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Chemical Disaster Preparedness for Hospitals and Emergency Departments

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ABSTRACT

Preparing to evaluate and treat victims of a chemical exposure incident is one aspect of hospital disaster preparedness. Past chemical disasters, including terrorist attacks and industrial or transit accidents, have highlighted the need for hospital planning, preparation, and training. Emergency department and hospital staff members must be familiar with their facility-specific protocols and be trained for their individual roles during these incidents. This article provides a brief review of the requirements and guidelines related to chemical disaster response from a healthcare perspective. Resources for training and the evaluation of chemically contaminated patients are discussed. Decontamination procedures, including pre-hospital and hospital-based decontamination of ambulatory, non-ambulatory, and at-risk patients are also reviewed. Physicians and clinicians, especially in the emergency department, must be familiar with methods of evaluating chemical exposures, identifying substances, recognizing toxidromes, ensuring appropriate personal protective equipment (PPE) use, performing decontamination, and initiating treatments for life-threatening conditions. By understanding the guidelines and resources available, clinicians will be better equipped to safely evaluate and treat chemically exposed or contaminated patients.

INTRODUCTION

During a disaster involving chemical exposures, hospitals will be called upon to care for victims. Emergency department (ED) and hospital staff need sufficient training to provide safe and effective care.¹ Several past chemical incidents have highlighted the need for hospital preparedness. In 1995, a large-scale chemical disaster occurred in Tokyo, Japan, involving the intentional release of sarin gas (an organophosphate nerve agent) in several city subway stations. As a result of that terrorist attack, over 5,500 victims sought medical attention, including approximately 500 patients arriving within the first hour at one hospital. Overall, 12 people died, 111 had moderate to severe injuries, and 110 health care workers were secondarily exposed and developed mild symptoms.^{2,3} This disaster highlighted the importance of preparing hospitals for chemical attacks and exposures. Aside from terrorism, more common causes of chemical disasters are industrial and transit incidents involving toxic industrial chemicals (TICs).¹ A 2005 train derailment in Graniteville, South Carolina, caused the rupture of a chlorine-containing tank car, releasing nearly 60 tons of chlorine gas. As the dense chlorine gas cloud spread out close to the ground, hundreds of people were affected: 597 patients were seen at emergency departments and clinics, 71 were hospitalized, and nine people died as a result of the chlorine exposure.⁴ In 2012, a train derailment in Paulsboro, New Jersey caused the leakage of 20,000 gallons of vinyl chloride into a creek. Within a few hours, 77 patients were seen in the nearby emergency department and six patients were admitted.⁵ These events, and many others, have illustrated the importance of hospital preparedness for chemical-related disasters.

PLANNING AND RESPONSE RESOURCES

In recent years, the United States federal government has sponsored and released several guidelines and resources to assist in the response to a chemical disaster. In 2005, the Occupational Safety and Health Administration (OSHA) released a comprehensive guideline for hospital-based first-receivers of victims from incidents involving hazardous substances.¹ This document outlined OSHA's guidelines for personal protective equipment (PPE), training, monitoring, response, and recovery related to these incidents. In 2018, the Primary Response Incident Scene Management (PRISM) series was updated, providing evidence-based guidelines on mass decontamination during a chemical incident.^{6,7} Additional clinical resources include the Chemical Hazards Emergency Medical Management (CHEMM) website and the Wireless Information System for Emergency Responders (WISER) website and smartphone applications. These electronic resources can be used in the clinical environment to help identify a chemical substance and guide the decontamination and initial treatments. Poison Control Centers (1-800-222-1222) also serve as valuable resources in providing guidance and elicit the expertise of a medical toxicologist to help identify chemical classes, recognize toxidromes, and assist with triage needs.¹⁰ Useful resources include:

- **WISER application (www.wiser.nlm.nih.gov):** Developed by the U.S. National Library of Medicine, WISER provides a wealth of information on hazardous materials, substance identification, decontamination, and health information designed for clinicians and first responders, free of charge. WISER also directly links to the CHEMM resources (CHEMM) and the Emergency Response Guidebook (ERG) used by first responders to identify and manage the initial phase of a chemical release.⁹

- **CHEMM website (www.chemm.nlm.nih.gov):** Sponsored by the U.S. Department of Health and Human Services, CHEMM includes guidelines for clinicians regarding the initial response, triage, decontamination, assessment, and treatment of chemically exposed patients. The website also directly links to two clinical decision tools for substance identification and decontamination. The PRISM Algorithm Suggesting Proportionate Incident Response Engagement (ASPIRE) tool assists in determining decontamination needs of exposed patients. The CHEMM Intelligent Syndromes Tool (CHEMM-IST) can potentially assist in the identification of a toxidrome or chemical substance group for severe cases of exposure to an unknown chemical.⁸

