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Definitive Care for the Critically Ill During a Disaster: Current Capabilities and Limitations*

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In the twentieth century, rarely have mass casualty events yielded hundreds or thousands of critically ill patients requiring definitive critical care. However, future catastrophic natural disasters, epidemics or pandemics, nuclear device detonations, or large chemical exposures may change usual disaster epidemiology and require a large critical care response. This article reviews the existing state of emergency preparedness for mass critical illness and presents an analysis of limitations to support the suggestions of the Task Force on Mass Casualty Critical Care, which are presented in subsequent articles. Baseline shortages of specialized resources such as critical care staff, medical supplies, and treatment spaces are likely to limit the number of critically ill victims who can receive life-sustaining interventions. The deficiency in critical care surge capacity is exacerbated by lack of a sufficient framework to integrate critical care within the overall institutional response and coordination of critical care across local institutions and broader geographic areas. ***(CHEST 2008; 133:8S–17S)***

Key words: disaster medicine; influenza pandemic; mass casualty medical care; surge capacity

Abbreviations: DMAT = Disaster Medical Assistance Team; ED = emergency department; NDMS = National Disaster Medical System

Mass casualty events occur frequently worldwide[1]; fortunately, the majority of these do not generate overwhelming numbers of critically ill or injured victims requiring definitive critical care. Mass critical care events, though, have garnered increasing attention[2] and stimulated new interest in critical care disaster preparedness.[3–9] In 2004, an analysis[10] of US critical care disaster response identified major limitations to respond to serious epidemics. In light of the increasing consternation about a potential influenza pandemic,[11,12] an updated review of critical care response capabilities is warranted.

Authorities continue to call for development of comprehensive guidance for managing mass casualty events.[13] A number of efforts are underway to meet this need, but detailed guidance regarding how to provide critical care for large volumes of patients remains underdeveloped.[5,14] To this end, the Task Force for Mass Casualty Critical Care (hereafter called the *Task Force*) was convened. The Task Force steering committee members (listed in the Appendix) were fairly certain that current critical care surge capacity for disasters had a number of limitations. However, the specific strengths and weaknesses of critical care response capabilities must be delineated to best inform development of novel strategies to augment critical care. This manuscript summarizes the current US and Canadian critical care disaster response capabilities, and provides the rationale and context for the guidance of the Task Force for critical care surge capacity and allocation of scarce life-sustaining interventions.

Role of Critical Care in Disaster Response

Disaster medical management has focused primarily on the response to trauma victims.[5,15] Victims who suffer critical injuries frequently die immediately or before rescue, so the vast majority of those who survive to receive hospital-based treatment have non–life-threatening injuries.[16–18] Disaster plans have assumed that critical care resources will be available when needed,[5] and generally this assumption has been correct. However, with the anticipation of large volumes of critically ill patients in future disasters, some believe that hospital capacity, and in particular critical care capability, will be a major limiting factor for survival.[15,19]

Numerous authorities have forecast scenarios that will result in large numbers of critically ill and injured casualties. Table 1 summarizes scenarios developed by the US Department of Homeland Security. Eleven of the 15 scenarios predict numbers of critically ill patients ranging from hundreds to tens of thousands in a metropolitan area. If such events occur, the demand on critical care resources will be multiple orders of magnitude greater than previous emergencies experienced in the past half century in North America.

The experience with the severe acute respiratory syndrome in Toronto, although not a mass casualty event, stands as example where critical care can prevent deaths even for a disease lacking specific treatment. In the absence of critical care, the case fatality rate in Toronto would have been more than triple (20%) the observed rate of 6.5%.[20] This lesson may have profound import were a serious influenza pandemic to occur. Further, the effectiveness of community mitigation as well as the utility and availability of antivirals to forestall serious illness remain uncertain.[21,22] Many people, particularly high-risk groups, may have critical illness[23] and without critical care will assuredly die. If critical illness directly or indirectly resulting from influenza is not uniformly fatal with essential critical care services, then availability of life-sustaining interventions may have a profound impact on community survival.[24]

