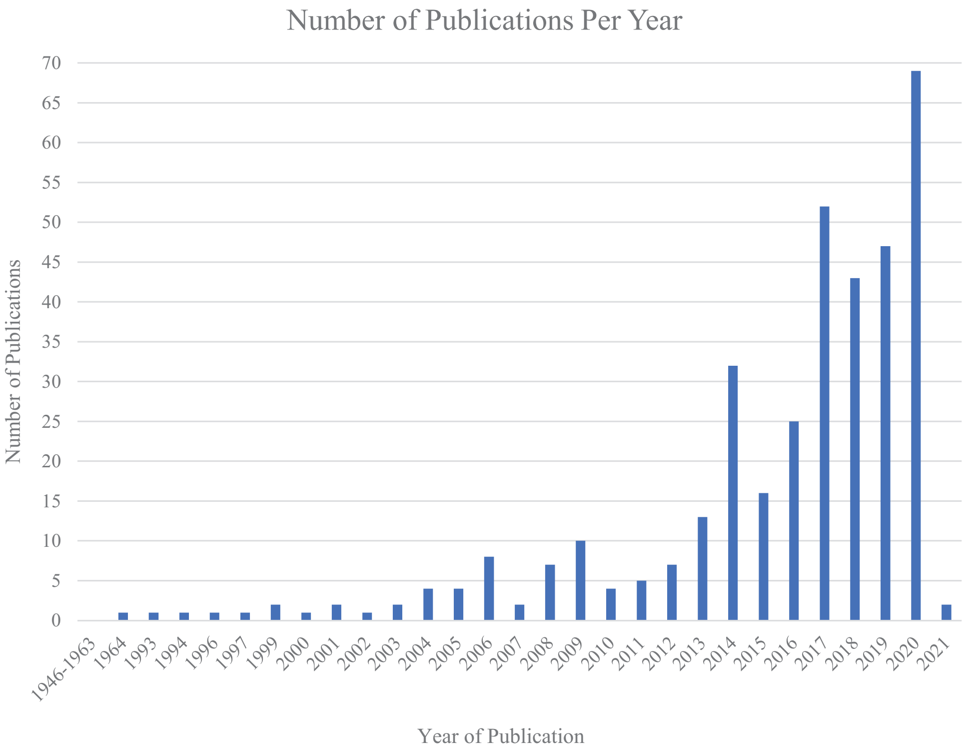

FIGURE 1 Publications by year. Number of publications identified by year in peer-reviewed and gray literature. No publications were identified between 1946 and 1963.

TABLE 2 Publications by type

Type of publication	Number of publications
Case report/series	50
Commentary/editorial	41
Cross-sectional	10
Government report	2
Industry website	5
Longitudinal	2
News article	41
Retrospective chart review	2
Retrospective cohort	7
Review/concepts	144
Survey/interview	58
Thesis	1
Total	363

Number of publications identified in peer-reviewed and gray literature, by type of publication.

by study methodology (Table 2). A table of selected disasters and their effect on the hospital(s) system was created (Table 3). The Supplementary Material provides a complete list of references reviewed. Topical themes and lessons identified in the literature review are outlined next.

4 | TOPICAL THEMES IN HOSPITALS AS DISASTER VICTIMS

4.1 | Loss of power

Power failures, including loss of electricity, are common during disasters. Power outages increase hospital admissions and mortality.[69] The loss of power poses significant and multifactorial challenges for hospitals, affecting nearly all aspects of patient care and hospital operations.[70,71] Hospital plans to manage power loss usually focus on backup generators, for 24 to 96 hours, when power could be restored or external resources mobilized.[72,73] In the cases of rain storms, flooding can render backup generators inoperable, especially if these units are on lower floors or subterranean spaces in the hospital.

Backup generators are at risk for damage from flooding, especially if located on lower floors of a hospital. They are also prone to mechanical failures, overheating, and fuel pump malfunctions.[31] In one example, generators were above floodwaters, but failure of a fuel pump required a "bucket brigade" to pass fuel to the generator located on the 13th floor of the hospital.[51] At Memorial Hermann Hospital in Texas, backup generators were located on the second floor, but the power distribution panel on the main floor was irreparably damaged during tropical storm Allison, resulting in loss of electricity.[34] Auxiliary power can be insufficient to support normal operations and the transition to auxiliary power can disrupt or disable computer-controlled equipment like

