Chemical Warfare Agents: Emergency Medical and Emergency Public Health Issues

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The threat of exposure to chemical warfare agents has traditionally been considered a military issue. Several recent events have demonstrated that civilians may also be exposed to these agents. The intentional or unintentional release of a chemical warfare agent in a civilian community has the potential to create thousands of casualties, thereby overwhelming local health and medical resources. The resources of US communities to respond to chemical incidents have been designed primarily for industrial agents, but must be expanded and developed regarding incident management, agent detection, protection of emergency personnel, and clinical care. We present an overview of the risk that chemical warfare agents presently pose to civilian populations and a discussion of the emergency medical and emergency public health issues related to preparedness and response.

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INTRODUCTION

The threat of exposure to chemical warfare agents (CWAs) has traditionally been considered a military issue. Several recent events, however, have demonstrated that civilians may also be exposed to these agents.[1-3] Potential sources of exposure for civilian populations include acts of terrorism, inadvertent releases from domestic chemical weapon stockpiles, direct military attacks, and industrial accidents. The intentional or unintentional release of a chemical warfare agent in a civilian community has the potential to create thousands of casualties, thereby overwhelming local health and medical resources. Although it is prudent not to overstate the risk posed by CWAs, the proliferation of chemical, biological, and nuclear weapons (weapons of mass destruction [WMDs]) was recently recognized by the US Congress as the most serious threat to national security.[2,3]

The resources of communities in the United States to respond to chemical incidents have been designed primarily for industrial agents. But major CWA exposures will present emergency personnel with several unique challenges, especially in the areas of incident management, agent detection, protection of emergency personnel, and clinical care. The current capabilities of communities to respond to hazardous materials incidents must therefore be expanded and developed to meet these challenges.

To effectively cope with CWA releases, communities must address both emergency medical and emergency public health issues during preparedness and response activities. The aims of this article are to present an overview of the risks that CWAs currently pose to civilian populations, followed by a discussion of the emergency medical and emergency public health issues related to preparedness and response.

RISKS TO CIVILIAN POPULATIONS

Terrorism

Terrorism has been defined as the use or threat of violence to sow panic in a society, to weaken or overthrow its leaders, and to bring about political change.[4] Terrorists have previously used more conventional means of violence, such as bombings, assassinations, and hostage taking, to promote their causes. Several recent events have demonstrated that some terrorists now have access to weapons of greater lethality, including chemical, biological, and radiological agents.[2-6] Terrorists may potentially threaten and harm communities with CWAs through the detonation of CWA-containing munitions, atmospheric dispersal, contamination of food and water supplies, and product tampering.[7-10]

Recent technological advances, easy access to raw materials, the ready availability of technical information (eg, on the Internet), the support of terrorists by certain foreign governments, and crime and corruption in the former Soviet Union have all contributed to the proliferation of CWAs.[11-13] Recognized technical and political constraints to the use of these weapons have diminished, indicating that the potential for terrorists to obtain CWAs has never been greater. Whether these developments and the acknowledged vulnerabilities of US cities will actually translate into a CWA terrorist attack is difficult to determine, and is the subject of debate.[12,14-16] Currently, a terrorist attack with a CWA in the United States is best characterized as a low-probability, high-consequence event.

The most publicized use of a CWA by terrorists against a civilian population occurred in 1995, when the Aum Shinrikyo sect released sarin vapor in the Tokyo subway. The clinical and public health effects of this attack, which resulted in 12 deaths and more than 5,500 casualties, have been well documented.[2,17-20] Subsequent investigations revealed that the sect had also released sarin and anthrax in previous attacks, and had produced tabun, soman, VX and botulinum toxin.[3]

The Tokyo subway incident has provided medical planners with important lessons about the health complications of a terrorist attack with a CWA. In addition to causing death and physical injury, the use of CWAs may result in widespread fear, panic, and psychological trauma. It is estimated that more than 4,000 of the patients who overwhelmed medical facilities after the Aum Shinrikyo attack had no detectable physical injury, but were suffering from the psychological stress associated with a potential exposure to a CWA.[17] The short- and long-term mental health complications of CWA exposure are reported to be significant, including posttraumatic stress disorder, depression, and anxiety states.[21-23]

In the United States, the most important act of terrorism in which there was an attempt to use a CWA was the World Trade Center bombing in 1993. The presiding judge at the trial after the crime stated that the explosive used by the terrorists contained sufficient cyanide to contaminate the entire structure. Fortunately, the cyanide was destroyed by the blast.[6] Threats against civilians by terrorists with CWAs have also been made in California, Chile, and Germany.[3,24]

To ensure that American cities and communities are appropriately prepared for a terrorist attack with a chemical, biological, or nuclear weapon, Congress passed The Defense Against Weapons of Mass Destruction Act of 1996 (WMD Act). The bill provides special funds to conduct training programs and exercises for prehospital, medical, security, and civil defense personnel in US cities.[4] In addition, the White House has issued Presidential Decision Directives 39, 62, and 63 to outline the US government policy on counterterrorism, to establish a management structure for counterterrorism, and to ensure the security of the nation's critical infrastructure.