The need to augment critical care is not unique to an influenza pandemic. Illness developing after exposures to chemicals,[25] infection with serious pathogens, and exposure to radiologic materials are all likely to result in life-threatening clinical conditions, such as severe sepsis or ARDS. Natural catastrophes, such as earthquakes[26–28] and tsunamis,[29] can also generate many victims with severe organ dysfunction. In the United States and Canada, severe sepsis and acute respiratory failure, including ARDS, are commonly treated in ICUs[30–32]; and importantly, at least half of patients survive with aggressive ICU care.[33–38]

Unlike the duration of surge demands on emergency departments (EDs) in mass casualty incidents, which are often measured in units of minutes or hours, the critical care response may need to be sustained for days to weeks. Several recent examples highlight this issue. Following the Rhode Island nightclub fire, the emergency department (ED) response lasted only hours, yet 47 critically ill patients admitted to a single hospital resulted in 406 ICU patient days with an average ICU length of stay of 21 days.[39] Similarly, following the 2005 London bombings, the major incident lasted in the ED lasted 3 h and 14 min, yet the average length of stay for the critically injured was 12.4 days (range, 6 to 22 days).[16,40] Complications seen in the critically ill or injured, such as ARDS, prolong recovery times in ICU[16,41–43] and should be anticipated in planning for future mass critical care events.

Current Critical Care Response Capacity

Within an effective command and control system to coordinate regional response,[10] surge capacity in critical care depends on three crucial elements: (1) "stuff," medical equipment and supplies; (2) "staff," appropriately trained health professionals to competently care for critically ill and injured patients; and (3) "space," the physical location suitable for safe provision of critical care. Although a rather simplistic conceptual approach, one can confidently state that a system that fails to meet any one of these requirements will not be able to cope with a large surge. Medical response to disasters, including the critical care response, is dependent on a number of nonclinical medical institution services (*eg*, logistics and procurement, environmental services, food services)

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Table 1—*Department of Homeland Security National Planning Scenarios

Scenarios	Description	Potential of Critically Ill Patients (Patients Receiving Mechanical Ventilation), No.	Requirements for Critical Care	Likely Duration of Critical Care	Likely Duration of Ventilation	Probability of External Support
Nuclear detonation: 10-kiloton improvised nuclear device	Terrorists assemble a nuclear device using highly enriched uranium. The device is detonated in the business district of a large city	Tens to hundreds of thousands (hundreds to thousands)	Burns; blast injury; bone marrow suppression; septic shock; cardiovascular collapse	Patient surges will occur in waves over several weeks	Days to weeks	If a single device, external support is likely but limited by risk of secondary exposure
Anthrax attack	A tractor-trailer truck drives through rush-hour traffic in a large urban city spraying approximately 100 L of wet-fill *Bacillus anthracis* (anthrax), exposing approximately 330,000 persons; 13,000 cases of inhalation anthrax would be expected	13,000–25,000 (approximately 13,000)	Pneumonia with respiratory failure; septic shock; ARDS	Days to weeks	Days to weeks	Likely to arrive in 24 to 96 h if localized attacks only
Pandemic influenza†	A pandemic of influenza sweeps the globe and affects a state with 11 million people	Approximately 10,000 (approximately 5,700)	ARDS; pneumonia; septic shock; myocardial infarction	Weeks to months	Days to weeks	External assistance unlikely
Biological attack with pneumonic plague	Terrorists release pneumonic plague in the bathrooms of the major airport of the city, at the main sports arena, and at the major train station	Approximately 6,000 (approximately 6,000)	Pneumonia; septic shock	Days to weeks	Days to weeks	Likely in 24 to 96 h if an isolated attack; however, because of rapid spread to other cities by those infected at the airport, external help will be delayed
Chemical attack: blister agent	Terrorists use a light aircraft to spray a blister agent (sulphur mustard and lewisite) into a packed college football stadium. The attack causes a large number of casualties that require urgent and long-term medical treatment, but few immediate fatalities occur	Hundreds to thousands (hundreds)	Upper airway obstruction; ARDS; trauma injuries from stampede out of stadium; sepsis arising from secondary infections in those with compromised skin	Days to weeks	Days	Likely in 24 to 96 h if an isolated attack
Terrorist attack on industrial sites	Terrorists launch rocket-propelled grenades at a petroleum refining plant and bomb several nearby container ships. Multiple fires occur, releasing smoke containing cobalt, nickel, molybdenum, cadmium, mercury, vanadium, platinum, isocyanates, nitriles, and epoxy resins	Hundreds (tens to hundreds)	Burns; blast trauma; smoke inhalation; exacerbation of chronic respiratory conditions	Days to weeks	Days	Likely in 24 to 96 h if an isolated attack

