SPECIAL REPORT

Civilian Exposure to Toxic Agents: Emergency Medical Response

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Abbreviations:
CBW = chemical and biological warfare
EMS = emergency medical services
HazMat = hazardous materials
TOXALS = advanced life support for toxic trauma

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Abstract
Civilian populations are at risk from exposure to toxic materials as a result of accidental or deliberate exposure. In addition to industrial hazards, toxic agents designed for use in warfare now are a potential hazard in everyday life through terrorist action. Civil emergency medical responders should be able to adapt their plans for dealing with casualties from hazardous materials (HazMat) to deal with the new threat.

Chemical and biological warfare (CBW) and HazMat agents can be viewed as a continuous spectrum. Each of these hazards is characterized by qualities of toxicity, latency of action, persistency, and transmissibility. The incident and medical responses to release of any agent is determined by these characteristics.

Chemical and biological wardare agents usually are classified as weapons of mass destruction, but strictly, they are agents of mass injury. The relationship between mass injury and major loss of life depends very much on the protection, organization, and emergency care provided.

Detection of a civil toxic agent release where signs and symptoms in casualties may be the first indicator of exposure is different from the military situation where intelligence information and tuned detection systems generally will be available.

It is important that emergency medical care should be given in the context of a specific action plan. Within an organized and protected perimeter, triage and decontamination (if the agent is persistent) can proceed while emergency medical care is provided at the same time.

The provision of advanced life support (TOXALS) in this zone by protected and trained medical responders now is technically feasible using specially designed ventilation equipment. Leaving life support until after decontamination may have fatal consequences. Casualties from terrorist attacks also may suffer physical as well as toxic trauma and the medical response also should be capable of dealing with mixed injuries.

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Toxic Agents: Definitions and Risks
Civilian populations are at risk from accidental or deliberate exposure to a wide range of both industrial and military toxic agents.[1] A toxic agent may be defined as any substance that is injurious to health in an unconfined state.[2] The civil HazMat system classifies many thousands of toxic hazards that are in general production and use.[3,4] Their toxicity to humans is incidental to their primary purpose unlike military hazards that have been developed specifically as weapons of warfare, and therefore, specifically to cause harm. Military toxic agents have been recognized for more than one hundred years and conventionally have been divided into chemical and biological threats.[5]

Biological agents may be considered to be self-replicating organisms injurious to health in an unconfined state, but in the sense of causing a deliberate rather than natural epidemic. Although military exposure to toxic hazards usually is deliberate whereas civil exposure is accidental, there are many similarities in the management of casualties. The traditional distinctions between chemical (including HazMat) and biological agents can be unified as a spectrum of hazards ranging from low to high molecular weight substances through to self-replicating organisms.[6] This approach has the advantage of highlighting common pathophysiological processes such as pulmonary edema and neuromuscular failure.

Physical and Toxic Trauma

All trauma may be classified either as conventional physical, toxic, or mixed trauma. Treatment of conventional, physical trauma is a major part of emergency medical service (EMS) practice. Poisoning, either individual or collective, usually is not classified in the same way, but there is a case for regarding it as a toxic form of trauma and for it to be integrated into patient management. A unified approach emphasizes the importance of mixed trauma that can occur particularly after explosive release of toxic agents as is the case with a military or terrorist attack.

Penetrating trauma causes hypovolemic shock which leads to a failure of the oxygen transport system to the mitochondria leading to cellular failure, lysosome release, and death. Blunt trauma ultimately leads to the same fate, although a complicated cascade of inflammatory mediators is involved. Toxic trauma is no different in its end stage due again to a failure of the oxygen cascade system from a variety of causes.

Toxic trauma produces both acute effects that involve biochemical disruption of all somatic systems and also effects that may become apparent after a period of latency. All of the major somatic systems may be affected, but the main risk is to the respiratory system with the production of ventilatory failure and arrest leading to secondary cardiac arrest and death.

Properties of Toxic Hazards

All toxic hazards in the CBW spectrum may be classified according to four fundamental properties.[7] These are *toxicity* and *latency* of action, which are determined by toxicokinetics and dynamics, and *persistency* and *transmissibility* of the hazard, which are determined by the physico-chemical properties of the agents. Transmissibility is sometimes referred to as secondary contamination in HazMat documents. Toxicity and latency define the danger to the victim and persistency and transmissibility define the danger to the rescuers.

Transmissibility and Contamination

Many of the civil hazards listed by HazMat are non-persistent and non-transmissible. Smokes, which fall into this category, are the toxic hazards most likely to be encountered in civil life.[8] Such non-persistent and non-transmissible hazards pose no contamination or transmissibility risk. This means that medical rescue teams can begin work upwind of the release without protection or decontamination. Of course, downwind there still will be a risk. Other civil hazards and most military hazards are both persistent and transmissible, and pose a major threat to EMS teams. In this situation, full protected entry to the contaminated zone is required, which produces potential difficulties for EMS responders. Emergency medical responders dealing with toxic trauma should be fully conversant with HazMat protocols and trained to work safely in a contaminated environment.[3,9]

CBW Agents: Weapons of Mass Destruction?