TABLE 3 List of disasters, strategies, and solutions

Type of disaster	Hospital/ Health System (Location)	Time	Loss of Power	Loss of Water[a]	Loss of HVAC[b]	Loss of Communi-cations[c]	Loss of HIT[d]	Loss of Staff[e]	Loss of Supplies[f]	Loss of Safety[g]	Structural or Non-structural Damage[h]	Strategies Employed	Outcome	Solutions	Refer-ence(s)
Earthquake (The Great Alaskan Earthquake)	Providence Hospital (Anchorage, AK)	March 1964	X	X	X	X						Emergency generators were functional and were used, water was pumped into the hospital from a nearby spring. Pumps were used to be able to flush toilets up to the top floor.	Shelter in place (155 beds, 75 patients present at the time of the earthquake) Received 22 patients from an evacuated hospital and 27 patients from a nursing home.	- Communication by ham radio and police radio. Radio broadcasting led to an influx of volunteers. - A civil defense hospital was made available to be erected.	30
Hurricane (Hurricane Hugo)	Medical University of South Carolina (Charleston, SC)	September 1989	X	X	X	X	X		X	X	X	Admissions limited to emergencies 36 hours before the hurricane; food stockpiled; ancillary generators obtained	Shelter in place	- Adjust generator cooling plans to not require outside water sources - Evacuation of critically ill patients before storm impact - Minimize number of physicians and staff not providing direct patient care	31
Earthquake (Northridge Earthquake)	Multiple health centers (Los Angeles, CA)	January 1994	X	X	X	X		X	X	X	X	Evacuation of most ill patients first, in most cases.	Evacuation of 8 acute care hospitals (6 immediate, 2 delayed)	- Establishment of field hospitals/alternative sites of care - Use of an emergency operations center to manage transfers as well as hospitals transferring patients independently	32
Earthquake (Great Hanshin-Awaji Earthquake)	Multiple health centers (Kobe, Japan)	January 1995	X	X	X	X		X	X		X	Helicopter transportation of injured patients given extensive roadway obstructions and damage	Multiple hospitals with structural and non-structural damage. Destruction of medical services and overwhelming numbers of patients.	- Development of disaster communications, trans-port, field first-aid stations - Reinforcement of search and rescue system - Creation of water wells solely for hospitals	33
Tropical Storm (Tropical Storm Allison)	Memorial Hermann Hospital (Houston, TX)	June 2001	X	X	X	X	X	X	X		X	Staff were reorganized to form a command center within the hospital. Pneumatic ventilators were used on intubated patients.	Evacuation of 406 patients, 169 discharged, total of 545 inpatient beds	- Take steps to preserve electricity, water, and other supplies. - Development of a regionalized commu-nications center, patient logging system, and media communication.	34,35
Hurricane (Hurricane Katrina)	Charity Hospital (New Orleans, LA)	August 2005	X	X	X	X	X	X	X	X	X	Prolonged evacuation. Staff contacted outside agencies for assistance.	Evacuation of ≈360 inpatients	- Elevate and protect generators and their fuel supply - Develop hospital infrastructure for disaster preparedness - Develop robust emergency evacuation protocols	36

(Continues)

TABLE 3 (Continued)

Type of disaster	Hospital/ Health System (Location)	Time	Loss of Power	Loss of Water[a]	Loss of HVAC[b]	Loss of Communi-cations[c]	Loss of HIT[d]	Loss of Staff[e]	Loss of Supplies[f]	Loss of Safety[g]	Structural or Non-structural Damage[h]	Strategies Employed	Outcome	Solutions	Refer-ence(s)
Hurricane (Hurricane Rita)	Multiple health centers (New Orleans, LA)	September 2005	X	X	X	X	X	X	X		X	Cancelled prestorm elective surgeries; discharged able patients, emergency departments stayed open	Evacuation of 7 hospitals	- Lengthening the 96-hour standard of emergency generator power fuel supply - Protect generators and their fuel supply - Develop robust emergency evacuation protocols and stock appropriate volumes of necessary supplies	37
Hurricane (Hurricane Rita)	University of Texas Medical Branch at Galveston (Galveston, TX)	September 2005				X	X					All evacuated patients transported with a paper copy of their medical records and medications (with some exceptions).	Evacuation of 427 patients, 730 inpatient beds before hurricane landfall	- Authorizing a single incident commander and establishing an incident command center -Avoiding delay in decision to evacuate - Conduct trial evacuation runs	38
Wildfires	Pomerado Hospital (San Diego, CA)	October 2007			X							Hospital was given a short window to evacuate given EMS was fighting fires. Charts were attempted to be copied and transferred with patients. ED went on ambulance diversion.	Evacuation of 77 inpatients, 107 inpatient beds)	- Improved communication to staff and handoff communication for receiving hospitals. - More efficient transfer of medical records - Role clarification for staff	39
Fire (Hospital Fire)	Royal Marsden Hospital Fire (London, England)	January 2008			X	X	X		X		X	Temporary shelter/triage area set up and transfer of patients to next door hospital with disaster hospital staff caring for them, runners used to communicate	Evacuation of 78 inpatients, 120 outpatients	- Handheld radio system - Better planning for medical record transfers - Consider designating a recordkeeper to document timing of meetings and decisions that take place	40,41
Flood	Mercy Medical Center (Cedar Rapids, IA)	June 2008									X	Flooding in lower level where backup generator was located	Pre-event evacuation or 176 patients, 236 inpatient beds	Elevation of backup generators	42
Fire (Hospital Fire)	University College London Hospital Fire (London, England)	July 2008			X	X	X		X		X	Shelter in place of neigh-boring maternity and neonatal services affected by smoke, partial closure and service diversion, ED used for triage of patients in labor	Shelter in place, neighboring maternity and neonatal services affected by smoke, partial closure and service diversion emergency department used for triage of patients in labor	- Purchase of handheld radio system - Modification of evacuation and sheltering-in-place plans	40