These guidelines and resources can assist hospitals in preparing for chemical disasters. Hospitals must also work with local and state emergency management and public health officials to coordinate preparedness and response efforts.^{1,5} Pre-planning for a large scale response should involve emergency medical service and fire department first-responders as well.¹ Chemical risks present in the local community, such as industrial sites or transportation routes, should be assessed in the hospital's hazard vulnerability analysis (HVA).¹ The HVA can help to identify local risks before an incident occurs, but cannot assess for every possible emergency situation. Thus, it is important for hospitals to develop chemical-disaster response guidelines as a part of the hospital's emergency operations plan (EOP) and ensure adequate training of staff members.¹

TRAINING

Health care workers should be trained to effectively evaluate and treat chemically-exposed patients. Many hospitals maintain a decontamination team or utilize an agreement with a local hazardous materials (HAZMAT) response team to provide decontamination of chemically-contaminated patients.^{1,11} OSHA's Hazardous Waste Operations and Emergency Response (HAZWOPER) regulation (29 CFR 1910.120) sets standards for the training of emergency personnel.¹² OSHA later released guidelines for hospital-based "first receivers" of contaminated patients.¹ The training level for first receivers depends upon the expected role of each individual and their likelihood of encountering contaminated patients.¹ Staff members who would be expected to work in the hospital decontamination zone are required to be initially trained to at least the "First Responder Operations" level, which includes a minimum training of eight hours and includes hazard recognition, substance identification, site safety, response roles, PPE use, and decontamination procedures, plus an annual refresher.^{1,12} The annual refresher must be "of sufficient content and duration to maintain their competencies, or shall demonstrate competency in those areas at least yearly" but a specific duration for the refresher training has not been established.^{1,12}

The hospital or employer may use existing course(s) or develop their own training to fulfill the eight-hour initial training requirement.¹ Alternatively, employees demonstrating competency in these specific training areas may waive the training requirement; however, the training or competency levels must be certified by the hospital or employer.¹ For employees who work

in the contaminant-free area but whom may be in the position to identify a contaminated patient (ED clinicians or triage staff), training to the OSHA level of "First Responder Awareness" is recommended.^{1,12} For support personnel that would otherwise be unlikely to encounter a contaminated patient, a "just in time" briefing is required if their assistance is unexpectedly needed in the hospital decontamination zone.¹ There are many resources for the training of health care workers. These include:

- **Center for Domestic Preparedness (CDP):** Organized under the Federal Emergency Management Agency (FEMA) and based in Anniston, Alabama, the CDP offers several courses, including an online HAZMAT awareness course and in-person courses such as CBRNE (chemical, biological, radiological, nuclear, and explosive) training, Hospital Emergency Response Training (HERT), and a train-the-trainer course which qualifies graduates to teach an eight hour course at their home institution. Courses through the CDP are typically free of charge, especially for local and state responders.¹³
- **Texas A&M Engineering Extension Service (TEEX):** Offers a free online 4-hour "WMD/Terrorism Awareness for Emergency Responders" course designed to meet OSHA's "First Responder Awareness Level" standards for hazardous materials and weapons of mass destruction (WMD).¹⁴
- **Advanced HAZMAT Life Support (AHLS):** Affiliated with the American Academy of Clinical Toxicology, the fee-based AHLS course focuses on the clinical care of chemical exposures for physicians and clinicians caring for these patients.¹⁵
- **American College of Medical Toxicology:** Offers several resources including a "Chemical Agents of Opportunity for Terrorism" course and free "Chemical Agents of Opportunity" webinar.¹⁶
- **U.S. Army Medical Research Institute of Chemical Defense:** Conducts a six-day "Medical Management of Chemical and Biological Casualties Course" geared to evaluating, triaging, and treating contaminated casualties.¹⁷
- Various other government and private organizations provide free and fee-based HAZWOPER or hazardous materials courses for decontamination team members.