Military stockpiles

The US government no longer manufactures CWAs and has signed an international treaty agreeing not to use them militarily. But it still possesses large stores of these weapons and has categorized them according to their inclusion in either the military "stockpile" or the military "nonstockpile."[25,26] The stockpile consists of the bulk of the nation's CWA arsenal. Although its exact size and composition is classified, it is estimated that up to 30,600 tons of nerve agents (tabun, sarin, VX) and vesicants (sulfur mustard, lewisite) are stored in 8 separate sites across the continental United States, and at Johnston Atoll in the Pacific Ocean.[27-29] Many of these agents are now more than 40 years old.[28]

Stringent storage and backup procedures are used at the stockpile sites, resulting in a minimal risk to surrounding communities. Currently, the most likely scenario to pose a threat to the public would be a CWA stockpile release as a result of a natural disaster, such as an earthquake.

In 1985, Congress passed a law directing the Department of Defense to destroy the CWA stockpile by September 30, 1994. Continued storage of the CWAs is considered a greater risk than destruction of the stockpile, as the condition of the weapons is deteriorating.[29] But the program has experienced significant delays because of technical problems and public concerns over the most appropriate destruction methods to be used. In October 1992, Congress extended the completion date to December 31, 2004.[25]

The nonstockpile is comprised of outdated chemical warfare material and recovered chemical weapons that are not appropriate for inclusion in the CWA arsenal. There are approximately 215 nonstockpile sites where these materials are contained and buried. The threat from agents within the nonstockpile to civilian populations is less than from the stockpile, in part because of the small quantities involved.[26] Some of these sites have been relinquished by the government, and are now being converted to other uses. The potential exists for some of these agents to be unearthed or discovered during construction on nonstockpile sites,[9] resulting in potential exposure to construction workers.

Military use

Uncommonly, civilian populations may become the direct targets of military attacks with CWAs. They may also potentially sustain unintentional collateral injuries when their own nation's military uses chemical weapons against enemy forces. Few cases of intentional use of CWAs by military units against civilians have been documented. Military use of CWAs against civilian populations was confirmed during the 1980s, when Iraq attacked its own Kurdish population,[30,31] and highly suspected during the Egyptian-Yemeni War of the 1960s.[32,33] In addition, the former South African apartheid regime is reported to have used chemical agents against opponents of apartheid.[13] The threat of a CWA attack by Iraq against Israeli civilians led the Israeli government to distribute gas masks and nerve agent antidotes to its entire population before the Gulf War of 1991.[23,32,33]

Despite international efforts to halt the proliferation of chemical weapons, at least 25 nations are currently suspected of possessing, or attempting to acquire, CWAs and other WMDs. Several of these nations are considered hostile toward the United States.[22] Although it is highly improbable that any of these nations would launch a military strike with CWAs against the United States, American civilians could conceivably be exposed during a military incident while abroad.

The United Nations' Chemical Weapons Convention, which bans the development, production, stockpiling, and transfer of CWAs, came into effect in April 1997. The treaty has been ratified by 120 countries to date, with notable exceptions including Iraq, Libya, and North Korea.

Industrial accidents involving chemicals used as CWAs

A number of agents that have been used as chemical weapons are routinely used in a variety of industrial processes. Large quantities of agents such as phosgene, cyanide, and chlorine are regularly stored at industrial sites and transported on interstate highways and rail lines.[9,34,35] Inadvertent releases of these chemicals, or terrorist attacks aimed at storage and transportation facilities, have the potential to threaten surrounding communities and may result in acutely life-threatening emergencies.[36]

Chlorine is one of the most common commercial hazards and is used in the paper, textile, metals, and pharmaceutical industries. Approximately 200 major unintentional releases of chlorine have occurred this century, with the most serious episode resulting in 68 deaths in Romania in 1939.[37] Phosgene is used in a number of manufacturing processes, especially in the dye industry. It can also be generated by heating chlorinated hydrocarbons, thereby placing firefighters, welders, and paint strippers at risk of exposure.[34,36] Cyanides are widely used in the plastics and metals industries, resulting in potential exposure for tens of thousands of Americans every day.[38] A related compound, methyl isocyanate, was responsible for the worst industrial disaster in history, when it was unintentionally released from a pesticide plant in Bhopal, India, in 1984. The resultant toxic plume covered an area of approximately 40 km^2, and was responsible for up to 5,000 deaths and 200,000 injuries.[39,40]

OVERVIEW OF CWA CLASSIFICATION AND CHARACTERISTICS

CWAs are broadly classified as nerve agents, vesicants, pulmonary agents, and cyanides (formerly "blood agents"). In addition to their more familiar generic names, chemical weapons are also referred to by military designator codes (Table). Their clinical effects, and their comparative advantages as weapons, vary according to their physicochemical characteristics, toxicity, and primary site of action. An analysis of these characteristics is critical to a clear understanding of the acute medical and public health issues relevant to CWAs.