(Continues)

TABLE 3 (Continued)

Type of disaster	Hospital/ Health System (Location)	Time	Loss of Power	Loss of Water[a]	Loss of HVAC[b]	Loss of Communi-cations[c]	Loss of HIT[d]	Loss of Staff[e]	Loss of Supplies[f]	Loss of Safety[g]	Structural or Non-structural Damage[h]	Strategies Employed	Outcome	Solutions	Refer-ence(s)
Fire (Hospital Fire)	Great Ormond Street Hospital Fire (London, England)	September 2008			X		X				X	Hospital placed on lock-down during the incident, all media inquiries were directed to the media office. Attempted cohorting of patients with similar illnesses	Evacuation of at least 23 children	- Modification of evacuation plans - Increased number of available sheltering-in-place sites	40,43
Fire (Hospital Fire)	Chase Farm Hospital Site Fire (London, England)	October 2008	X		X			X		X	X	Staff were called indi-vidually to alert them of the incident. Unique incident involving psychiatric inpatients detained under a Ministry of Justice order	Evacuation of 70 patients, 151 inpatient beds	- Adjustment of major incident plans - Preparation of joint statements from fire and police - Emergency backup communications system	40,44
Fire (Hospital Fire)	Northwick Park Hospital Fire (London, England)	February 2009	X	X	X						X	Unclear who the decision-makers were initially given multiple agencies responded. Unclear naming of areas within the hospital	Evacuation of 123 patients, 600 inpatient beds. Discharged patients well enough to leave the hospital.	- Keep up-to-date floor plans of the hospital easily accessible - Updated fire training for staff	40,45
Earthquake, Tsunami (Great East Japan Earthquake)	Sendai Hospital, Fukushima Medical University (Fukushima Prefecture, Japan)	March 2011	X	X		X			X		X	Deployment of multiple disaster medical assistance teams (DMATs) Established a 362-bed evacuation facility specifically for the elderly	Evacuation of 1770 older patients whom were residents of hospitals, nursing homes and other care facilities out of the mandatory evacuation zone, 840 patients left stranded	- Development and enforcement of minimum standards for public health needs - Annual drills	46
Tornado, Wind Damage	St. John's Regional Medical Center (Joplin, MO)	May 2011	X			X					X	Evacuation in 45 minutes; makeshift ED off site; mobile surgical hospital deployment within 1 week	Evacuation of 183 patients, over 350 inpatient beds	- Annual drills - Back-up communications systems	47
Hurricane (Hurricane Irene)	North Shore-Long Island Jewish Health System (Long Island, NY)	August 2011									N/A	947 patients evacuated 12 hours before hurricane landfall	Preevent evacuation due to concerns for water and wind damage (947 patients, transferred, 6000 beds total)	- Trial run of evacuation plan; annual drills - Predesignate receiving hospital for certain patients - Using "master" patient lists, EHRs, universal patient ID/wristbands, etc. - Top-down hospital construction (protecting vital components such as heating/air conditioning/ power/patient care/etc.) - Early discharges and cancel elective surgeries/non-emergent admissions	48

(Continues)

TABLE 3 (Continued)