EVALUATION

When initially evaluating a chemically-contaminated patient, it is vitally important that the health care worker remains safe and does not contaminate him/herself.^{1,11,18} Although the type of chemical substance is often known at industrial facilities, or can be identified by labeling placards in transportation incidents, in many circumstances the substance released may be unknown.^{1,19} In these cases, clinicians should maintain a safe distance, use appropriate PPE (discussed in the "decontamination" section below), and attempt to determine the route of exposure and symptoms the patient is experiencing.^{1,19,20} The following steps are recommended to evaluate victims of chemical exposures (see Figure 1):

• **Identify a Chemical Release:** Initially, responders and victims may be unaware of a chemical release or exposure. Several signs of a mass casualty chemical exposure include similar physical symptoms, in several individuals, in a corresponding time frame (for example, eye irritation, nausea, difficulty breathing, weakness, confusion, burning sensation, etc.). Other indicators include environmental signs such as mass casualties of humans, wildlife, or insects in a delineated area, or discolored vegetation, coatings on surfaces, unusual odors, puddles, powders, or low-lying gas plumes. Having a high index of suspicion improves the rapidity of response to mitigate the health effects of a chemical release.²¹

• **Identify Substance (if possible):** Chemicals at industrial site and transportation incidents are typically marked to allow for the identification of involved material(s).¹⁹ In these settings, a Material Safety Data Sheet (MSDS or, more recently, referred to as “SDS”) should also accompany the material and can help guide the patient’s initial care.¹¹ It is important to ask pre-hospital or industrial site responders for the material’s SDS. If an SDS is unavailable, obtaining the United Nations (UN) four-digit identification number or Chemical Abstract Service (CAS) number can identify a substance and assist in determining appropriate care of the exposed patient.^{9,22,23} The WISER application and Emergency Response Guidebook (ERG) or NIOSH Pocket Guide can assist in the identification of a substance by UN or CAS number.^{9,23,24} It is important to note that many products consist of several chemical substances in combination and each substance should be identified. Manufacturers may be hesitant to reveal the specific chemical identity of a proprietary or “trade secret” product; however, according to OSHA, the specific identity must be disclosed “to a treating physician or nurse when the information is needed for proper emergency or first-aid treatment.”²⁵

• **Unknown Substance:** If the type of substance is not known, the clinician can gather information and obtain greater situational awareness by using signs, symptoms, and observations from the field to help determine the type of chemical or chemical group. The route of exposure (inhalation, dermal, ingestion), type of exposure (vapor, liquid, powder), duration, and location (home, industrial facility, farm, retail store) should be determined from the patient and first responders. Physical signs and symptoms can provide important information to assist in the identification of a chemical group or toxic syndrome (toxidrome).^{20-22,26}

• **Toxidromes:** It is recommended that “toxidrome recognition” be used to further assist in the identification of chemical classes to which patients may have been exposed. Toxidrome recognition utilizes the constellation of clinical signs (vital signs, mental status, respiratory, skin findings) and symptoms that are characteristic of general classes of chemical substances.^{26,27} Chemical groups with similar properties often produce similar clinical effects that help identify a toxidrome.^{26,27} Learning to recognize toxidromes is an important skill, especially in a mass

casualty event, to execute an effective and timely response. Examples of toxidromes associated with chemical exposures include “irritant/corrosive” (cough, wheezing, and skin/mucous membrane irritation or inflammation from corrosive acids/bases), “anticholinergic” (dilated pupils, confusion, dryness with reduced sweating, temperature elevation), “cholinergic” (salivation, lacrimation, urination, “leaking all over”), “anesthetic/sedative” (decreased level of consciousness, respiratory depression), “convulsant” (seizure-producing), “knockdown” agents (asphyxia, decreased level of consciousness, cardiorespiratory effects), and “blister agents/vesicants” (dermal burns, mucosal and dermal irritation, pain, upper and lower airway effects).^{11,26-30} This list is not all-inclusive, but provides a general idea of the concept of chemical toxidromes.