Table 1—*Continued*

Scenarios	Description	Potential of Critically Ill Patients (Patients Receiving Mechanical Ventilation), No.	Requirements for Critical Care	Likely Duration of Critical Care	Likely Duration of Ventilation	Probability of External Support
Chemical attack: nerve agent	Terrorists release sarin vapor into the ventilation systems of three large commercial office buildings in a metropolitan area. The agent kills 95% of the people in the buildings, and kills or sickens many of the first responders and those in adjacent buildings	Hundreds (tens to hundreds)	Seizures; paralysis; coma; respiratory failure	Days to weeks	Hours to days	Likely in 24 to 96 h if an isolated attack
Chlorine tank explosion	A chlorine gas (liquefied under pressure) storage tank ruptures, releasing a large quantity of chlorine gas downwind of the site in Chicago	15,000–20,000 (8,000–12,000)	ARDS; pulmonary edema	Days to weeks	Days	Likely in 24 to 96 h
Earthquake	A 7.5-magnitude earthquake occurs in a major metro area with a population of 10 million	Tens to hundreds (tens to hundreds)	Crush injuries (pulmonary contusions, renal failure)	Days to weeks	Hours to days	Likely in 24 to 96 h
Major hurricane	A category 5 hurricane that makes landfall at a major metro area with a storm surge > 20 feet above normal. Low-lying escape routes are inundated by water hours before the eye of the hurricane reaches land	Minimal (may be more if existing infrastructure fails and hospital in affected area is evacuated)	Trauma; sepsis from waterborne infections; drowning	Days	Days	Likely in 24 to 96 h
Radiologic attack: radiologic dispersal devices	Terrorists detonate "dirty bombs" containing cesium-137 in several major cities	Tens to hundreds (tens to hundreds)	Blast injury; radiation sickness	Days to weeks	Days	Likely in 24 to 96 h
Conventional explosion	Terrorists detonate a series of truck bombs and explosives on a transit system	Tens to hundreds (tens to hundreds)	Head injury; lung blast injury; burns; multiple trauma	Days to weeks	Days to weeks	Likely in 24 to 96 h
Biological attack: foreign animal disease (foot and mouth disease)	Terrorists introduce disease into the food chain	None	None	N/A	N/A	N/A
Cyber attack	Terrorists conduct cyber attacks against critical infrastructures reliant on the Internet	None‡	None	N/A	N/A	N/A

*From Department of Homeland Security.[13] N/A = not applicable.

†Data used for Ontario, Canada. Population approximately 11 million, assuming 35% attack rate over 6 weeks.

‡Although a cyber attack does not directly result in human casualties, given the highly technology-dependent nature of critical care, and critical infrastructure in general, computer viruses in medical equipment and electronic medical records or losses crippling the capacity for information exchange could lead to large numbers of critically ill patients.

and external services (*eg*, transportation, consistent functional utilities, commerce infrastructure). For expediency, this article will focus on critical care-specific capabilities.

Stuff

Mechanical ventilators are unique to the critical care environment, and they are essential equipment for the management of respiratory failure. There are no realistic substitutes for ventilators. Proposals to train hundreds of volunteers to provide manual ventilation to patients during a pandemic are naïve and fraught with serious logistical and scientific shortfalls, such as the lack of staff or volunteers during bioevents as well as the risk of secondary transmission to the caregivers who must remain at the bedside and the adverse consequences of prolonged manual ventilation.

