

Preparedness Lessons from Modern Disasters and Wars

Saqib I. Dara, MD, FCCP^a, J. Christopher Farmer, MD, FCCM^{b,c,d,*}

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In life, unlike chess, the game continues after checkmate.

Isaac Asimov, 1920–1992

In 2003, the severe acute respiratory syndrome (SARS) outbreak unmasked the vulnerability of health care professionals caring for these contagious patients.^{1,2} In some countries, 50% of the SARS casualties were health care workers.³ A tsunami in 2004 killed an estimated 230,000 people, mostly in Indonesia.⁴ In 2005, Hurricane Katrina struck the United States, an industrialized nation with enormous resources. Despite the presence of a substantial response infrastructure in the United States, news images revealed an initial paralytic aftermath with individuals “dying in the streets” and stranded critically ill patients in the shells of hospitals. Ensuing floods rendered intensive care units (ICUs) nonfunctional.^{5,6} News headlines in 2008 estimated that more than 100,000 people died in Myanmar⁷ as a consequence of cyclone Nargis and almost 70,000 people died following earthquakes in China last spring.⁸

Fortunately, in the wake of these events, medical response to disasters significantly evolved.^{9–11} Most recent disasters around the world have witnessed brisk execution of well-structured, integrated response, albeit with occasional operational flaws.^{12,13} Much of this progress has occurred as a result of governmental policy shifts that followed disasters.¹⁴ In the United States, for instance, there has been a clear increase in focus on disaster preparedness since the events of September 11, 2001.¹⁵

^a Critical Care Medicine, Al Rahba Hospital—Johns Hopkins International, Abu Dhabi, United Arab Emirates

^b Critical Care Medicine, Mayo School of Graduate Medical Education, Mayo Clinic College of Medicine, Rochester, MN, USA

^c Department of Medicine, Mayo Clinic College of Medicine, Rochester, MN, USA

^d Program in Translational Immunovirology and Biodefense, Mayo Clinic College of Medicine, Rochester, MN, USA

* Corresponding author. Department of Medicine, Mayo Clinic College of Medicine, 200 First Street SW, Old Marian Hall, OL2-115, Rochester, MN 55905.

E-mail address: farmer.j@mayo.edu (J.C. Farmer).

At the government level, we witnessed the creation of the Department of Homeland Security to streamline and improve the efficiency of multiple response agencies.¹⁶ In addition, the ongoing scientific,^{17,18} technical,^{19–21} and educational advances^{22–24} and their integration with disaster medicine^{25,26} have advanced our ability to respond to disasters. For example, we have increased capability of transporting very sick patients,^{27,28} improved early detection of unusual and previously unidentified microbes,²⁹ and enhanced our ability to rapidly acquire information from disaster scenes through mobile telecommunications systems, global positioning, and telemedicine technologies.³⁰

What lessons can we learn from these events and from other disasters over the last many decades? Despite the varied nature of these catastrophes, many critical care themes are common to all:

Planning matters—a lot!^{12,31,32}

The absence of sufficient training and education equals confusion, uncertainty, and increased secondary casualties (including injuries and fatalities to health care professionals).³³

The provision of critical care must include “portability,” defined as the ability to provide credible, sustainable, sophisticated care outside of the normal confines of an ICU.^{9,34–36}

Dispelling myths: It’s too many casualties, so what possible impact would a (relative) “handful” of resources mean to this many patients?

To address these issues, we need to identify simple, broadly available technologies that can be universally employed.^{28,37}

What follows is a representative, but not exhaustive, list of representative disasters that have occurred over the last few decades, with a summary of each disaster, as well as specific clinical lessons learned. Finally, we offer suggestions regarding how each of these disaster events should influence our current critical care preparedness planning.