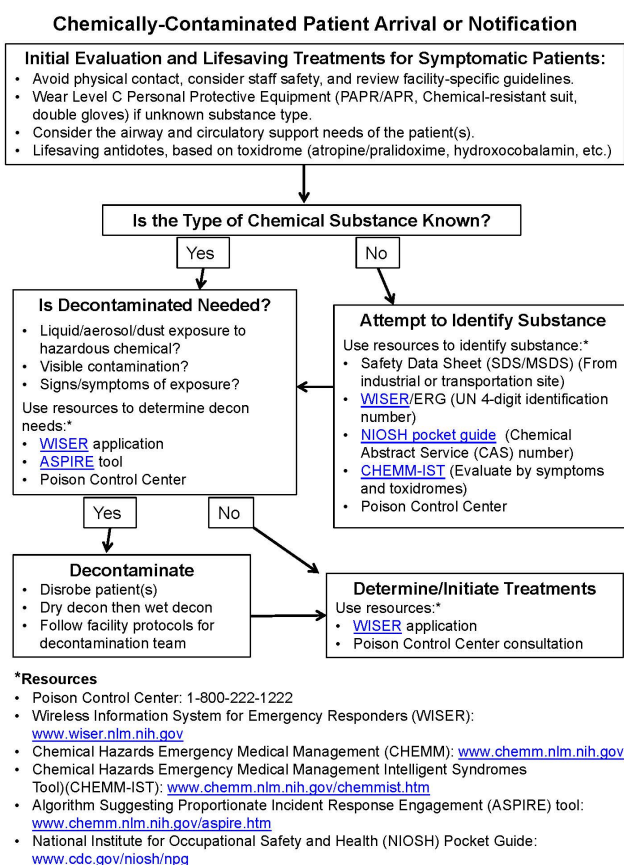


Figure 1. Chemically-Contaminated Patient Arrival or Notification

DECONTAMINATION

After considering the circumstances of the exposure and the involved substance or chemical group/toxidrome, the need for decontamination (“decon”) must be determined. Although research-based recommendations of when to perform decontamination are limited, guidelines exist to help make this determination. The decision to decontaminate should take into account patients’ signs, symptoms, and evidence of visible exposure or contamination, proximity of the patient(s) to the chemical release, and the properties of the specific chemical (if known).^{6,7,11,18} Additionally, decontamination should be considered if the patient requests it or if there is any reasonable risk of exposure to first responders or first receivers.¹⁹

Decontamination is typically started on the scene of a controlled incident; however, patients from uncontrolled or mass-exposure incidents may leave the scene and self-transport to the hospital ED. Hospitals must be prepared to receive and decontaminate these potentially contaminated patients.^{1,6,30} Figure 2 shows the typical structure of a hospital decontamination corridor.



Figure 2. Hospital Decontamination Zone. In a mass-casualty chemical incident, a decontamination corridor is often used to rapidly clean and move patients through the hospital decontamination zone. Photo by Gregory Wanner, at Hospital Emergency Response Training in Anniston, AL.

Regarding personal protective equipment (PPE), hazardous materials responders at the scene (“hot zone”) of an unknown type of chemical release are often outfitted in Level A (fully encapsulating suit with self-contained breathing apparatus [SCBA]) or Level B (chemical resistant suit with SCBA) equipment.^{11,31-33} This high level of respiratory protection, however, is not necessary for hospital-based first-receivers working in the potentially contaminated “hospital decontamination zone” away from the site of a release.^{1,11} A time lapse of at least 10 minutes between a patient’s exposure and hospital arrival allows for “substantial levels of gases and vapors from volatile substances to dissipate.”^{1,18} For this reason, Level C PPE, consisting of an air-purifying respirator (APR) or powered air-purifying respirator (PAPR) with appropriate filter cartridge, and a chemical-resistant suit with two layers of chemical resistant gloves, are recommended for first-receivers in a hospital decontamination zone (see Figure 3). Level D PPE (work uniform and everyday PPE) may be used for non-hazardous “nuisance” contamination or in handling clean patients after decontamination in the uncontaminated “post-decontamination zone.”^{1,11,31-33}

Current decontamination procedure recommendations involve the following steps (see Figure 1):

- **Disrobe:** Patients should be instructed to remove all potentially contaminated clothing. This should occur either by carefully cutting or unbuttoning and gently pulling clothing downward, avoiding contact with the face and hair.⁶ If clothing cannot be moved down and removed from the feet and no cutting instrument is available, patients should carefully guide the garment over their head, avoiding contact with the face, while holding their breath and eyes closed. Traditionally, it has been claimed that clothing removal from a fully clothed person reduces contamination by 80

to 90 percent; however, the source of this claim is unclear. More recent estimates suggest that clothing removal reduces contamination by at least 50 to 70 percent, depending on the location of contaminant on the body and type/amount of clothing worn.⁶ In addition to removing liquid or powder/dust, removing clothing can also decrease exposure to vapors trapped within clothing or off-gassing of volatile liquids (such as gasoline).^{6,34}