Volatility

Volatility is the tendency of a liquid to evaporate and form a vapor, or gaseous form. At usual atmospheric temperatures and pressures most CWAs are in liquid form.[41-44] After the detonation of a munition containing a CWA, the agent is dispersed primarily as a suspension of fine liquid droplets. The classical liquid CWAs have a broad range of volatility. Phosgene and cyanides are the most volatile agents; the volatility of sarin is similar to that of water, and is greater than both tabun and soman; sulfur mustard and VX are the least volatile of the CWAs.[41,42]

Importantly, the vapor of all CWAs, with the exception of hydrogen cyanide, is heavier than air. A vapor will generally sink to the lowest point of an area, such as the bottom of ditches and basements. Therefore, exposed individuals are safest if they are able to ascend to a higher point, such as the top floor of a building. Even standing provides a relative degree of protection from CWA vapors, as the concentration that an individual will be exposed to when standing may be significantly lower than when lying down.[9]

Table.
Chemical warfare agents.

Category	Common Name	US Military Code
Nerve agents	Tabun	GA
	Sarin	GB
	Soman	GD
		VX
Vesicants	Sulfur mustard	HD
	Lewisite	L
	Phosgene oxime	CX
Pulmonary agents	Phosgene	CG
	Chlorine	CL
Cyanides	Hydrogen cyanide	AC
	Cyanogen chloride	CK

Persistence

Persistence is inversely related to volatility. The more volatile an agent, the quicker it evaporates and disperses. A volatile agent is therefore less likely to persist and contaminate the surrounding environment. The military classifies CWAs as persistent or nonpersistent, depending on whether an agent evaporates in less than or greater than 24 hours.[9,41] Other authors have used the term "semipersistent" to distinguish agents that disperse quickly from those that will persist for several hours.[43,45]

In general, most industrial chemicals (eg, hydrochloric acid) are nonpersistent. Military agents, however, are intended to be persistent (eg, sulfur mustard, VX) or semipersistent (eg, sarin). This is clinically relevant, as persistent agents are slower to evaporate and will remain in contact with body surfaces for longer periods. They are therefore more likely to penetrate the skin to cause clinical effects. Persistent and semipersistent agents also pose the greatest threat to rescue and medical personnel, as there is a risk of secondary exposure and contamination from patients and the surrounding environment.[18,45] To minimize this threat, emergency responders will be required to clearly demarcate the contaminated zone, to establish protected entry and exit points, and to implement decontamination procedures.[45]

Toxicity

Toxicity is defined as the potential for an agent to cause injury in biologic systems.[46] The toxicity of a particular agent is often represented by the median lethal dose (LD_{50}), which indicates the single dose of the agent that will cause death in 50% of exposed laboratory animals.[45] The median effective dose (ED_{50}) represents the dose at which 50% of an exposed population will begin to develop clinical symptoms and/or signs. The ED_{50} and LD_{50} are generally used to describe the effective and lethal doses of drugs and agents that are given parenterally or orally. But they have limited utility in discussion of the toxicity of agents that are inhaled or absorbed across the skin and mucous membranes, such as vapors and aerosols. In these settings, it is more appropriate to determine toxicity in terms of exposure rather than dose and other measurements are therefore required.

The concentration-time product (Ct) is often used to describe or approximate the relevant exposure to an agent. The Ct is the concentration of the agent in air, multiplied by the time that an individual is exposed to that concentration; it is represented as milligrams per minute per cubic meter. Similar to the ED_{50}, the LCt_{50} represents the Ct of an aerosol or vapor that is lethal to 50% of the exposed population, and the ECt_{50} represents the Ct of an aerosol or vapor that will result in clinical effects in 50% of the exposed population.[9,42] Stated simply, the LD_{50} relates to dose and the LCt_{50} relates to exposure. It is important to make the distinction that dose does not equal exposure.[42]

Two other important concepts related to the toxicity of CWAs are lethality and incapacitating effects. The cyanides and nerve agents are the most lethal of the CWAs. At high concentrations, death may occur within 5 minutes of inhaling a cyanide and within 15 minutes of absorption of a nerve agent through the skin or respiratory tract.[9,43]

The incapacitating effects of CWAs can be even more important than their lethality.[45] The military utility of incapacitating effects is that they produce injuries that remove combatants from the field of battle and result in the diversion of enemy resources to casualty evacuation and the provision of medical care. When CWAs are used against civilian populations, multiple casualties may result that can potentially overwhelm EMs providers. The vesicants are considered primarily incapacitating agents, and although they produce severe injuries, fewer than 5% of exposed individuals will die.[9] The incapacitating effects of the CWAs can be expressed as ICt_{10}, which represents the Ct of an agent that will incapacitate 10% of exposed individuals.[42]

Latency

Latency refers to the time delay between absorption of an agent and the onset of clinical symptoms or signs. Sulfur mustard and the pulmonary agents are the CWAs with the longest latency. The clinical effects of other vesicants, the nerve agents, and cyanides are usually seen within seconds to minutes.

The symptoms and signs associated with sulfur mustard exposure generally do not develop for approximately 6 to 8 hours, and may be seen anywhere from 2 to 24 hours. Although the clinical manifestations are delayed, cellular and biochemical damage actually occur within minutes of exposure. Emergency responders must be aware that although a patient may not exhibit clinical symptoms or signs, a significant exposure may still have occurred. Therefore, responders may be at risk of secondary contamination until appropriate decontamination has been performed.

Patients who have been exposed to the pulmonary agents may not have dyspnea or other clinical manifestations for up to 24 hours, although the exact period will depend on the extent of the exposure. Individuals who have been exposed to any agent with significant clinical latency require medical monitoring for up to 24 hours.[45] The need for monitoring by large numbers of exposed individuals can potentially overwhelm the resources of inpatient medical facilities.