Type of disaster	Hospital/ Health System (Location)	Time	Loss of Power	Loss of Water[a]	Loss of HVAC[b]	Loss of Communi-cations[c]	Loss of HIT[d]	Loss of Staff[e]	Loss of Supplies[f]	Loss of Safety[g]	Structural or Non-structural Damage[h]	Strategies Employed	Outcome	Solutions	Refer-ence(s)
Flooding (Hurricane Sandy)	NYU Langone Medical Center (New York, NY)	October 2012	X			X						Transport sleds in stairwells. Movement of patients away from vulnerable areas of the hospital. EMR data were printed before power loss.	Evacuation (Early discharge of about 600 patients, transferred 215 patients, 725 inpatient beds)	- Protect and fortify generators and their fuel supply	49,50
Flooding (Hurricane Sandy)	Coney Island Hospital (New York, NY)	October 2012	X						X		X	Early discharges and elective surgeries cancelled before storm and admissions from the ED transferred to other hospitals, battery packs for ventilators secured	Evacuation of ≈215 patients, 371 inpatient beds.	- Consideration of vulner-abilities and earlier evacuation, consideration of a clearinghouse for patient bed availability - Discharge packets created for patient evacuation	49
Flooding (Hurricane Sandy)	Bellevue Hospital (New York, NY)	October 2012	X	X	X	X	X		X		X	Initiation of a fuel brigade to carry fuel up to a generator fuel tank. Messengers were sent between areas and floors of the hospital. In-hospital courier system for medications. A research "help desk" was employed.	Evacuation (> 736 patients evacuated, 828 inpatient beds)	- Protect and fortify generators and their fuel supply - Develop robust alternative means of communication - Develop alternative water sources	51,52,49
Fire (Fort Murray Wildfire)	Northern Lights Regional Health Center (Alberta, Canada)	May 2016			X	X					X	Preevent evacuation of a 136-bed hospital in ≈2 hours	Evacuation of 73 acute care patients, 32 long-term care residents, 22 visitors, 136 inpatient beds	- Improve plans for prepa-ration of evacuation - Establish an emergency communications system - Criteria for establishing an incident command post	53
Flooding (Hurricane Harvey)	Texas Medical Center (Houston, TX)	August 2017	X	X		X			X		X	Multiple strategies applied that were learned from Hurricane Allison and focused on disaster infrastructure, culture, technology, communica-tion, preparedness	Shelter in place	- Infrastructure investment (flood gates, walls, dikes, etc.) - Protect generators and their fuel supply, invest in alternative power supply (co-generator plant) - Develop robust communications avenues	54,55
Flooding (Hurricane Harvey)	Ben Taub Hospital (Houston, TX) Part of Texas Medical Center	August 2017	X	X				X	X		X	Evacuation prolonged and patients eventually sheltered in place due to rising flood waters Staff able to be relieved with other health care workers, partial food delivery completed before hospital running out of food	Evacuation initially planned for 350 transfers, 3 patients eventually transferred, 444 inpatient beds,	- Fortification of water/ sewer lines, elevate storage of medications/ supplies/food	56–60

(Continues)

TABLE 3 (Continued)

Type of disaster	Hospital/ Health System (Location)	Time	Loss of Power	Loss of Water[a]	Loss of HVAC[b]	Loss of Communi-cations[c]	Loss of HIT[d]	Loss of Staff[e]	Loss of Supplies[f]	Loss of Safety[g]	Structural or Non-structural Damage[h]	Strategies Employed	Outcome	Solutions	Refer-ence(s)
Hurricane (Hurricane Harvey)	Lyndon B. Johnson Hospital (Houston, TX)	August 2017									X	Ambulance diversion, deferred elective procedures, scheduled procedures completed at a different hospital during repair period	Evacuation (34 patients transferred, 207 inpatient beds)	-Reinforce water and moisture control systems	58
Hurricane (Hurricane Harvey)	Memorial Hermann Sugarland Hospital (Houston, TX)	August 2017									X	Preevent evacuation	Preevent evacuation of 150 patients	-Fortify flood-prone equipment	61
Hurricane (Hurricane Irma)	Lower Keys Medical Center (Key West, FL)	September 2017		X	X						X	Evacuated patients before hurricane arrival; stock-piled fuel, food, water, and linens; volunteers stayed to staff the ED	Preevent evacuation (13 medical and behavioral patients, 167 inpatient beds)	- Annual evacuation drills - Effective planning before the storm may lead to earlier reopening (ED able to be reopened within hours of storm passing)	62,63
Hurricane (Hurricane Maria)	University of Puerto Rico Medical Center (Puerto Rico)	September 2017	X	X					X			Established emergency coverage rosters; canceled elective surgeries and clinics	Shelter in place, some cases transferred to mainland United States	- Backup of communications systems - Stockpiling of supplies - Fortification of power and fuel sources	64
Fire (Napa Wildfires)	Sutter Santa Rosa Regional Hospital (Napa County, CA)	October 2017	X		X	X	X	X			X	Use of city buses to transport patients, use of schools and fairgrounds to continue patient care	Evacuation (84 inpatient bed capacity hospital)	- Annual evacuation drills/planning - Pharmacy and medication preparations -Expanding hospital privi-leges during disaster	65
Hurricane (Hurricane Matthew)	Beaufort Memorial Hospital (Beaufort, SC)	October 2016	X								X	Suspended medical services, staff relocated in close proximity to resume emergency services after the storm	Preevent evacuation of ≈70 patients	- Fortification of power and fuel sources	66,67
Internal Structural (Flooding)	Grady Memorial Hospital (Atlanta, GA)	December 2019									X	Diversion of ambulances, mobile ED	Evacuated 83 patients (57 to acute care hospitals, 26 to other facilities)	- Continued planning for regional coalitions	68

[a] Loss of water/limited water supply/plumbing failure.
[b] Loss of heating, ventilation, air conditioning, and air quality.
[c] Loss of or inadequate means of communications.
[d] Loss of health information/health information technology.
[e] Loss of staff/staffing shortages.
[f] Loss of supplies and disruptions of logistics and supply chain management.
[g] Loss of safety and security.
[h] Structural and/or non-structural damage (including flooding, smoke and/or fire damage).
List of selected disasters, with information available about: loss of key entities (ie, loss of power, water, etc.), the strategies employed during the disaster, and the outcome of the disaster.
Abbreviations: EHR, electronic health record; EMR, electronic medical record; EMS, emergency medical services; HIT, health information technology; HVAC, heating, ventilation, air conditioning.