Although CBW weapons have long been classed together as "weapons of mass destruction", there is no necessity to view them in such a nihilistic way. Rather, they are weapons of potential mass injury which, in the absence of early life support measures may lead to mass destruction in the form of major loss of life. The high mortality rate in toxic releases such as in Bhopal[10] and during the Iran–Iraq War[11] were the result of medical facilities being overwhelmed or non-existent.

The overview of toxic trauma has changed in recent years from being something essentially overwhelming and unmanageable to a mass incident that can be managed by EMS systems using knowledge, clinical analogies, and skills acquired in normal emergency medical practice.[12]

Release of Toxic Agents

The release of military toxic agents usually takes place as part of a battle. The agents to be encountered often are identified beforehand from intelligence reports and may be detected by tuned detection systems. If a toxic attack is anticipated, military personnel usually are prepared and have the advantage of both individual and protective protection. The response to attack and injury usually is part of a structured response to the hazards and threats of the battlefield. Civil toxic release on the other hand usually is accidental and unforseen. The exception to this is the recent use of toxic agents by terrorists.[13] The hazards usually are from a HazMat system and can be identified from code numbers and databases of published information about the nature of the hazard and the special measures needed for decontamination. There usually are no fixed detection systems and signs and symptoms among the victims usually are the first indicators of attack. These may present with variable latency.

Civil exposure to toxic agents may be sudden or insidious, but there is a flexibility or response available that is not the case for the military. However, the degree of preparation and knowledge of the EMS personnel may be variable. The facts that the targets are ordinary civilians who are untrained and often uncontrolled (and unaware), may lead to panic that is out of proportion to the real dangers. It is important to realize that not all civil toxic releases necessarily will lead to mass injury, but the potential for transmission is significant, as was seen in the 1995 Tokyo sarin incident in which many hospital personnel became casualties.[13]

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- Planning and liaison with fire and other services
- Familiarity with HazMat procedures
- Training in use of protective equipment
- Recognition of hazards and the requirement for decontamination
- Ability to provide life support in the decontamination zone

Table 1—Stages in the EMS management of toxic release incidents (HazMat = hazardous materials)

Management of Toxic Release

Incident Management

The management of toxic trauma begins with the management of the incident, which is outlined in Table 1. This begins with planning and joint exercises with the other services that potentially will be involved. Usually, HazMat incidents are under the overall control of the fire services, but the police and civil defense organizations also are concerned. It is essential that EMS plan to work safely within the cordons and protection-decontamination procedures set up by the incident controller. Triage, to determine both the contamination and injury status is of vital importance to use the available resources to the best advantage.[9]

Given the dangers posed by transmissibility of toxic hazards, the key point for the medical responder is to avoid being the next casualty. In this respect, a toxic release incident is no different from others in the importance of establishing site safety and the use of protective ensembles and respirators, represent a special case of this concept. It also is important that the EMS responder is totally familiar with HazMat operating protocols and information sources, including the code systems that provide specific and general medical advice for the management of injuries from specific agents.[4]

Casualty Management

The emergency medical stages in the management of toxic trauma are shown in Table 2. These involve prehospital care, which may start inside the decontamination zone if the toxic injury is serious and the patient requires decontamination. Recently, protocols for the provision of life support inside the decontamination zone have been described and implemented in some HazMat emergency plans.[9] After leaving the decontamination zone, the next stage of the patient care will take place in the advanced medical post. Here, advanced life support measures will continue, and the early management of associated traumatic injuries also is possible. Further detailed assessment of the patient is possible bearing in mind that toxic trauma is determined in many cases by the latency of the causative agent and may be revealed or concealed. Constant monitoring of the airway, breathing, and circulatory status is essential. At the hospital level, toxic trauma will involve a further assessment of the clinical status and the provision of specific antidote therapy and supportive therapy. There still is a potential risk to attending medical personnel if the patient decontamination has not been complete, and hospital staff should be as aware as the prehospital responders of the risks from transmission of toxic hazards. Beyond the emergency room, patients may require longer term ventilatory, circulatory, and organ system support.

- Prehospital, within decontamination zone of HazMat cordons established by combined emergency response-advanced life support for toxic trauma (TOXALS)
- Advanced medical post management of revealed and concealed toxic trauma (latency determined)
- Hospital Management
  - Immediate, advanced life support and specific antidote and supportive therapy
  - Intensive care: longer term ventilatory, circulatory and organ system support

Table 2—Stages in casualty management following toxic trauma

Specific management of the patient is determined by the many sites of attack by toxic agents. These are the central and peripheral nervous systems including voluntary and autonomic systems, epithelial layers, the cardiac and circulatory and alimentary systems and, most important of all, the respiratory system. Here, there may be airway damage at all levels of the respiratory tree, failure of the breathing control and effector mechanisms and also of celluar respiration. The end results of these effects are airway blockage, increased airway resistance, decreased compliance (expandability) of the lungs, increased arteriovenous shunting, faliure of ventilation, hypoxaemia and hypercarbia, and finally secondary cadiac arrest.