EVENT: CHERNOBYL NUCLEAR DISASTER

Summary

On April 26, 1986, a large-scale nuclear disaster occurred at Chernobyl, a small town in Ukraine, which was a part of the Soviet Union.^{38,39} Compared with other large-scale disasters, such as the nuclear bomb detonations in Hiroshima and Nagasaki and exposure to cesium-127 in Brazil,⁴⁰ this is the worst nuclear disaster in history. It resulted from overheating of a reactor core, while testing a safety procedure. An estimated 56 deaths occurred, including 28 radiation deaths among reactor operators and firefighters.⁴¹ Additionally, it is estimated that there may be have been hundreds of subsequent cancer occurrences among the adjacent population, as well as among the 6 million people who lived within the radiation fallout plume.⁴²

Relevance to Today and Clinical Teaching Points

The medical literature contains little about the immediate response to the Chernobyl disaster. Even so, lessons can be learned about the gaps in reporting and communication and the secrecy of the authorities at the time. This failure to inform generated fear, rumors, and uncertainty.³⁹

There could be very high rates of posttraumatic stress disorder after a major radiation exposure. Groups particularly at risk include children, pregnant women, mothers

of young children, and emergency workers. Prevention is essential through openness and communication.⁴³

Another important lesson from Chernobyl is that a major radiation incident also results in thermal and radiation burns, wounds, fractures, and other trauma injuries, thus adversely affecting the prognosis of the patient. The immune function may become compromised, predisposing patients to sepsis. Compromised immune function was observed for Chernobyl firefighters and should be a treatment priority.⁴⁴

These lessons have assumed greater significance in the context of the current geopolitical realities. The ongoing oil crisis makes it likely that there will be more reliance on nuclear production of energy. Although global nuclear war may be less likely than in the past, terrorist use of radiologic weapons is an increasing threat.⁴⁵

Lessons for Critical Care

- We often overlook the need to provide surveillance for posttraumatic stress disorder in our critical care health care professionals, as well as follow-up for patients and family members. Posttraumatic stress disorder may have more significant longer-term negative ramifications than we earlier believed.⁴⁶
- It is anticipated that in the event of a nuclear disaster, a casualty stream would include significant numbers of patients with both traumatic injuries and radioactive contamination. Critical care preparedness should include provisions (ie, decontamination access) to deal with both problems.⁴⁰
- Potassium iodide is touted as an “antidote” to “radiation poisoning.” Remember, however, that this is protective only to the thyroid gland.
- Complete critical care planning includes a triage plan for radiation-exposure victims. This plan should incorporate a predictive matrix that projects severity of illness and probability of survival (based on probable radiation-dose exposure). **Table 1** offers an example. Others employ more complicated methodologies, such as rate of lymphocyte depletion.
- The secondary radiation risk to health care workers from exposure to contaminated casualties (or their excreta, body fluids) is limited.⁴¹

EVENT: BHOPAL DISASTER

Summary

One of the worst chemical disasters in history occurred on December 2, 1984, in Bhopal, Madhya Pradesh, India.⁴⁷ At a Union Carbide plant, a faulty valve allowed 1 ton of water for cleaning internal pipes to mix with 40 tons of methyl isocyanate.⁴⁷ Pressure and heat from the reaction in the tank continued to build. As a safety valve

Time from Exposure to Onset of Vomiting	Estimated Dose	Predicted Mortality
<10 min	>8 Gy	100%
10–30 min	6–8 Gy	100%
31–59 min	4–6 Gy	100%
1–2 h	2–4 Gy	>50%
>2 h	<2 Gy	>50%

Adapted from Radiation Emergency Assistance Center - Training site (REACTS) and International Atomic Energy Agency (IAEA). (Other sources quote different times, but trend is similar.)

gave way, a plume of methyl isocyanate gas escaped, killing around 4000 people immediately.⁴⁷ The injured soon overwhelmed the local hospitals, a crisis deepened by a lack of knowledge of exactly what gas was involved.⁴⁷

The number of people killed in the first few days are estimated at 10,000.⁴⁷ At least 200,000⁴⁸ and, according to some reports, more than 500,000 people were exposed to the gas. These data are, however, likely to underrepresent the true extent of adverse events as many exposed individuals left Bhopal immediately following the disaster and were lost to follow-up.⁴⁷

Relevance to Today and Clinical Teaching Points

These mass casualty incidents pose an overwhelming demand on hospital resources because of the need to decontaminate and manage a large number of critically ill patients. Following the initial release of methyl isocyanate, an estimated 200,000 people sought medical care.⁴⁹ The city had four major hospitals but there was a shortage of physicians and hospital beds and no mass casualty emergency response system was in place in the city.⁴⁹