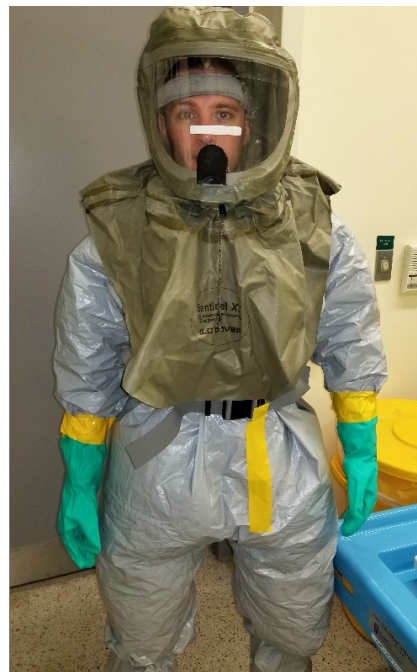


Figure 3: Level C PPE for Hospital Decontamination Team. Level C PPE includes a powered air-purifying respirator (PAPR), chemical-resistant suit, and double gloves secured with chemical-resistant tape. Pictured is Dr. Nicholas Colazzo, emergency medicine resident physician, Christiana Care Health System. Photo by Gregory Wanner.

- **Dry Decontamination:** Once clothing is removed, dry decontamination can be performed as an initial emergency decontamination method with any available absorbent material. Patients can self-perform this by blotting then carefully rubbing to avoid abrading the skin. This should start with the face and hair and work downward. Dry decontamination can be started immediately and can effectively begin to remove contaminant.^{6,35} It can also be performed while setting up equipment for wet decontamination, if indicated.⁶
- **Wet Decontamination:** Involves using water and soap to remove caustic or harmful chemicals. Wet decontamination will likely be needed for exposures to a harmful liquid, aerosol, powder, or dust, but is less often needed for exposure to vapor or gas.^{11,18} The decision to perform wet decontamination depends upon the signs/symptoms and properties of the chemical involved.^{11,19} The potential for adverse effects, such as hypothermia, should also be considered.^{6,19,33} Water-reactive chemicals can produce harmful effects (such as toxic or flammable gas) or a violent reaction when mixed with water.^{11,19} Although rare, the

involvement of water-reactive chemicals should be considered and identified using the WISER application or ERG.^{9,24} If the chemical substance can be identified, the ASPIRE tool can be used to help determine the need for wet decontamination.³⁶ Poison control centers can also provide valuable guidance regarding decontamination needs.

Wet decontamination typically involves two steps. The first step, “gross decontamination” is often performed at the exposure scene, unless the patient transports him/herself to the hospital prior to decontamination.⁶ Gross decontamination may involve use of a safety shower at an industrial site or laboratory, or the fire department may set up a high flow, low pressure water mist often called a “ladder pipe system.”^{6,19} In mass-casualty chemical incidents, gross decontamination is sometimes termed “mass decontamination.”⁶

Following gross decontamination, a more thorough washing should occur.^{6,11,18} This second step is often referred to as “secondary,” “clinical,” or “technical” decontamination (note that some references call this step “technical” decontamination, while others use the term “technical” decontamination when referring to decontamination of staff and equipment; we will use the term “secondary” decontamination when referring to this step).^{1,6,19} Secondary decontamination is supervised or assisted by trained decontamination team members. Washing is performed from head to toe using a washcloth, warm water, and mild soap (such as hand dishwashing detergent and/or baby shampoo).^{6,11,19,35} Recommendations for washing time range from two to five minutes; however, more recent research suggests that at least 15 seconds of gross decontamination followed by a washing/rinsing period of 90 seconds may be adequate.^{1,6,18,35}

The washing period should be followed by active drying with a towel or absorbent material.⁶

- **Triple Protocol:** A recent study tested the three-stage combination of:
 1. Disrobing and dry decontamination
 2. Ladder pipe system irrigation for 15 seconds
 3. Secondary/technical decontamination washing for 90 seconds with a washcloth and baby shampoo, after intentional contamination with methyl salicylate mixed with baby oil.

The study found this “triple protocol” removed 100 percent (SD+/-1%) of chemical contamination. In contrast, dry decontamination alone removed 70 percent (SD+/-38%) of contaminant (highly dependent upon the cooperation of victims), and secondary/technical decontamination alone removed 95 percent (SD+/-9%) of contaminant.³⁵

- **Non-Ambulatory and At-Risk or Special Needs Casualties:** Planning for decontamination procedures must also consider non-ambulatory patients, children, and patients with difficulty communicating or cognitive/physical disabilities.^{6,19,33} These patients may require additional time and assistance with decontamination procedures.^{6,19,35} Children should be kept with their families, if possible, who can assist with decontamination.^{6,11,19} Patients who are non-ambulatory may

need to be carried on a stretcher by decontamination zone staff. Patients with language barriers or hearing difficulty may be assisted by pictorial instructions, body language gestures, or interpreters, if available.^{6,19}