computed tomography (CT) scanners, laboratory devices, and fire alarm systems.[74]

4.2 | Loss of water

Disruptions in water supply or loss of potable water can necessitate hospital evacuation. The availability of potable water and adequate water pressure is critical to basic hospital functioning and of particular importance during a disaster.[75] Lack of water pressure within the first few hours after the disaster affects the ability to flush toilets, perform hand hygiene, sterilize instruments, perform dialysis, and provide heating and cooling capabilities.[71,52] In an earthquake, hospitals continued with functional backup water stores from wells and holding tanks augmented by emergency supply transported to the hospitals by truck.[76] The potential for plumbing failures and damage to storage tanks should be accounted for in this backup system.[76] Other innovative measures have been taken to ensure water availability such as using normal saline and sterile bottled water for hand washing and pouring water into toilets for manual flushing.[71,77]

A lack of potable water is a frequent problem after a disaster. In some cases, tertiary care hospitals have struggled to maintain operating suites and intensive care services when municipal water supplies are disrupted.[31] Secondary water sources (eg, bottled water) from external suppliers frequently do not arrive for several days, in one case 36 hours after a call for help.[71]

4.3 | Loss of heating, ventilation, air conditioning (HVAC): temperature and air quality

Heating, ventilation, and air conditioning (HVAC) systems are critical to a hospital's ability to provide patient care, yet redundancy in heating and cooling systems is uncommon. Functioning HVAC systems control ambient temperatures and ensure air quality inside hospital buildings. Depending on weather conditions at the time of disaster (ie, loss of cooling in summer and heating in winter months), loss of ambient temperature control via loss of hospital boilers, chillers, and other HVAC systems could lead to hospital evacuation.[75] Temperature control is necessary for patient and staff comfort and safety and ensures the quality and availability of certain blood products, biologic specimens (eg, bone grafts), and technologies such as CT scanning machines, ventilators, medical gases, and incubators. Degradation of air quality due to fire has led to hospital evacuation.[39] Loss of negative pressure ventilation in isolation areas has also been described as an air quality (and infection control) concern after a power failure.[71]

4.4 | Loss of communications

Hospitals can lose internal and external communication capabilities in a disaster. Landline and cell phone service are both prone to failure during disasters. Having reliable in-hospital communications systems that can function independent of the availability of electricity has been a valuable lesson observed during multiple disasters. A common approach is battery powered 2-way radios, although their supply might be too limited to facilitate effective communications to maintain operations.[52] Another alternative approach to communication failures is to communicate via runners, although this approach is not without its own difficulties.[78,52]

Communication challenges often extend beyond single hospitals, with regional and national cellular telephone service interruptions leading to difficulty in communicating with other medical facilities, with emergency medical services, and with mobilizing external resources for patient care and supply needs.[52] Hospitals have used television and radio broadcasts for information regarding numbers and types of injuries from the disaster, roadway conditions, and the status of other hospitals.[74]

4.5 | Loss of health information and technology

Health information technology (HIT) supports patient care in clinical orders, documentation and communication of clinical care, diagnostic and other test results, and patient tracking. Unexpected downtime of electronic health information systems leads to longer operative times and increased time to disposition for patients in the emergency department.[79] A growing concern, beyond the scope of this review, are cybersecurity threats to HIT infrastructures, including ransomware.

Protocols for the maintenance and transfer of paper medical records during a disaster are not common. During a disaster, paper medical records may not be transported with the patient and electronic documentation may not be kept or available.[37,49,52,80] In one example, a hospital fire led to transport of patients to another area within the hospital, but documentation and tracking of patients were not available.[40] During Hurricane Rita, patient tracking was negatively affected by variations in the maintenance and transfer of patient medical records, with some hospitals sending original medical records and others sending copies of patient records.[37,81] After Hurricane Sandy in the United States in 2012, some patients had no medical record accompanying them and were untraceable by their families.[82]

4.6 | Loss of staff

Staff availability, including clinical and non-clinical personnel, is another way that hospitals can be victims of disasters. Staff might be lost to illness, as during seasonal influenza or the COVID-19 pandemic, or injury during a disaster. Other staff might have ethical, safety, or other concerns about reporting to work during a disaster.

