

Chapter 46

ANESTHESIA FOLLOWING CHEMICAL, BIOLOGICAL, RADIOLOGICAL, AND NUCLEAR EXPOSURE

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INTRODUCTION

In the current global political climate, the possibility of a chemical, biological, radiological, or nuclear (CBRN) incident in combination with a mass casualty situation cannot be ignored. Although unsophisticated groups may attempt a chemical, biological, or radiological attack, the nuclear option is likely only available to nation states. The probability of a nuclear incident is significantly lower than a chemical, biological, or radiological event, but the potential impact of any CBRN attack would be catastrophic. Recent natural disasters throughout the world, such as the devastating earthquake and subsequent cholera epidemic in Haiti in 2010 and the earthquake-induced tsunami in Japan in 2011 (which resulted in a radioactive zone bigger than that left by the 1945 bombings of Nagasaki and Hiroshima) demonstrate how sudden and debilitating a CBRN event can be. Emergency preparedness and planning for CBRN threats is imperative in any community.

Chemical, biological, and radiological events are

difficult to recognize and are completely transformative incidents. Traditional chemical weapons are rare, but toxic industrial chemicals (TICs) contribute myriad compounds during combustion and other reactions. Many of the treatments for exposure are supportive, but misdiagnosing a toxidrome for which an antidote exists is a serious shortcoming. Biological and radiological releases are rarely recognized at the scene without adequate background intelligence or detectors and only become apparent as illness progresses.

This chapter aims to provide practical guidance and reassurance to critical care specialists faced with casualties exposed to CBRN events, including TIC exposures. It is likely that intoxication and trauma will combine to worsen the prognosis. However, with careful forethought and preparation, deviating from damage-control resuscitation for poisoned patients should be unnecessary, and trauma surgery can be performed in concert with chemical resuscitation.

INCIDENT MANAGEMENT AND EMERGENCY RESPONSE

Incident Management

When faced with the prospect of multiple poisoned casualties, individual safety must be a priority before attention is turned to the scene and the injured. In the United Kingdom, incidents are managed using the standard major incident medical management and support approach, with minor differences (Figure 46-1). Initial priorities include establishing safety, cordons, command, and communication. Command and control personnel, when possible, should don personal protective equipment (PPE) and be located upwind and uphill from the incident. In the United States, disaster management occurs on three distinct levels or tiers: (1) federal, (2) state, and (3) local responses. In most instances, the local community establishes initial and lasting response authority and sets up the incident command center through an incident commander, often a fire chief. The incident commander is responsible for directing and controlling resources. Prior planning in the predisaster period is crucial to preventing widespread panic and a deteriorating mass casualty situation.

Recognizing Chemical, Biological, Radiological, and Nuclear Incidents

In the absence of local intelligence or obvious environmental clues, recognizing that an incident has

a CBRN aspect may be difficult, depending on the agent. Scene assessment precedes clinical assessment, and surveyors should pay attention to unusual smoke, smell, liquids, or patterns of dead animals, including insects. The diagnosis of nerve-agent exposure in Tokyo, Japan, in 1995 was made by clinicians noticing that many of the patients in cardiac arrest had miosis, a situation encountered the year before in the Matsumoto sarin attack.¹ The "Safety Triggers for Emergency Personnel 1-2-3" approach is used by many emergency services to aid recognition. For example, a single patient with symptoms indicating CBRN exposure is likely explained by disease processes other than CBRN exposure, but the arrival of three or more patients with similar suspicious symptoms should alert providers to a CBRN attack. A blast in a confined space is likely to produce some incomplete combustion products that may be harmless in low exposure but could trigger PPE use in the presence of simple detection methods (Exhibit 46-1).²

The London bombings of July 7, 2005, demonstrated the uncertainties of a terrorist attack at multiple sites.³ Initial scene and casualty assessment did not suggest a chemical or radiological hazard. Dust masks would have provided adequate protection from a low-level radiological dispersal device.⁴ Radiological detectors are unlikely to be distributed in similar mass-casualty situations. Additionally, excessive dust rarely prompts unsuspecting troops to protect them-