Estimates of the total number of full-feature ICU ventilators available in the United States vary widely. One study[12] reported 105,000 ventilators (35 ventilators per 100,000 population); other published studies and unpublished data place the estimate between 53,000[44] and 70,000 (17 to 23 per 100,000 population). These devices are distributed among the 72,000 to 87,500 non-federal ICU beds in the United States.[45,46] A 2006 review of ventilators in Ontario, Canada, reported similar quantities when corrected for population size: 1,990 ICU ventilators (16 per 100,000 population) [A. Stuart; Emergency Management Unit, ON Ministry of Health & Long Term Care; personal communication; May 16, 2006].

For immediate surge capacity, available ventilators are more important than the total number. Most institutions often have only a minimal number of reserve ventilators on site at any time. When all of the full-feature hospital ventilators are occupied, additional units are usually rented from a vendor. A study by Kaji and Lewis[47] in Los Angeles found that 71% of hospitals in the Los Angeles area had fewer than six ventilators available for immediate use at any time. If several local hospitals require additional ventilators, rental supplies may be insufficient to meet need, as it is common for vendors to contract to provide the same finite pool of ventilators to several institutions.

Data from the National Healthcare Safety Network[48] show that the majority of ICUs have, on average, $< 70\%$ of their occupied beds filled with patients receiving invasive mechanical ventilation. Based on these data, at least 10,000 full-feature ventilators are likely available across the United States at any time for use during a disaster. This predicted available national mechanical ventilator quantity may at first seem reassuring, but it also has potential to mislead. Numerous logistic hurdles will hamper immediate distribution to areas of need during a disaster. Thousands of ventilators may be available at hospitals nationwide, yet an affected community requiring just hundreds of additional devices may not be able to get them in a timely manner. Also, published and unpublished models of varying sophistication portend there will still be a large gap between the total number of ventilators required during the peak of a serious influenza pandemic and available devices.[23,49–51] In all models, the predicted need will far exceed even the tens of thousands of available ventilators. Hence, strategies for rational augmentation of positive pressure ventilation capacity are necessary.

In the United States and Canada, stockpiles of ventilators are available from government sources.[52,53] Currently the strategic national stockpile in the United States[54] has approximately 4,600 ventilators, and there is a stated intention to purchase additional ventilators.[44] Furthermore, some local institutions, municipalities, and states are also developing stockpiles. For some events, these devices, together with staff augmentation strategies, may allow for many additional patients to survive (see "Definitive Care for the Critically Ill During a Disaster: A Framework for Optimizing Critical Care Surge Capacity" and "Definitive Care for the Critically Ill During a Disaster: Medical Resources for Surge Capacity"). For more catastrophic events, these additional ventilators may be beneficial but still insufficient to serve all in need; in such cases, scarce mechanical ventilators will need to be allocated to those patients who are prioritized (see "Definitive Care for the Critically Ill During a Disaster: A Framework for Allocation of Scarce Resources in Mass Critical Care").

The "just-in-time" supply chain management systems used by many hospitals creates a significant threat to successful disaster response as many hospitals maintain only a minimal store of medical supplies on site.[55] Of the typically "consumable" medical supplies required for the provision of critical care some may have the potential for limited disinfection and reuse in a disaster when no alternative exists. There are a variety of inotropes and vassopressors that are interchangeable again increasing availability. However, oxygen remains a critical consumable resource which has a limited supply and distribution network. Most hospitals rely on large storage tanks of liquid oxygen. If this source runs low, oxygen must be trucked in from a supplier. The number of suppliers of medical grade oxygen in North America is limited as are the number of tanker trucks available to transport oxygen. Portable oxygen supplies for use during an infrastructure failure or in

off-site critical care facilities are very limited, inefficient and not included in the strategic national stockpile.[44]

Staff

Like many areas of health care, critical care units face shortages of various team members[56] required for critical care delivery.[44,50,57–61] Data from Ontario show that 49% of critical care units had nursing vacancies and 20% had physician vacancies.[50] ICUs facing staffing shortages are routinely forced to cancel surgeries and divert ED admissions to other hospitals.[50] The need to resort to such actions even in non-surge periods bespeaks the limited surge capacity in the critical care system.