An analysis of staffing and administrative problems in the California earthquake of 1989 cited issues including staff anxiety, poor internal communication, and confusion of roles.[74] The American Medical Association published a recommendation that states physicians participating in disaster responses should "have an obligation to evaluate the risks of providing care to individual patients versus the need to be available to provide care in the future."[83] Staff preparation and readiness in disasters has been described as generally insufficient.[84] Increased staff absenteeism during moderate and severe influenza epidemics compared to non-epidemic timeframes has been outlined in prior investigations.[85,86] Therefore, protection of staff who are able to work is also paramount given current hospital models focusing on efficiency.[87] Mental health professionals have been added to some medical teams to assist in evaluating health care workers and assist in mitigating stress.[88]

Competing personal, family, and community demands and responsibilities might also impact staff availability. Problems related to staffing are often due to need for child/elder care and supervision or lack of available public or personal transportation. Staff availability is often dependent on availability of childcare.[89–92] One report noted that a hospital was able to temporarily maintain normal staffing without disruptions in patient care until the next group of staff arrived as relief.[71] During Hurricane Hugo, preemptive steps were taken to ensure staffing before the hurricane made landfall by splitting available staff into 2 groups: 1 group remained at the hospital anticipating the storm, and after the storm passed, the second group arrived at the hospital to relieve the first group.[31]

Scheduling modifications can be implemented to help with staffing challenges. In university medical centers and teaching hospitals, where physicians-in-training are a substantial part of the workforce, staffing can be more complex. For example, in the days and weeks after Hurricane Sandy, clinical hours were lengthened, and conferences and formal lectures were delayed for weeks because of to technical limitations and patient surge. Clinical teams from facilities that were evacuated were relocated to functional hospitals to maintain continuity of training and supplement the staffing needs of these hospitals. However, these relocated teams faced challenges related to a lack of access to laboratory, radiology, and medical records.[80] These experiences can have positive impacts on education.[93] Cross-training and cross-credentialing staff can also augment staffing shortages in a disaster.[94] Frequently, physicians and other clinical staff are willing to volunteer assistance in a disaster.[84,89,90,95]

4.7 | Loss of supplies: disruptions of logistics and supply chain management

During disasters, hospitals frequently exhaust supplies of common items such as linens and personal protective equipment. These supplies are frequently not considered in disaster planning. Insufficient stock of these items can be amplified by surges in demand, particularly with just-in-time, scheduled procurement supply chain models. For example, one study showed that in a region in China, only 11% of hospitals had a stockpile of supplies.[96] After Hurricane Maria in 2017, intravenous fluid shortages were experienced in the United States because the manufacturing factories in Puerto Rico were damaged.[97–99]

Batteries are another "high-demand" item and supplies are frequently exhausted as they power communication devices, flashlights, exit lighting, emergency overhead lighting, and devices such as ventilators and medication pumps. In extreme cases, a lack of batteries can limit device-dependent therapies such as positive pressure ventilation..[78] Other items such suture kits, dressings, wheelchairs, and gurneys might also be in short supply.[74] Loss of medications or access to medications can also create a significant burden on patients and medical relief teams and can result in ED visits for medication requests.[24,30,46,65,100–102] A number of pieces of emergency clinical equipment and their quantities are considered to be very important or very important to be available during a sudden-impact mass casualty incident.[103] In the case of a prolonged disaster, such as the COVID pandemic, priorities shift to resource allocation and the suspension of non-essential services to optimize finite supplies.[104–108]

4.8 | Loss of safety and security

Physical security can be challenging during a disaster or terrorism event. Approximately half of active shooter events in the United States end within 5 minutes and 70% end within 15 minutes.[109] In a review of hospital-based shootings, approximately 60% of shootings occurred in the hospital and the ED was the most common environment where the shooting occurred.[110] In 23% of ED shootings, the perpetrator had taken the gun from a security guard.[110] Providing adequate equipment and robust training to staff when there is an active shooter threatening the hospital building or health care staff is important. A study of out-of-hospital professionals' willingness to respond into a "warm zone," where the scene was not definitively secured, increased with provision of protective ballistic equipment and training.[111]

During a case of intentional harm, such as an active shooter event or an act of terrorism, preservation of evidence and collection of evidence, should be considered after the scene has been secured.[112] Chain of custody for evidence should be established early to best preserve quality of evidence obtained. Training a team of professionals, including a photographer, to document the surroundings and victims should also be considered.[113]

During a regional full-scale simulation of release of 2 dangerous chemicals, security and decontamination were noted to require continued assessment.[114] Also, disaster debris can complicate response and recovery efforts and block access for emergency staff, including law enforcement.[115] Disaster waste also may pose a significant public health risk and its continued presence serves as a reminder of community hardship.[115]

Depending on the area, flood waters may be highly contaminated and toxic owing to the presence of local manufacturing facilities.[116] This was the case as the result of Hurricane Harvey as Houston was responsible for 40% of the US petrochemical production and 30% of the US oil refining, and multiple refineries experienced structural failures and multiple superfund sites were flooded.[117]

4.9 | Structural and non-structural damage

Certain types of disasters put hospital infrastructure, resources, and operations at greater risk during the index event as well as in the immediate aftermath. Non-structural damage may include water damage, loss of electrical power, and destruction of supplies and equipment. In a review of hospital evacuations after an earthquake, initial survey of non-structural damage was associated with higher rates of facility evacuations and disruptions in patient care.[32]