The greatest numbers of patients seeking care in such disasters are often those who perceive they have been poisoned, but do not exhibit obvious signs or symptoms of poisoning.⁵⁰ Many of these patients may have no exposure, and are merely worried.⁵¹ Demands from these anxious people decrease the ability of the medical system to effectively triage and identify the most critically ill patients.⁴⁹ This event can be circumvented by planning for treatment of thousands of patients at the same time.⁵²

This event in Bhopal dramatically highlighted the threat to the first responder, as was proven later in the sarin incident in Tokyo where almost 10% of the 1364 first responders sustained injuries.⁵³ These injuries to first responders were related to inadequate training and preparation.⁵⁴

The events in Bhopal revealed the disastrous consequences of expanding industrialization in developing countries without simultaneous investment in safety regulations.⁵⁵ Accidents involving hazardous toxic materials are predicted to occur predominantly in developing countries.⁵⁶ However, the sarin poisoning incident in Japan revealed that developed nations may be equally vulnerable.⁵⁷

The danger to communities from hazardous materials accidents is continuously on the rise. Of the 70,000 chemicals used industrially in the United Kingdom, more than 2000 are considered harmful and 200,000 tons are transported daily.⁵⁰ In the United States, 15 events of gas release exceeding the Bhopal incident in quantity and toxicity occurred during the 1980s.⁴⁹ Over 80,000 chemical agents commonly produced, transported, or used in the United States are toxic enough to rapidly produce life-threatening conditions.⁴⁹ Even so, a survey conducted in 2003 revealed gross under-preparation.⁵⁸ With the heightened threat of deliberate offensive use of chemical warfare agents, it is imperative that hospitals be adequately prepared to handle such large-scale disasters⁵⁹ through an effective response strategy,⁶⁰ drawn on basic toxicologic principles.⁴⁹

Lessons for Critical Care

- A mass casualty incident involving a toxic plume of gas may generate a significant number of casualties with impending or actual acute respiratory failure.
- Do you know if there is a hazardous materials route through your region/city/town that carries these sorts of materials? Do you currently have a critical care-specific triage plan that includes the procurement and allocation of mechanical ventilators?⁶¹

- Do you have an education plan in place that instructs critical care personnel in self-protection from contamination?^{50,62}
- A lot can be learned from the evolution of the chemical disaster response system in Japan over the last decade.⁵⁷
- Rescue workers and medical personnel must be trained to operate under the threat of chemical contamination.⁵²

EVENT: OKLAHOMA CITY BOMBING

Summary

On April 19, 1995, a truck carrying a mixture of ammonium nitrate fertilizer, nitro methane, and diesel fuel exploded near the Alfred P. Murrah Federal Building in downtown Oklahoma City, Oklahoma. This terrorist attack destroyed one third of that building and damaged numerous other buildings in a 16-block radius. Of the 361 persons who were in the federal building, 319 were injured, of whom 163 died, including 19 children. The most frequent cause of death was multiple injuries. Among survivors, musculoskeletal and head injuries were most common.⁶³

Relevance to Today and Clinical Teaching Points

The most important lesson learned from the events of Oklahoma was that terrorists could wage their war on American soil.⁵⁴

The second most important lesson—and one that is more sobering—is how easily explosives can be assembled. The bomb used by the Oklahoma bombers was primitive and assembled from easily available material.

Members of the hospital staffs at the receiving hospitals, such as the Columbia Presbyterian Hospital, have written of the valuable lessons about managing a sudden increase in activity, equipment and supplies, and staffing resources.⁶⁴ One of the most significant problems was maintaining adequate communications. Even the hospital emergency administrative radio system was operational in only 3 of the 15 hospitals that handled patients.⁶⁵ We need to have alternative back-up plans tested and in place now, before any event.