TREATMENT

An initial assessment of airway, breathing, and circulation is paramount in managing patients with chemical exposures.^{11,26} In a mass casualty incident, this initial “primary survey” assessment typically occurs rapidly along with the performance of triage. It is during the primary survey and triage of the patient that life-saving interventions should be considered, such as opening the airway, hemorrhage control, or chest needle-decompression of a tension pneumothorax.^{11,37} One triage method, the “Sort, Assess, Lifesaving interventions, Treatment/Transport” (SALT) Mass Casualty Triage Algorithm, specifically includes these life-saving interventions along with the use of an antidote by auto-injector if a cholinergic toxidrome is observed.³⁷ The importance of quality supportive care should not be understated. Removal of the patient from the area of exposure and decontamination (if indicated) are vitally important steps.^{26,27}

After the initial assessment with appropriate life-saving stabilizing interventions, a more comprehensive “secondary survey” should be performed to determine whether signs of a toxidrome are present and to administer antidotes, if indicated.^{20,26,27} The use of resources mentioned in the “Planning and Response Resources” section of this article and discussion with the Poison Control Center are recommended. While the full spectrum of treatments available in a chemical disaster is beyond the scope of this article, a brief review of time-sensitive treatments for a few toxidromes include the following:

- **Cholinergic:** For organophosphates or nerve agent exposures, the patient must be removed from the environment, decontaminated, and started on supportive treatment and antidotes. For the “leaking all over” effects of cholinergic agents, atropine is given in high doses. Pralidoxime is also used to prevent the irreversible inhibition of acetylcholinesterase (called “aging”) in cases related to organophosphates. A commercially available auto-injector combines 2 mg of atropine with 600 mg of pralidoxime. The initial administration of up to three auto-injectors is recommended for adults, depending on severity of symptoms. Diazepam (10 mg) auto-injectors may also be needed to control seizures.^{20,26,27} Instructions for auto-injector use are available from the National Institutes of Health (NIH).³⁸
- **Irritant/Corrosive:** Treatments related to the chemical irritant or acid/base are dependent upon the symptoms and the water-solubility of the chemical. Evacuation from the exposure, decontamination, oxygen, and nebulized bronchodilators may be needed. Water soluble chemicals (such as ammonia or chlorine) typically cause immediate symptoms, while relatively insoluble irritant chemicals (such as phosgene) can cause delayed symptoms, such as pulmonary edema.^{20,26}
- **Asphyxiant or “knockdown” agents:** These agents include various chemicals which can displace oxygen (such as

carbon dioxide, helium, propane, methane or nitrogen) or cause systemic effects (such as cyanide, carbon monoxide, or hydrogen sulfide). Removing the patient from the environment and providing 100% oxygen are most important. Agent-specific treatments should be considered, based on the situation. For example, a patient being transported from a house fire with respiratory distress, coma, or cardiac arrest could have carbon monoxide and/or cyanide toxicity. If cyanide poisoning is suspected, treatment with hydroxocobalamin should be started immediately in life-threatening cases, before laboratory results are available.^{20,26,27}

Response and treatment are part of the overall community effort. It is important for hospitals to coordinate with their local EMS, law enforcement, fire departments, and emergency management agencies. Coordination between each of these groups is necessary to ensure stockpiled supplies and antidotes can be quickly distributed to an initial wave of patients.^{19,26} Communities must also understand when to ask for state or federally available resources. Federally available resources include the Strategic National Stockpile for various medications and the CHEMPACK program for nerve agent antidotes. These resources can be quickly mobilized during a chemical disaster to augment local supplies.^{26,39,40}

CONCLUSION

Chemical disasters do occur and hospitals must be ready. An effective hospital response starts with preparation. Previously mentioned resources, in addition to guidelines and checklists such as those available through OSHA, PRISM, and Massachusetts General Hospital's Decontamination Resources, can help prepare hospitals and emergency departments.^{1,6,41} Fortunately, chemical attacks are rare; however, many toxic industrial chemicals are commonly used, stored, and transported throughout the community each day. Understanding the concepts of chemical substance identification, toxidrome recognition, PPE, and decontamination procedures is important in managing chemically exposed or contaminated patients. Physicians and clinicians must have the training and be familiar with the resources available to safely evaluate and treat victims of a chemical exposure incident.

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