ISSUES IN DISASTER PREPAREDNESS

It is widely acknowledged that most prehospital and emergency medical personnel in the United States are currently not well prepared, trained, or equipped to deal with incidents involving chemical, biological, or nuclear weapons.[7,27,29,48,49] Recent field and tabletop exercises have exposed serious deficiencies in preparedness and major problems of coordination.[11,27] Any emergency medical or public health response to a major incident involving a CWA will require coordination and cooperation among local, state, and federal bodies. Preparedness activities should build on the existing EMS/disaster management infrastructure. Relevant issues in disaster preparedness for an incident involving a CWA include education and training of emergency personnel, disaster planning, public education, deployment of specialized teams, and stockpiling of appropriate antidotes.

Education and training

A limited number of opportunities currently exist for civilian health professionals to learn about the characteristics of CWAs, and the clinical assessment and management of patients exposed to these agents. The US Army Medical Research Institute of Chemical Defense conducts a course on Medical Management of Chemical and Biological Casualties for military medical personnel, but few civilians currently have access to this training. The Chemical Stockpile Emergency Preparedness Program (CSEPP) coordinates courses on CWA incidents for prehospital and emergency medical personnel living in specified communities near stockpile sites. The Occupational Safety and Health Administration's Hazardous Waste Operations and Emergency Response (HAZWOPER) standard provides for the training of all employees who could potentially be exposed to hazardous materials. But this training focuses on occupational health aspects of hazardous materials incidents, and does not cover issues related to CWAs, acts of terrorism, or military stockpiles. Several courses are also available through the private sector, but these have not received official endorsement from certifying professional organizations.

Currently, the largest training initiative that addresses CWAs for civilian personnel is the National Domestic Preparedness program, which was mandated by the WMD Act of 1996. Under the program, training is to be provided to emergency responders and hospital personnel in the 120 most populous cities across the United States. It uses a "train the trainer" format and incorporates a modular design so that sessions can be tailored to meet the specific needs of individual cities. Although classes and exercises will be conducted in a limited number of regions, the intent is that individuals trained by the program will then be able to conduct subsequent training in neighboring communities.

The Soldier and Biological Chemical Command (SBCOM), representing the Department of Defense (DOD), has played the leading role in coordinating training under the National Domestic Preparedness program. Other agencies to have contributed to this collaborative initiative include the Federal Bureau of Investigation (FBI), the Federal Emergency Management Agency (FEMA), the Department of Energy (DOE), the Department of Health and Human Services (DHHS), and the Environmental Protection Agency (EPA).

Importantly, a Task Force appointed by the American College for Emergency Physicians has recently developed a strategy that aims to establish effective, sustainable training opportunities for prehospital personnel, emergency nurses, and emergency physicians. The training will address medical issues related to WMD incidents. Key elements of the strategy will be to develop courses aimed specifically at emergency personnel, to integrate WMD-related content into graduate medical education and specialty certification programs, and the development of continuing educational opportunities.

Disaster plans and exercises

It is essential that training be conducted in parallel with a review of hospital and community disaster plans, which should include a component addressing WMD incidents. Issues of special relevance to WMD incidents, including command and control, scene assessment, equipment, triage, decontamination, population evacuation, patient treatment, and disposition should be addressed.

This need has already been recognized at the federal level. Guidelines for hospitals near stockpile sites recommend that CWA protocols be included in each facility's disaster plan.[29] An annex that addresses terrorist incidents, including chemical incidents, was developed for the Federal Response Plan before the 1996 Olympic Games.[50] The Federal Response Plan, which was first published in 1992, is the main document that outlines federal government agency responsibilities after a domestic disaster.[51] A second edition is scheduled for release this year and will include an updated terrorism annex. In addition, the DHHS has developed the Health and Medical Services Support Plan for the Federal Response to Acts of Chemical/Biological Terrorism.[7]

The National Domestic Preparedness Office (NDPO) has recently been established to assist local and state agencies with the integration of WMD components into their current disaster plans. A key element of this process will be to ensure that local and state plans interface with the federal WMD plans.

Once a disaster plan has been updated to include a WMD component, it will be critical to conduct regular exercises to evaluate the plan, and to train personnel.[52] Importantly, the WMD Act has mandated that communities conduct yearly exercises to assess their readiness to respond to a WMD incident. In addition, the Joint Commission on Accreditation of Healthcare Organizations mandates that hospitals conduct semiannual drills to evaluate the effectiveness of their plans, although this regulation does not require them to specifically address WMD incidents. Communities and institutions can now seek guidance and technical support from NDPO for the development of WMD exercises.

The NDPO will play an important role in assisting communities to develop and conduct training exercises. NDPO is housed within the FBI, but collaborates closely with other agencies under the NDP program, including FEMA, DOE, DHHS, EPA, and DOD.

Public education

Public education activities are necessary to keep the community well informed and to counter the spread of misinformation. This is especially important for communities near military stockpile sites. These communities should have a clear understanding of the risks of a potential CWA release, the health consequences associated with exposure, and the steps that they should take after the announcement of a release. Appropriate instructional methods include community seminars, the distribution of publications, presentations on local radio and television, multimedia products, and Internet-based services. Information should be provided in a manner that it is clear and readily understood by non–health professionals.