We also learned that structural collapse is the most important risk factor for fatality in a building bombing. Better building designs might make structural collapse less likely. Evacuation drills might reduce potential fatalities.⁶⁶

Lessons for Critical Care

- Do you have a communications plan in place that will allow you to mobilize and augment critical staffing on extremely short notice? Can this plan be executed if usual telephone (including cell phone) access is overloaded?
- Posttraumatic stress disorder in health care workers is significant and must be treated early and effectively.⁶⁷
- This does not require terrorists to make these a reality...what about a large-scale conventional explosion at a factory? Are you ready? Does your ICU have a plan?

EVENT: SEPTEMBER 11, 2001

Summary

On September 11, 2001, terrorists hijacked four passenger planes and crashed two of these planes against the World Trade Center towers in New York City.⁶⁸ This was the largest terrorist attack ever on United States soil. At the time, approximately 60,000 people worked and an estimated 90,000 more people visited the buildings each day. A total of 2726 persons were killed.⁶⁸ In Washington, D.C., a hijacked jet was

flown into the Pentagon building. The crash and fire killed almost 200 people and injured an additional 500.⁶⁹

Relevance to Today and Clinical Teaching Points

Preparedness

The city of New York was prepared adequately at multiple levels. St. Vincent's Hospital was one of the main receiving hospitals and performed well to avoid over-triage⁷⁰ and kept a balance between early treatment of the critically ill patients while catering to a large number of minimally injured patients.⁷¹ The most important factor in enhancing the hospital's preparedness for this event was the prior involvement in caring for the 1993 World Trade Center bombing victims. As a result of that event, the hospital had developed a more detailed disaster plan and conducted a series of drills.

At the city level, New York had the Metropolitan Medical Response System, a well-developed system that made for smooth coordination with regional response networks and quick distribution of the National Emergency Stockpile assets.⁵⁴

Lateral thinking

However, there were instances of flawed communications and inefficient sharing of information in the wake of the September 11 tragedy.⁷² These problems stemmed from the vertical hold some agencies and organizations had on decision-making capacity.⁷³ All large-scale mass casualty events require decision-making capacities that are lateral in nature as no one organization has the expertise needed to make all vital decisions.⁷⁴

Poor awareness of secondary contamination

A number of health care providers were sent to Ground Zero without taking precautions for possible involvement of nuclear, biologic, or chemical weapons, or even for the toxic productions of combustion. This put them at great risk for significant illness.⁷¹

Logistical problems

Several logistic problems made an impact on treatment efforts. Within hours of the disaster, electricity and phone services were lost, cellular communications were not operative, and computer communication lines failed. The use of two-way radios by key hospital personnel served to minimize the disruption in intrahospital communications.⁷¹ These problems illustrate the need for systems that simultaneously use several communication alternatives, all of which may be deployed on handheld computers.⁷⁵

Lessons for Critical Care

- Even though the September 11 attack involved conventional explosives, critical care specialists must be prepared to deal with contaminated casualties as a secondary complication.⁷⁶
- Communications, communications, communications...
- Clinical volunteers may not be who they claim to be. Credentials must be verified.
- We are critical care specialists, not first responders. We are not trained to recognize danger at the incident site (eg, live electrical wires, unstable building structures, toxic substances). Stay in the hospital.
- Doctors can be trained in such skills as extrication, triage, and transport.⁷⁷
- Hospitals are only a small part of an overall disaster response plan. The primary function of an incident response plan is not only to evacuate casualties, but also to protect the uninjured.

EVENT: OUTBREAK OF SEVERE ACUTE RESPIRATORY SYNDROME**Summary**

In 2003, an infectious disease outbreak began in China. Initially involving animal-to-human transmission of a coronavirus that caused a severe and even fatal acute respiratory illness, this outbreak originated with food handlers in the “wet” markets of Southern China, rapidly spread to Hong Kong, to other parts of Asia, and then to other parts of the world over the ensuing weeks to months.⁷⁸ The rapid worldwide transmission of this disease reflects our current global mobility via commercial air travel.⁷⁹ Ultimately, SARS killed approximately 800 people and infected over 8000 others in almost 30 countries on every continent.