Structural and non-structural failure in the absence of an external event can also occur without warning. After a ceiling collapse in an ED, a hospital's acute medical/observation unit was converted to a temporary ED to allow continued patient care and for repairs.[118] On a larger scale, an urgent care center with an emergency medicine-run observation service was implemented after an ED experienced disaster.[119]

In cases of partial structural damage to a hospital, on- or off-campus alternate sites of care might be established such as a field hospital, medical tents, or mobile disaster care units.[120,121] These permanent or temporary medical facilities have their own intrinsic challenges based on which type of structure is to be erected but also include providing staffing, information technology, logistical and supply chain challenges and may be limited in what services they can provide.[122–124]

4.10 | Other considerations

There are several other considerations to be made by hospitals affected by disasters, including non-hospital based care, such as home health services and the use of paramedics to provide patients with medications and durable equipment, provide transportation to alternative housing, and arrange access to other outpatient resources for those with chronic illness.[125] In other settings, drones have been used to augment telecommunications infrastructure and deliver medications during a disaster.[126] Hospitals need to consider how to protect resources from further damage when a disaster strikes, for example, the protection of biospecimens and research materials.[127,56] Additionally, a small number of hospitals around the world have fortified their health centers for acute, intermediate, and long term or "under-siege" disaster situations.[128] During the COVID pandemic, inpatient visiting policies have been modified in hospitals around the world to protect visitors and staff from the spread of infection.[129] Finally, the rapid expansion of telemedicine consultations has shown utility in bringing health care services beyond the walls of the traditional hospital setting.[130]

4.11 | Limitations

There are several limitations to our study. First, the review could have missed specific disaster events directly affecting hospitals and health systems. We used an established scoping review methodology and manually searched additional literature identified in the scoping review, adhering to the principles of reporting scoping reviews as outlined by the PRISMA extension for scoping reviews.[29] The reproducible method provides an expansive, if not exhaustive landscape of the available evidence in this area of disaster research. The majority of the existing literature is observational and qualitative, and there is the potential bias of over- or underrepresenting certain themes and concepts. This review collates the most frequent themes encountered in the disaster literature. Because of the heterogeneity of reports and the inconsistency in reporting disasters in peer-reviewed literature, some detailed information of the events listed were not available. (See Table 3.) The literature search was restricted to electronic databases and, therefore, was limited in capturing gray literature or news reports that are not available online. The contribution of additional bias related to the databases searched and the search algorithm may be why there were no reports of disasters relating to hospitals during the time frame of 1946–1963.

This study focuses primarily on the experience of hospitals as disaster victims in the United States; however, international examples are also included. Unique systems of care, hospital infrastructure and physical plant design, and the role of governments contribute to differences in planning and response. However, by including an international sample of hospitals, including hospitals that differ in size and resources, the results are more likely to be generalizable. This is particularly true for themes that are relevant in specific regions, such as flooding risks in storm prone areas and earthquake damage in regions with likelihood of seismic activity. Finally, non-hospital health care settings, such as skilled nursing facilities and outpatient clinics, were not included in this analysis. These facilities are part of the spectrum of health care provided to communities, although are less likely to be used for advanced or emergency care frequently needed during disasters, such as surgical and critical care capabilities.

Given the research librarian output, the authors do not know how many initial papers were found on the initial, unrefined literature search. However, our results are consistent with the trend in increase of publications on disaster research more recently.[11] This literature is dynamic and ever growing and our goal was not to capture every publication but to provide an overview of existing literature. Additionally, systematic reviews of the literature to date do not provide significant amounts of evidence as disaster research does not lend itself to controlled trials. In some cases, it was difficult to determine when events occurred during a disaster in referring to pre-event/post-event evacuations. It is also challenging to establish clear categories of preparations, response to and outcomes of a disaster (eg, what is complete vs partial evacuation and what occurs pre- vs during vs post-event). We categorized evacuations (complete and partial) together as evacuations because it is felt that the decision and effort of evacuation is more thematically important than the quantity of patients evacuated.

We did not review ethical considerations or crisis standards of care that might need to be implemented when a hospital is no longer capable of providing patient care during a disaster. These considerations are important; however, they are beyond the scope of this review that focuses on physical infrastructure and supporting resources such as power, water, and professional staff.

Finally, we did not evaluate the financial considerations of institutional disaster preparedness. Financial resources dedicated to disaster preparedness vary by location and can be affected by regulatory requirements for preparedness. This is an area for future research given that financial burdens related to preparations for high risk, low likelihood events can be considerable.