The Israeli government undertook extensive public education campaigns relating to chemical and biological incidents before and during the Gulf War. A number of educational materials were published, including a Chemical Warfare Family Defense Manual that was provided to each household.[23] As has been noted, gas masks and antidotes (autoinjectors of atropine) were distributed to all civilians. Subsequent reports concluded that such measures were generally safe, but at least 6 civilian deaths were attributed to incorrect use of gas masks.[21,32,53]

Specialized response teams

A variety of specialized teams have been established throughout the United States to increase the local, state, and federal capacity to respond to incidents involving CWAs and other WMDs. The DHHS has developed Metropolitan Medical Response Systems (MMRSs) in 27 major cities across the United States. MMRSs represent local resources that are specifically trained and equipped to respond to incidents involving nuclear, biological, or chemical (NBC) agents.[54] The National Guard has been tasked to establish rapid response teams in 10 states to increase the regional NBC response capabilities. On the federal level, the DOD has developed 2 consequence management Response Task Forces that are trained and equipped to detect, neutralize, contain, and dispose of WMDs.[51]

Predeployment of specialized federal response teams may occasionally be indicated for mass gatherings and other important events. Indications for predeployment include events that represent a potential terrorist target, such as major sporting competitions, political conventions, and visits of prominent world leaders. Recent events during which teams with specialized chemical and biological response capabilities were predeployed include the 1996 Olympic Games in Atlanta,[55] the 1996 Republican Convention in San Diego, and the 1997 Group of Seven political meeting in Denver.

The US Marines Corps' Chemical/Biological Incidence Response Force (CBIRF) may predeploy in anticipation of an incident involving a chemical or biological weapon.[48,56] This unit consists of approximately 300 personnel skilled in the provision of security and area isolation, agent detection and identification, patient decontamination, and medical support.[57] The US Army's Chemical/Biological Rapid Response Team can also predeploy and has the capacity to detect, neutralize, contain, and dispose of WMDs.

Stockpiling antidotes

Most medical facilities will have insufficient quantities of antidotes to treat a large number of casualties after a CWA release. The stockpiling of antidotes in strategic locations has therefore been suggested as a potential component of preparedness activities for a terrorist attack with a CWA.[58] Appropriate medications for such a stockpile include antidotes to the military nerve agents and cyanide kits.

There are several significant problems associated with the development of antidote stockpiles. The appropriate quantities of drugs to be stored for separate communities are difficult to determine. The appropriate site at which to store these agents, and how to rapidly redistribute them after a CWA release also pose major difficulties. Most individuals with significant exposures to nerve agents or cyanide will require an antidote within minutes, and transporting antidotes from a stockpile site that is remote from the actual CWA incident can result in critical delays.

It is not cost-effective to develop stockpiles in all communities, as the antidotes are expensive, have limited shelf-lives, and are unlikely to be used in large quantities. Infrequently, temporary stockpiles have been assembled in the past for important events that represented a potential terrorist target, such as the 1996 Olympic Games.[57] Currently, the Centers for Disease Control and Prevention is leading an interagency process to assemble and manage a national stockpile of antidotes, antibiotics, and other drugs for the treatment of civilian casualties resulting from a chemical, biological, or nuclear incident.

PRINCIPLES OF EMERGENCY RESPONSE AND MEDICAL TREATMENT

Regardless of whether civilian exposure to a CWA is the result of terrorism, a release from the military stockpile, or an industrial incident, a multidisciplinary approach will be necessary to address emergency medical and emergency public health needs. Coordination among prehospital personnel, law enforcement, emergency physicians, public health specialists, toxicologists, laboratorians, environmental engineers, and security personnel will be required.

Levels of response

A graduated emergency response with activation of sequential tiers of the community disaster plan is the best strategy when managing incidents involving CWAs. Local responders will generally be first on the scene after most CWA releases, but their capabilities and resources to respond to these incidents is severely limited in most regions. The primary goal of the Domestic Preparedness program is therefore to increase the capacities of local emergency personnel to respond to terrorist incidents involving chemical, biological, and nuclear agents. Larger CWA releases will require the assistance of emergency personnel from neighboring municipalities to enhance the local response. Communities without appropriate resources or capabilities will require mutual aid agreements with other jurisdictions.

In addition to local and regional responders, federal resources will be mobilized after a suspected terrorist act or a release from a CWA stockpile site. The federal response to terrorism consists of 2 components: crisis management and consequence management. Crisis management primarily deals with law enforcement issues, and is comprised of those measures required to anticipate, prevent, and/or resolve a terrorist incident. The lead federal agency for crisis management is the FBI. Consequence management refers to measures that alleviate the adverse health and environmental effects of a terrorist event. Consequence management is implemented under the primary jurisdiction of the affected local and state governments. The federal government augments the local response when required. The lead federal government agency for consequence management is FEMA.[50]

Command and control

In the United States, coordination of response activities after a domestic disaster is generally organized under the Incident Command System (ICS). ICS is a management system that promotes coordination and communication between responding agencies and minimizes duplication of effort. A major advantage of this system is the provision of a unified command, to oversee the various agencies and disciplines responding to a disaster. FEMA uses ICS routinely because of its simplicity, flexibility, and practicality.[52] The FBI, however, interfaces with ICS less frequently.