In the past, staff shortages have not typically been a major problem during disasters.[62] However, a report[7] revealed that staffing can be a problem, with staff absenteeism during a disaster ranging from 10 to 60%. The authors[7] described disasters that were prolonged, were of a type rare for the community, or impacted the personal lives of employees (*ie*, school closures, day-care closures, or elder-care issues) were associated with higher rates of absenteeism. Estimated absenteeism for future bioevents is predicted to be even higher.[63,64] In bioevents, staff may fail to report for duty for a variety of reasons, including fear of infection or infecting their families.[63–66] Although volunteers often converge on disaster-stricken communities,[67,68] rarely do these volunteers possess the skills necessary to provide critical care; and even if they do, rapidly verifying credentials during a disaster can be logistically challenging.

It is important that the staff available to respond have adequate preparation to do so. Critical care physicians in general are poorly prepared to respond to mass casualty disasters.[3,4,69] A study[70] of other physician groups report that preparedness for bioterrorism or public health emergencies are particular areas of weakness, and deficiencies in training to respond to mass casualty events are not limited to physicians. Hospital administrators, who are often called on to lead the response in a health-care facility, also lack appropriate training.[71]

Space

Critical care requires specific functionalities, including electricity, oxygen, suction, medical gas, monitoring equipment, and physical space for equipment and patient management. As a result, there are limited areas in which critical care can be provided on a routine basis outside of current critical care areas (ICU, postanesthesia care unit, ED). As with staffing, some hospitals face shortages of critical care spaces,[46,71–73] although occupancy varies across the United States. In Ontario in 2006, there were 1,789 critical care beds, 1,057 of which were capable of accommodating mechanical ventilation.[74] The occupancy rate for these beds approaches 90%.[50] Demands on critical care resources are expected to increase in both the United States and Canada as the populations age.[75]

On a day-to-day basis, additional capacity can be created in the critical care system by expanding critical care to areas of the hospital such as the postanesthesia care unit. However, this expansion is still limited by the issues of stuff and staff discussed earlier. Therefore, even though the bed spaces may be available to use for critical care, if the hospital rents its ventilators and has no more on site, the ability to expand critical care remains limited unless specific advanced planning and preparation are undertaken. Finally, although it is possible to convert off-site locations[17,53] (*ie*, hotels, gymnasiums, sports fields) into medical treatment facilities, the ability to convert such areas to critical care facilities on a large scale is curtailed because of the functional requirements and logistical challenges, such as large-volume portable oxygen supplies.

Stockpiling Costs

While unlimited stockpiles of medical equipment could mitigate the shortfall of critical care resources during a disaster, this is not a realistic solution in part because of the costs of stockpiling. Extrapolating from even an incomplete list of equipment required to care for critically ill patients[53] results in an estimated cost of $1,789,876 to manage 100 critically ill patients for 3 days. This cost does not take into account the cost of the financing to purchase the stockpile or the potential returns from alternative investments those funds could be used for. This considerable expense also does not include the cost of maintaining and storing equipment. Furthermore, the period of treatment being considered is very short and not representative of the typical length of ICU stay. Thus the cost is substantial, imposing significant fiscal limitations on the ability to stockpile. Therefore, a balance must be struck between service provision today and preparation for potential events of the future. Finally, stockpiling does not resolve the staffing issue.