Relevance to Today and Clinical Teaching Points

Notably, a startlingly high percentage of the patients were health care workers.⁸⁰ These cases illustrated how insufficient infection control practices can be lethal. And also raised important questions about how people react to such an outbreak: Who will show up for work in the hospital? How will people respond if their workplace (ie, the ICU) significantly places them at risk for contracting a life-threatening illness?⁸¹

The SARS epidemic has better prepared the world’s public health authorities for a major influenza or other pandemic.⁸¹ While there are differences, many of these same issues are applicable to pandemic influenza or a bioterrorism event.⁸² In fact, many authorities remain concerned that a pandemic influenza outbreak (such as an avian influenza outbreak) would be orders of magnitude greater in scope than SARS and the goal to minimize damage from such an event has become a global health priority.⁸³ Therefore, infection control and other preventative measures are of major importance,⁸⁴ but so will be triage and allocation of mechanical ventilators and other life-support measures.⁸⁵

Furthermore, education and training of ICU personnel in the assiduous practices of self-protective measures will also be key to ensuring that absenteeism does not become a problem (ie, not coming to work because of concerns related to contracting the disease).⁸⁶ Finally, no plan equals chaos. To ensure that the appropriate education and training occur, and to establish effective triage strategies/algorithms for your hospital,⁸⁷ advance work to achieve leadership consensus should happen now, not after a disaster begins.

One of the key lessons is that we are vulnerable to events far away.⁸¹

Lessons for Critical Care

- What percent of your ICU personnel are current for fit-testing of N-95% masks? If your hospital is typical, that number is perhaps 50%. And if we can keep up with this simple requirement, then what of more advanced vital skills, like flawless (error-free) donning and doffing of personal protective equipment?⁸⁸
- Do you have a ventilator triage plan?⁸⁹
- Do you have a pandemic influenza plan that includes your ICU?⁹⁰ Does it work? Has it been exercised or practiced in some measurable capacity?
- Do you have a plan to prevent bronchoscope-associated infection?⁹¹

EVENT: TSUNAMI**Summary**

On December 26, 2004, an earthquake beneath the Indian Ocean triggered a large tsunami that struck in Indonesia, Sri Lanka, India, Somalia, and Thailand.⁹² This 9.2-magnitude earthquake and the ensuing tsunami led to the death of an estimated

225,000 people in at least 11 countries and the displacement of over 1 million people. In terms of deaths and population displacement, this tsunami was among the most devastating in human history. Between 30% and 40% of the total number killed were children. The medical infrastructure in most of the coastal region was destroyed in these countries,⁹³ and there was no secure (uncontaminated) water source.⁹² Consequently, many people had little or no access to medical care for trauma injuries, infections, and subsequent public health-related outbreaks, such as cholera and malaria.⁹⁴ There were also very high rates of posttraumatic stress disorder among survivors.⁹⁵

Relevance to Today and Clinical Teaching Points

The clinical teaching points from the tsunami disaster were best described by Claude de Ville de Goyet, MD,⁹³ retired director of the Emergency Preparedness Program of the Pan-American Health Organization (PAHO), and others⁹⁶ in detail. One of the essential flaws was a gaping gulf between the needs of the local communities as they perceived them and the needs assessment performed by the aiding agencies.⁹³ World response to the event included over \$13 billion in aid.⁹³ However, many donations from industrialized countries included aid items that were not germane to postdisaster needs of casualties. Nevertheless, these items required the same logistical support to unload or store, thus redirecting time and energy away from important relief efforts to things that were not as helpful.⁹⁷ A hasty response that is not based on familiarity with local conditions contributes to more chaos. It is prudent to wait until real needs have been assessed.⁹⁸

False alarms were raised about the probability of more deaths from secondary epidemics than from the tsunami itself.⁹³ These “overly alarmist announcements” related to problems that did not materialize provide valuable lessons in appropriate and responsible disaster communication.

Foreign mobile hospitals rarely arrived in time for immediate trauma care, leaving local, sometimes damaged facilities to provide immediate, life-saving care.⁹³ In many instances, immediate assistance to the injured was provided by uninjured survivors with whatever basic first aid they knew without any tools or resuscitation equipment.⁹⁹ This experience supports proposals for teaching life-supporting first aid courses to the public.¹⁰⁰

A lot has been written about the dynamics of assistance during disasters. In general, however, as depicted in **Fig. 1**, human nature dictates an initial outpouring of generosity as attention focuses on the first news of the disaster. This widespread generosity falls off quickly over time, leaving committed responders behind to carry the burden of responsibility for aid. The response to the tsunami followed this pattern.