A CWA release caused by an act of terrorism therefore presents potential command and control challenges. The major concern is to coordinate crisis management and consequence management activities in such a manner that law enforcement priorities do not compromise patient care. To clarify this issue, the US policy on counterterrorism states that a single agency, either the FBI or FEMA, will be responsible for overall coordination of the federal response.

If terrorism is suspected, an FBI crisis management team will take over control of the scene from local responders. Other agencies will then provide guidance and assistance to the FBI as outlined in its Chemical/Biological Incident Contingency Plan.[50] The FBI contingency plan describes mechanisms to promote cooperation among the responding agencies and is particularly concerned with coordinating crisis management and consequence management. FEMA will coordinate consequence management in support of the FBI until the attorney general transfers the lead agency role to FEMA. The decision to transfer lead agency responsibilities from the FBI to FEMA will be made after senior representatives from both agencies have determined that the responsibility to contain the crisis has been superseded by the responsibility to protect the population and to relieve further suffering. After transition of the lead agency role, the FBI will continue to conduct law enforcement operations and to support FEMA as appropriate.[50]

Personal protective equipment

Responders must take measures to protect themselves before entering a contaminated area. The use of personal protective equipment (PPE) to protect the airways, skin, and eyes is an indispensable component of the emergency response. Full-face respiratory masks, self-contained breathing apparatuses, and liquid-proof and vapor-impermeable suits may all be required. Limitations to the use of PPE are significant and include restrictions of physical activity, dehydration, heat-related illness, and adverse psychological effects, such as claustrophobia.[59,60]

The EPA has outlined detailed combinations of respirators and chemical protective attire that may be used in certain hazardous environments. These grades of protection are classified as levels A, B, C, and D.[61] Level A equipment provides the greatest degree of protection and consists of an encapsulated, vapor-impermeable, and chemical-resistant garment, chemical-resistant gloves and boots, and a self-contained breathing apparatus. Level A suits will protect against most military and industrial compounds. Many hazardous materials teams throughout the United States have level A capabilities, but this is by no means universal. The PPE used by the military (mission-oriented protective posture [MOPP] 1-4) is protective against most CWAs, but may not protect against certain industrial chemicals.

All emergency personnel who enter the contaminated zone or who have direct contact with contaminated victims will require PPE. The risk of secondary exposure and contamination is high if victims have not been decontaminated, or if decontamination has been inadequate. As a component of community disaster preparedness, EMS services, hazardous materials teams, and hospitals must ensure that they have a cadre of personnel who have been trained and equipped to appropriately select and use PPE.

Assessment

The initial personnel to enter the scene should be members of the regional hazardous materials team or equivalent. Although often not trained in medical care, they can conduct an initial scene assessment and often perform basic triage to ensure that the most severely affected individuals are the first to be rescued from the area.[10] A more detailed health assessment may subsequently be performed by emergency medical personnel wearing appropriate PPE.

The key principles of a rapid assessment after a CWA incident are similar to those following any disaster. The rapid assessment aims to determine the nature and magnitude of the emergency, the presence of ongoing hazards, the extent or risk of injury to the population, the availability of local resources, and the need for external resources.[62] A well-conducted assessment will assist in determining appropriate patient care and public health recommendations, including mass decontamination, the use of antidotes, and the need for evacuation.

Often, basic estimates such as the number of people killed or injured will be sufficient basis on which to assess the magnitude of the event and to determine emergency response options. Other important information will include the nature and extent of the CWA release, wind direction, clinical presentations, and details regarding agent detection, identification, and confirmation. Such information may alert responders of the need to deploy specialized laboratory equipment and technical teams, and to coordinate the transfer of chemical samples to reference laboratories.

Demarcation of the contaminated area

One of the main priorities of emergency responders after any chemical release is to demarcate the contaminated area, or "hot zone." This area must be clearly marked with appropriate barrier devices, and have a designated access/egress point. In addition, both a "warm zone" and "cold zone" should be established. The cold zone will serve as a clean, uncontaminated patient treatment and dispatch area. It is positioned upwind of the hot zone, 50 yards or more from the warm zone. The warm zone separates both hot and cold zones. It should be several hundred yards upwind of the contaminated area.[9] It is essential to ensure that no one crosses through the warm zone from the contaminated area to the clean treatment area without being decontaminated.

Agent detection and identification

The rapid identification of an unknown agent may assist in determining early medical and public health interventions. Several handheld military detection devices are currently available, including the Chemical Agent Monitor (for vapor), M8 Detection Paper (for liquid), and the M256 Detection Kit (for vapor and liquid). These devices have several limitations, including low specificity, an inability to detect all military agents, and deficiencies in the detection of many industrial chemicals.

The equipment currently used by hazardous materials teams varies across the nation and usually includes devices to detect volatile organic compounds and flammable agents, and to monitor oxygen levels. Their ability to detect and identify military chemical warfare agents may therefore be significantly limited.