Role of Mutual Aid

One option most health-care facilities consider when they are overwhelmed is to seek help from outside, either by transferring patients out or having help sent in.[14] Generally, if a health-care facility elects to transport a patient to another hospital for

ongoing treatment because it does not have the ability or resources to manage that patient, it is the responsibility of the sending facility to arrange transportation. However, this is often difficult to do during a disaster when ambulances are occupied with the ongoing prehospital response. Moreover, most areas will not have a sufficient number of dedicated critical care transport teams to evacuate large numbers of critically ill; thus, regular critical care staff would be required. This would take critical care staff away from the hospital during transport and would be an inefficient use of valuable staff (*ie*, 2:1 or 3:1 registered nurse/respiratory technician/medical doctor-to-patient ratio).

If local resources are insufficient for patient evacuation, the US Department of Health and Human Services maintains contracts with a private ambulance service for ground transport coordination, and the Department of Defense is responsible for evacuation within the National Disaster Medical System (NDMS).[76] Although the Department of Defense is capable of transporting critically ill patients,[5,77] its ability to do so is has been estimated at 81 patients in 54 h. Civilian ground, aeromedical rotor-wing, and fixed-wing assets may assist, if not dedicated to the on-scene major incident response, but the total number of aircraft in the United States is limited (*eg*, 800 civilian rotor-wing aircraft),[78] and all are designed for the transport of one to two critically ill patients at a time. This limited capacity certainly is not sufficient to move large surges of critically ill patients; nor is it likely that these transport assets from outside regions will be available during the first 12 to 24 h of a mass casualty event. Thus, a hospital cannot rely on immediately evacuating critically ill patients as a response to a mass casualty event.

If patients cannot go to help, then it is logical for help to come to the patient. Depending on the situation, assistance can come from the local, regional/state, or national levels. Local assistance is usually facilitated by the sharing of staff in an emergency through a prearranged mutual aid agreement.[53] This type of an arrangement can be very useful in the event of small surge situations, but is not helpful in the type of mass casualty scenario where all hospitals in a local area will be overwhelmed. The US federal health response includes the NDMS to address medical and mental health needs during a disaster.[79] The NDMS was created to address civilian disasters and military contingencies in which there might be a large number of casualties that cannot be accommodated by the Departments of Defense or Veterans Affairs.[76] The NDMS is a private/public partnership that includes a number of specialized teams comprising some 7,000 to 8,000 volunteers and a network of 2,000 hospitals with a total of approximately 100,000 beds. Similar teams are being developed elsewhere in North America.[52]

The NDMS has been a valuable resource in many prior disasters.[80] However, there are significant concerns that the system is not equipped to respond to an event involving large numbers of critically ill patients, particularly a biological event, such as a pandemic.[14] Disaster Medical Assistance Teams (DMATs) of the NDMS are made up of practicing clinicians who will leave their local communities and deploy to disaster sites. While it may be possible to piece together a team or two of available volunteers from a distant unaffected area to respond to a geographically isolated event, it will be a significant challenge to find enough available DMAT members to meet the needs of many communities during a widespread event, such as an influenza pandemic or simultaneous terrorist attacks in major cities across the nation.

For disasters in which DMATs are available, another limitation is their critical care capability. The teams are staffed primarily by members who are not trained in critical care, and the teams are not equipped to provide critical care beyond initial resuscitation.[81] The primary responsibilities of DMATs include triaging patients, providing medical care in austere environments, and preparing patients for evacuation.

Finally, assuming that DMATs are able to be staffed and equipped to provide critical care on a large scale, they still face the issue of time, something many critically ill patients do not have. Because of logistic issues, deployment typically may take hours to days.[82,83] This is not unique to DMATs but a fact for any deployable disaster response team.[27] However, unlike many less acutely injured patients in past disasters, critically ill patients are unlikely to survive without care while awaiting the arrival of the team.

Conclusion

Although great strides have been made to prepare the health-care system to respond to disaster, these plans fall short for mass casualty events with a large number of critically ill. Most countries have insufficient critical care staff, medical equipment, and ICU space to provide timely, usual critical care to a surge of critically ill and injured victims. Were a mass casualty critical care event to occur tomorrow, many people with clinical conditions that are survivable under usual health-care system conditions might have to forgo life-sustaining interventions. Failure to provide critical care will likely result in high mortality rates.

Appendix

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