Emergency Management of Toxic Respiratory Failure

Although toxic respiratory failure may be relatively rare and unfamiliar, there are direct parallels with more familiar conditions such as bronchial asthma and bronchiolitis, and there should be no reluctance to apply standard resuscitation concepts because of the special nature of the situation. Resuscitation must be based upon the essential ABCs of basic and advanced life. Until recently, the accepted view was that life support by EMS personnel only could begin after complete decontamination of the patient. However, this may lead to life-threatening delays in the provision of care. This approach now should be regarded as being unacceptable because of the potential delay in starting treatment for seriously injured persons. Advanced life support may be defined as the provision advanced life support in a contaminated zone by properly equipped and trained medical response personnel. Advanced life support may be conveniently summarized by an extension of the ABC system.

A: *Assessment and Airway*—Assessment must be of the environment and of the patient as a whole, remembering that traumatic injury may be present along with toxic, particularly if the release was accompanied by an explosion or fire. Before entry if possible, the nature of the hazard must be determined from the HazMat placards and other information. This must be done in conjunction with the fire and rescue services who will retain overall control of the HazMat incident. If reliable information is not available, a persistent, transmissible threat must be assumed. In this active threat situation, protected entry to the decontamination zone

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is mandatory and must be effected in conjunction with the site controller.

B: Breathing—This assessment relies on the rate, form, and depth. Because of the need for personal protection, normal ventilatory assessment by auscultation usually will not be available.

C: Circulatory Support—Including control of hemorrhage and management of dysrhythmias when appropriate.

D: Decontamination—Depending on the persistency of the toxic hazard which must be integrated with necessary life support measures.

Disability—From both toxic and traumatic causes assessed in a primary survey.

E: Evacuation—Initially, this will be to the decontamination zone surrounding the contaminated zone. Triage of the patients is required before entry to the decontamination zone. After decontamination is completed, transfer will be possible to the clean zone, and then, to hospital care.

Airway Management

With the EMS responders in protective suits, airway management will be more difficult than in conventional situations and it is important that training in all the major actions should take place in a non-toxic environment such as an anesthetic room to gain experience in working with gloves, suit, and respirator. Simple measures such as lateral positioning of the patient are vital in a contaminated zone, since vomiting is very likely. Good airway clearance through effective suction is vital, since secretions often are copious. The airway may be secured according to the skills of the responders, but intubation remains the desired measure for unconscious patients who will require ventilation.

Ventilation

Patients with toxic trauma who are in ventilatory failure require ventilation, starting as soon as possible in the decontamination zone. Different services have various approaches, but special difficulties arise since patients may have increased airway resistance and reduced lung compliance as a result of the toxic agent effects. Ventilation using a bag-valve device is not ideal and automatic, gas-powered ventilation is a better option. Ideally, this should be done using 100% oxygen, but cylinder life is limited and resupply may be difficult in the contaminated zone. Recently, an autonomous ventilator has been developed that uses filtered air as a diving gas; it is capable of providing extended periods of ventilation without a requirement for power or compressed gas.[14]

Pharmacological Support

Many specific and general antidotes exist for toxic agents which are listed in the HazMat protocols. These should be used in conjunction with continuing life support measures. Supportive drugs with actions on the airways include atropine, adrenergic bronchodilators, and systemic and inhaled steroids. Specific information about their use will be available from the guidelines, from central HazMat database centers operated in several countries or from poisons centers. Supportive drug therapy will be required in the chain of evacuation to a hospital emergency room and to an intensive care unit.

Following the initial care for toxic trauma, there is an important requirement for continuing care and observation, even if there is no apparent pathology. After inhalation of hazards causing pulmonary edema, such as phosgene, there is an established risk of developing acute pulmonary edema during the period up to 24 hours following exposure. This was well-recognized during World War I and is related directly to the amount of physical activity. Patients, therefore, ideally should be observed during a 24-hour period of bed rest following exposure. When complications arise, intensive care may be required with patients ventilated. Apart from pulmonary relapse, reparalysis may occur following organophosphate poisoning (the Intermediate Syndrome[16]) and ventilation again may be required for several days.

Conclusions

Civilian populations are at risk from exposure to toxic materials from a variety of causes which now include terrorism. Emergency medical services must adapt their HazMat plans and training to deal with the new threat.

There are many similarities between the treatment of casualties from CBW and HazMat agents. Each of these hazards is characterized by qualities of toxicity, latency of action, persistency, and transmissibility, which determine both the incident and medical responses. The relationship between mass injury and loss of life depends on the quality of the protection, organization, and emergency care provided.

It is important that emergency medical care should be given in the context of a specific action plan unified with other emergency services. The provision of advanced life support in the decontamination zone by protected and trained medical responders now is feasible technically and such life support measures should be integrated by EMS personnel into their triage and decontamination procedures.

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