Lessons for Critical Care

- History keeps repeating itself: In the wake of a large-scale disaster that creates an austere care environment, systems are needed for rapidly deploying portable, sophisticated care, but such systems are rarely in place.
- Critical care doctors must be prepared to perform in surroundings with suboptimal public health structure in the wake of a disaster.^{101,102}
- Flexibility to adapt to local circumstances and fit in the local incident command system is essential for doctors helping in foreign disasters.⁹³

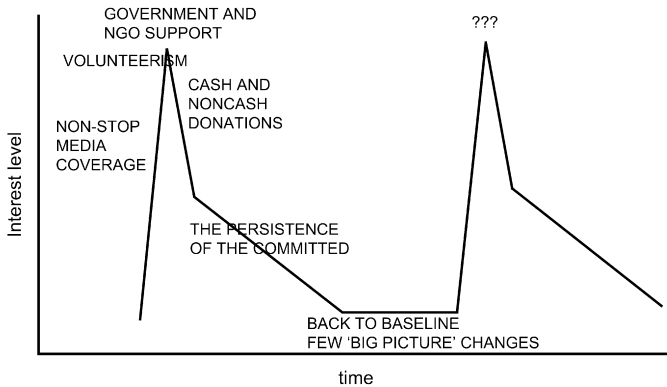


Fig. 1. Rise and fall over time of desire to “help” with disaster relief, NGO, nongovernmental organization.

EVENT: HURRICANE KATRINA

Summary

In August 2005, Hurricane Katrina caused the rupture of levees protecting New Orleans, Louisiana, leading to devastating flooding and the destruction of much of the city’s infrastructure. This resulted in a public health emergency that displaced more than 4400 physicians in the greater New Orleans area and led to the closure of 13 of 16 hospitals. This caused widespread destruction, reducing hospital capacity by 80% and clinic capacity by 75% in New Orleans.¹⁰³

Relevance to Today and Clinical Teaching Points

As we look at the big picture, it appears that the poor outcome in this disaster was not the result of lack of knowledge, but rather the result of inaction¹⁰³ and poor implementation¹⁰⁴ of the necessary measures.¹⁰⁵

We witnessed the impact of a complete loss of critical care capability on the general population. Specifically, there were numerous secondary casualties—patients with chronic critical illnesses who lost access to care rapidly became ill.¹⁰⁶ These patients consumed a significant amount of the available rescue medical care.¹⁰⁷

A number of lessons pertinent to critical care were (re)learned at a very high cost.¹⁰⁸ The foremost was how much the delivery of critical care services depends on support services, such as water and electricity. The worst hit hospital in New Orleans was Charity Hospital. Rising floodwaters submerged the hospital’s emergency electrical generators. This left no reliable electrical power for life-support systems, such as mechanical ventilators, suction machines, bedside monitors, intravenous fluid pumps, and dialysis machines. Even air conditioning was lost.¹⁰⁹ Radiology and laboratory capability became extinct. Patients who required positive-pressure ventilation had to be hand ventilated with bag-valve devices in total darkness.⁶

Lesson in evacuation surge capacity

Many hospitals were incapacitated simultaneously.¹¹⁰ This left the option to either deploy field hospitals or to evacuate. Unfortunately, portable critical care exists only at certain facilities and is generally not developed as a deployable asset. Therefore, all hospitals in general and especially those located in regions subject to hurricanes and earthquakes should make extraordinary investments to develop coalition partners

and to ensure portability of sophisticated care.¹¹¹ A reasonable solution would be collaboration across regions to enable long-distance patient and staff transfer during emergencies.¹¹² Adequate knowledge of the operational status of surrounding facilities expedites such transfer. The Department of Health and Human Services Critical Infrastructure Data System was employed to track 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 would allow proper resource deployment and use.¹¹³