Definitive identification of an agent will require the resources of an analytical laboratory and will generally take several hours. It will therefore be necessary to base early medical and public health interventions primarily on scene assessment and clinical judgment.[63] Clinical symptoms and signs in exposed individuals may be the most useful indicators of the likely agent and will be critical in guiding emergency medical care. A patient manifesting signs consistent with exposure to an organophosphate nerve agent, for example, will require appropriate antidotes and emergency care before definitive identification has occurred.

In addition to samples of air, soil, water, and munitions, biological specimens may be required to precisely identify the agent and to quantify levels of exposure. Careful attention must be paid to the appropriate collection, handling, and transport of forensic and pathology specimens. This will assist with the crisis management component of the response if a terrorist event is suspected. These important aspects of the response should be addressed in the local disaster plans and during disaster exercises and drills.

Triage

Triage of individuals exposed to a CWA poses several challenges, but the underlying principles are the same as for any multiple-casualty incident. The primary objective is to allocate medical personnel, supplies, and facilities in a manner that provides the greatest good to the greatest number. If a large number of casualties is present after a CWA release, a triage station should be established in the hot zone to assist in determining priorities for resuscitation, decontamination, pharmacological therapy, and site evacuation.[64] Triage at the scene should be conducted by specially trained emergency medical personnel who are familiar with CWAs and the use of PPE. The triage officer's ability to perform a rapid clinical assessment may be hampered by PPE, as a result of reduced mobility and impaired sensory input.

The familiar triage casualties of immediate, delayed, minimal and expectant can be applied to chemical casualties, provided that the triage officer is familiar with the chemical agents.[63] When required and appropriate, advanced life support (ALS) measures should be initiated at the scene and continued throughout the evacuation and decontamination phases.[45] Triage is a dynamic process and should occur at every stage of patient management, including initial assessment, decontamination, evacuation, and emergency department care.[52]

Decontamination

Successful rescue entails separating casualties from the chemical agents. Evacuation of victims from the contaminated area and removal of contaminated clothes will be required. Rapid decontamination of the skin is particularly indicated after exposure to the liquid or aerosolized form of an agent. Decontamination may not be necessary if the victim has been exposed to vapor alone.[2,17] It is most effective when conducted within 1 minute of exposure, but in practice this is rarely possible.[9]

When indicated, decontamination should be performed as close to the scene as possible (ie, in the warm zone), and ideally before patient transportation.[45,63] The most appropriate method and agent should be used for decontamination, which requires identification of the chemical contaminant(s). Occasionally, however, it is not possible because the agent is unknown or there are mixed agents. Simple water and soap can provide effective decontamination in many instances. When needed, a commonly used agent for skin decontamination is hypochlorite or household beach. The military generally uses .5% hypochlorite for skin decontamination; most EMS units use 1% to 2% concentrations. Commercially available bleach is usually 5% hypochlorite.[9] There is a great deal of recent discussion and reevaluation of decontamination strategies and agents, so careful consideration of the most current recommendations is important.

Each community or hazardous materials team should have established procedures for decontamination. These vary by locality, and responders should be familiar with the procedures in their area.[10] In general, facilities should be established in separate, nearby areas for ambulatory individuals and for those on litters. Decontamination must be performed on all victims and responders before they cross into the noncontaminated area.

Preparedness of the emergency department

ED personnel require training in the recognition and clinical management of chemical casualties. As noted, hospital disaster plans should be expanded to address CWA incidents. This will include the establishment of special hospital teams that are skilled in the use of PPE and in decontamination procedures. It will be necessary to activate the chemical emergency response plan as soon as the hospital has been notified that it will be receiving chemical casualties. Noncritical patients should be transferred or discharged from the ED and additional staff mobilized as required. The department should be well stocked with supplies, including appropriate antidotes.

If there is a large number of casualties, the hospital can expect to receive patients who have not yet been decontaminated. Contaminated patients may make their own way to the ED or may be transported by EMS when decontamination at the scene has not been possible. Steps must be taken to ensure that staff and patients already within the hospital are not at risk of secondary exposure to the CWA. Security personnel should be present to provide crowd control and to ensure effective and efficient patient flow.

Decontamination is performed by specially trained personnel wearing PPE in a demarcated area outside the department. Each hospital should have at least 1 shower permanently established in this area for the management of victims of chemical exposures. Runoff from the shower must be contained and disposed of safely, to ensure that it does not enter community drainage systems. If multiple contaminated casualties arrive at the ED, separate areas should be established for the decontamination of litter patients and for ambulatory patients. A second showering facility, such as a portable device, will be required in this setting.

Protecting the public

The use of public warning and information systems will be critical to inform the community about the nature of the incident and the appropriate measures that they can take to protect themselves.[34] Timely, accurate information will assist in minimizing panic in the affected community. The media plays a central role in this area and should already have an established responsibility of providing emergency and disaster-related information to the public.