5 | DISCUSSION

Disaster preparedness and emergency response literature is largely focused on processes for planning and risk mitigation using an all-hazards approach before, during, and after the event. Case studies, media reports, and anecdotal accounts have described how disasters affect health care resources, including hospitals. The results presented here are novel as the first comprehensive review of themes and lessons observed when hospitals and health systems become victims of a disaster and, as a result, have their operations interrupted, displaced, or halted. Hospitals are described as victims, not to imply that they passively experience disaster, but to provoke thought about the responsibility of hospitals and health systems as part of the critical infrastructure of local, regional, and national disaster preparedness and response. Therefore, it is incumbent upon hospitals to be hardened and prepared.

The overarching themes presented in this paper, across time, geography, and type of disaster, highlight the need for a disciplined and dynamic all-hazards approach. The lack of quantitative data and analysis on these themes in the literature offers an area for further research. A structured review and analysis of these themes are critical to focused planning, to resource allocation, and to maintaining hospital operations during a disaster. Maintaining the operational capabilities of hospitals during disasters is fundamental to an all-hazards approach.

The consistent themes identified as threats to hospital operations, even in the context of different types of disasters, suggest that there remain gaps in and opportunities for improvement in disaster preparedness. These opportunities include issues related to infrastructure, processes, and personnel. There are consistent themes facing hospitals as outlined in Table 3 and there is evidence of what is at risk (eg, generators and fuel supplies in lower levels of hospitals). Over the course of time, in different types of disasters, and in unique geographic regions, these risks remain, suggesting the need to employ strategies from prior lessons observed. There is evidence for successful hospital disaster mitigation strategies implemented >50 years ago.[30]

To the authors' knowledge, this is the first structured review of the impact of disaster on hospitals and health systems as it relates to their functioning through a disaster by outlining common themes and lessons observed. The disaster literature shows that hospitals, health systems, EDs and staff around the world are not prepared for disaster, adequate disaster plans are not in place, plans already in place are highly variable, and the current level of disaster-related education is inadequate for health care workers.[131–159] Over the past 2 decades, there has been an increase in publications relating to disaster and emergency preparedness and response. The results of this systematic review add to the existing literature and have important implications for emergency preparedness and response. This review highlights a unique perspective on the multifaceted disaster literature and adds knowledge to better prepare hospitals and health systems by incorporating a more practical backdrop for health systems to create a more robust all-hazards approach to disaster preparation. The results of our work suggest that existing disaster and response resources should include the recognition that hospitals can be rendered incapacitated as a result of directly being affected by a disaster.

Historically, evacuations occur in 2 time frames, either in anticipation of a known disaster event, or after a disaster occurs. However, patients frequently still arrive at an evacuated hospital for medical and non-medical care.[21,49] An additional consideration surrounding facility evacuation is how to communicate the facility's status as "out of service" to the community so that patients avoid arriving at that facility. There have also been reports of patients being transported from evacuating hospitals, and arriving at the referral hospital that had also begun evacuating.[48] Regional coordination among facilities and stakeholders is critical for managing patient flow to individual hospitals that can safely manage additional patient surge, while avoiding those facilities that have been damaged or destroyed.

Although beyond the scope of this paper, special considerations should be made for the needs of different patient populations, the contributions of different types of physicians, both generalists and specialists, and differences in types of hospitals (eg, university, government, etc). Special populations who may be particularly vulnerable in a disaster also must be considered in disaster planning.[160–167] These populations might include pediatrics, geriatrics, patients who are technology or highly resource dependent, and those living in settings lacking technology infrastructure or sufficient transportation.

6 | CONCLUSION

This review reveals multiple thematic lessons and examples of disruptions in operations that can affect hospitals and health systems in a disaster. The results are relevant to hospital and health care system leaders, governments, health care professionals, and communities as they inform and help to define emergency operations plans and their implementation. Although it is impossible to prepare for all circumstances, these results suggest that there are common gaps, threats, and vulnerabilities facing hospitals as disaster victims. The lack of qualitative data presents an opportunity for further research on this topic. Preparations and future research should aim to increase hospital resilience as well as to respond quickly and effectively to future disasters.

ACKNOWLEDGEMENT

The authors would like to acknowledge Mary Jo Devereaux, MLS, for her assistance in the literature review.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Eric Melnychuk, DO, provided assistance in the literature search, curation of the data and formal analysis, methodology, visualization of the data, writing of the original draft, review, and editing

Thomas D. Sallade, DO, provided assistance in curation of the data, methodology, and writing of the original draft, review, and editing

Chadd Kraus, DO, DrPH, conceptualized the study, provided project administration and supervision, and provided assistance in the literature search, formal analysis of the data, visualization of the data, writing of the original draft, review, and editing.

Eric Melnychuk, DO, and Chadd Kraus, DO, DrPH, have accessed and verified the underlying data. All authors contributed to the manuscript to the degree that meet ICJME authorship guidelines. All authors contributed to the manuscript per ICMJE guidelines

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Melnychuk E, Sallade TD, Kraus CK. Hospitals as disaster victims: Lessons not learned? *JACEP Open*. 2022;3:e12632. https://doi.org/10.1002/emp2.12632