Field hospitals

Significant experience was gained in the deployment and management of field hospitals. A prominent example is the Carolinas Med-1.¹¹⁴ This mobile hospital consisted of two 53-ft tractor-trailers. One served as an equipment storage unit and the other as the patient care facility.¹¹⁴ Up to 130 beds, including emergency room beds, ICU beds, and surgical suites, could be accommodated. It also provided diagnostic radiology and point-of-care laboratory services. During the 6-week deployment, more than 7400 patients were evaluated and treated at this mobile facility by integrating seamlessly into the existing local, state, and federal facilities.¹¹⁴

Staffing issues

Out-of-state physician volunteers who responded to this were practicing medicine without a license, potentially placing them at risk for penalties. Louisiana Governor Kathleen Blanco issued an executive order that suspended regular licensing procedures. However, the policies of each state regarding physician licensure during disasters ought to be determined.¹¹⁵

Lessons for Critical Care

- What happens if you suffer a power outage in your ICU, and the generators fail to work? It happens...sometimes even without a natural disaster^{5,116}
- If you had to completely evacuate your ICU out of the building, including even the sickest patients, could you do it safely?¹¹⁷ How? Where would you go? What is the plan?¹¹⁸
- Under extreme circumstances, would you come to work?¹¹⁹ Think about it...
- Do you have a plan for regional cooperation between hospitals and ICUs?¹²⁰ Have you ever conducted an exercise around this premise?¹¹¹
- Chronic illnesses will coexist and may aggravate management of acute illness.^{121–123}
- Responsible crisis communication is essential to prevent avoidable secondary complications.¹²⁴

EVENT: OPERATION IRAQI FREEDOM AND OPERATION ENDURING FREEDOM

Summary

Operation Enduring Freedom (OEF) was the coordinated military operation that started in October 2001 in Afghanistan to oust the Taliban from power. In Operation Iraqi Freedom (OIF), the United States–led coalition forces entered into armed conflict with Iraq on March 19, 2003, and by May 1, 2003, active hostilities were declared over.¹²⁵ According to the US Department of Defense online data of American military casualties (the number of wounded or dead) from OIF/OEF, the operations led to the deaths of 4733 American servicemen as of September 3, 2008.¹²⁶

Traditional battlefield medicine has focused on providing “definitive” trauma casualty care within the theater of operations. Injured soldiers were then transported back

to their home country when they became “stable.” This translated to 15 to 45 days in-theater before evacuation to hospitals in their home countries. In addition, because moving unstable casualties (who now require advanced ICU care) rearward after surgery is so difficult and unreliable, moving trauma surgical care closer to the point of injury was generally not done. So historically, casualties had to survive until they were evacuated back to an echelon where surgical care became available.

During these most recent conflicts in Iraq and Afghanistan, a concept of portable critical care has been employed with great success and has proven to be an advancement over the traditional methods of battlefield medicine.^{127,128} A casualty receives “damage control” (targeted, limited, life-saving) surgery as soon as possible after the injury and as close as possible to the battlefield location of injury.²⁰ Then, critical care teams are used to evacuate these patients rearward.¹²⁹ Along the way, subsequent additional “damage control” procedures may be required. Today, from time of injury a casualty is typically evacuated back to the United States within 72 to 96 hours, and may have had several incremental surgical procedures performed along the way.¹³⁰ This approach has resulted in the lowest died-of-wounds rate in the history of warfare.¹³¹

These critical care teams were developed and are maintained by the U.S. Air Force. They are part of the Critical Care Aeromedical Transport Team program.¹³² These teams are capable of providing all aspects of critical care, including advanced mechanical ventilatory support; invasive cardiovascular monitoring; pharmacologic support, diagnosis, and treatment of sepsis or other forms of shock; limited laboratory assessment; portable ultrasound; portable bronchoscopy; and even extracorporeal support in limited circumstances.¹³³ Much of this occurs in austere settings, such as the back of an Air Force cargo plane during flights from the Middle East to Germany, and again across the Atlantic Ocean.^{134,135}