Measures to reduce exposure of the public to chemical agents include evacuation, sheltering in place, and the distribution of gas masks.[32,53,65] Analyses using plume dispersion models have determined that when there is sufficient time available, evacuation is the most appropriate measure to protect populations likely to be affected by a chemical release.[29,65] Evacuation is a complex process, however, and may not always be possible after a sudden release. Sheltering in place involves maintaining people in their homes, institutions or businesses, and sealing windows and doors from an external vapor threat. It is the preferred option when there is not time to evacuate, or when evacuation is impractical, such as in hospitals and nursing homes. The distribution of gas masks to the public is currently not recommended in the United States, even to communities near stockpile sites, because of the low risks of exposure, and the potential complications of their use.[29]

Medical treatment and antidotes

Subsequent medical care may involve continuing ALS measures, administration of antidotes, and supportive therapy. As noted, triage is an ongoing process and casualties must be monitored closely for an acute deterioration in their condition and delayed presentations. ALS measures may include mechanical ventilation to treat the respiratory failure associated with nerve agents and pulmonary agents. Mechanical ventilators are usually in limited supply, and a mass casualty incident involving a CWA could conceivably overwhelm the resources of a single hospital, or even entire community.[34]

Specific antidotes exist for the nerve agents (atropine and pralidoxime), cyanides (amyl nitrite, sodium nitrite, sodium thiosulfate, 4-dimethylaminophenol, dicobalt edetate), and lewisite (dimercaprol). The indications, dosages, and complications of these agents have been well described elsewhere.[9,10,41,44,66,67-70] There are no specific antidotes for sulfur mustard, phosgene, or chlorine. Treatment is usually supportive and directed at treating the associated complications.[9,71-73]

Military nerve agents are organophosphates, but are significantly more toxic than the familiar organophosphate insecticides. Large doses of both atropine (up to 20 to 30 mg) and pralidoxime (up to 8 g) may be required by an individual patient after a nerve agent exposure.[2,66] In the setting of multiple casualties, a hospital's entire stock of the 2 drugs could therefore be rapidly depleted. In the ED these medications are usually administered intravenously, but autoinjectors of atropine, pralidoxime, and combinations of the drugs are available for rapid intramuscular injection in the field. Autoinjectors of these antidotes were distributed to American military forces and the Israeli population before the Gulf War.[23,64] A benzodiazepine such as midazolam or diazepam is generally indicated to treat severe cases of nerve agent toxicity to prevent or treat complicating seizures.[9]

Cyanide antidotes must be administered rapidly if they are to have any chance of success. This presents significant challenges in the field, as most cyanide antidotes must be given intravenously, usually in large volumes. The only exception is amyl nitrite, which is less effective than the other available antidotes.[68] Dimercaprol, the antidote for lewisite, can be given parentally for systemic toxicity, or topically for skin lesions. But there is no indication for its use in the field, and it has several limitations. Parental administration is by painful intramuscular injections, dosages are limited by toxicity, and it may be associated with severe drug reactions.[67] Intramuscular administration of dimercaprol has no effect on skin lesions. These can only be prevented or reduced by immediate decontamination.[9]

Supportive therapy for other CWA exposures may include eye care, attention to skin lesions, supplementary oxygen, bronchodilators, pulmonary toilet, and the treatment of complicating infections. Monitoring patients for up to 24 hours may be indicated after exposure to sulfur mustard and pulmonary agents to detect latent or escape syndromes.[45]

As previously noted, in most settings the exact identity of the agent will not be immediately known. The management of patients exposed to an unknown agent will include life support measures, decontamination, and supportive care. The need for a specific antidote will be based largely on the clinical presentation. If patients demonstrate clinical evidence of organophosphate exposure, such as miosis, salivation, and bronchospasm, then atropine and pralidoxime will be indicated. Hyperpnea and cardiovascular collapse suggest cyanide exposure, indicating that specific antidotes must be administered immediately. Emergency personnel must therefore be trained in the recognition and management of the clinical syndromes associated with various CWA exposures.

Poison control centers

Poison control centers (PCCs) are an important resource during the preparedness and response phases of a CWA incident. They can provide valuable information concerning agent characteristics, agent toxicology, clinical effects, and medical management. PCCs should therefore be consulted during the development of both community disaster plans and emergency response guidelines. In addition, they should contribute to the training of rescue personnel, physicians, and nurses who may respond to a chemical incident. After a CWA exposure they may be able to provide emergency personnel with advice concerning the most appropriate PPE, the potential for secondary contamination, appropriate decontamination procedures, and specific treatment and antidotes.[74]

Surveillance

Establishing a surveillance system will often be required to assess health effects, to identify groups at increased risk of adverse outcomes, to evaluate medical interventions, and to determine research needs.[2,75] Potential long-term adverse health outcomes include neurotoxicicity after a nerve agent exposure, blindness and lung cancer after sulfur mustard exposure, chronic pulmonary damage after phosgene or chlorine exposure, and psychological trauma.[71,76-78] Disease and injury registries should be established as soon as possible after the incident to facilitate long-term follow-up.[17,79]

In conclusion, recent trends in terrorism, the production and transport of industrial chemicals, and the aging of the military stockpile have increased the risk that civilians may be exposed to chemical warfare agents. A significant CWA release would place major strains on local responders, who are presently inadequately prepared to deal with such an event. Several programs are currently under way to expand the response capacity at the local, state, and federal levels. But further efforts are required to appropriately train, equip, and update personnel who may be required to respond to CWA incidents. Emergency physicians need to be aware of the risks posed by CWAs, to be familiar with emergency response and clinical management issues, and to ensure that their departments are prepared to respond to a mass casualty incident involving these agents.

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