Relevance to Today and Clinical Teaching Points

Provision of critical care in a transport setting imposes unique challenges, particularly when the duration of patient transfer is prolonged.^{9,136} As a simple example, monitoring technologies must overcome limitations imposed by noise. Automated blood pressure monitors, measurement of oxygen saturation, and end-tidal carbon dioxide with limited electrocardiography may represent the only available cardiopulmonary monitoring. Ventilators must offer a range of tidal volumes, but a limited number of modes may be available. Variable minute ventilation must be provided over a wide range of barometric pressure conditions. Infusion devices must be compact and robust with extended battery life and pressure-activated occlusion alarms. Only point-of-care laboratory testing may be available in remote settings and in the transport environment. Finally, a limited drug list must be developed to include provision for analgesia and sedation, and to accommodate the need for vasoconstriction, inotropic support, or vasodilatation with various shock states.

Beyond its use by the Critical Care Aeromedical Transport Team, this approach to critical care may be adapted for a significant potential role in disaster response medicine. An aeromedical transport system adapted for civilian use could go a long way toward addressing many of the issues raised in this article, including (1) the transport of ICU patients when a hospital is rendered unusable or the number of critically ill or injured casualties exceeds local/regional capability, (2) a surge of patients with chronic critical illnesses who lose access to ongoing support following a disaster (and who significantly tax other disaster-response assets), and (3) the overall need to extend critical care capability within the disaster response locale (eg, expanding hospital ICU capability to non-ICU areas of the facility).

Lessons for Critical Care

- “Portable” critical care is a necessary component of any robust disaster medical response capability. Without this, we do not have an effective answer for the needs articulated in this article.
- Interagency collaboration and communication assumes even greater importance during complex humanitarian emergencies, such as wars.¹²⁵
- Opportunities for collaboration exist between military and civilian response systems to translate shared expertise into benefits for all critically ill patients, whether in a roadside accident or on the battlefield.²⁵

SUMMARY

This effort represents our attempts to review a cross-section of representative disasters that illustrate recurring, important themes related to critical care and hospital disaster response. It is by no means comprehensive; unfortunately disasters that impact large numbers of patients, and require critical care resources occur commonly. We selected disasters for discussions that illustrate core principles relevant to critical care practitioners. To summarize these “lessons learned” include:

1. *Disaster preparation typically focuses all pre-hospital care requirements, and often neglects the needs of the hospital, and especially intensive care units.* This impacts ICU response in several ways including sufficiency of space, equipment and supplies, triage protocols, and so forth.
2. *A burgeoning number of non-hospitalized individuals with chronic critical illness.* When a disaster occurs that limits access to advanced medical care, these patients rapidly decompensate, and in many circumstances utilize/consume more disaster response resources than primary casualties.
3. *Following a disaster, existing critical care resources may be insufficient to meet demand for services.* Developing a deliberate plan (5) that pre-identifies alternative care sites for ICU patients is essential. This must include access to sufficient quantities of 50 psi oxygen, suctioning, medical devices, and necessary pharmacy support.
4. *Following a disaster of sufficient magnitude, non-critical care hospital personnel will be called to assist with the care of ICU patients.* It is important to know, in advance what will be the scope of practice of these individuals, what education is needed to ensure that this care is efficient and of reliable quality, and who will provide supervision and assistance for these activities.
5. *Following a disaster, it is vitally important to ensure the protection of ICU personnel from communicable diseases/outbreaks, as well as physical harm.* This requires a plan, practice, and proper education of staff.
6. *When a large scale disaster occurs, medical care processes quickly migrate below usual standards of care due to resource limitations.* This degradation of care should be planned and not haphazard. This can also be pre-planned as it relates to access to mechanical ventilation, staffing ratios, aggressiveness of resuscitation based on probability of survival, etc. The goal is to predictably orchestrate transition from “standard of care” to “sufficiency of care.”

Except for individuals who volunteer their time or who are engaged in disaster preparedness, there is generally a limited willingness by health care professionals to accept that these concerns as relevant to their daily professional lives. Furthermore, in a cost-constrained hospital, these low probability but high consequence needs

do not compete favorably with more tangible, other needs (eg, purchasing a new CT scanner).

But as with everything else ...

Those who cannot learn from history are doomed to repeat it.

—George Santayana.

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