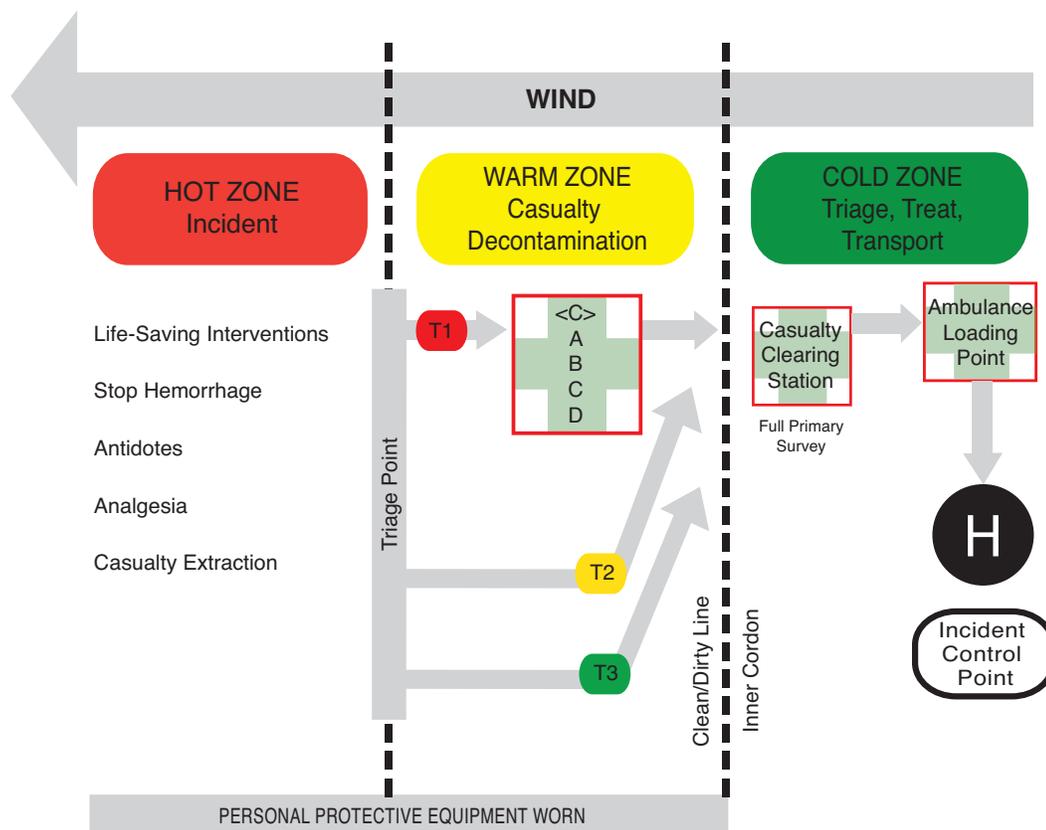


Figure 46-1. Medical hazardous materials site plan. Note the attention to wind direction in assisting decontamination. Care in the “hot zone” is limited to life-saving interventions, including antidotes as dictated by the clinical situation. For tier 1 (T1), serious casualties, decontamination does not detract from the primary assessment and treatment of catastrophic hemorrhage, airway, breathing, circulation, and disability (<C> ABCD). Tier 2 (T2) refers to urgent cases; tier 3 (T3) to delayed case. H: hospital

selves adequately. Given modern weaponry, people worldwide must maintain a high index of suspicion for a CBRN event.

“Quick Look”

“Quick Look” is a rapid method of assessing intoxicated and injured casualties. It is based on the brisk evaluation of a casualty with minimal exposure, to recognize classic toxidromes (Table 46-1).⁵

Personal Protective Equipment

Casualties may be treated within a civilian or field hospital or by an emergency response team at an incident scene. The incident commander should advise medical staff of the type of incident and the appropriate PPE; however, this may not be known at the time, and the correct PPE may not be readily available. Issued respirators will not protect against many TICs and pro-

vide no protection from carbon monoxide inhalation. The US Centers for Disease Control and Prevention classifies PPE into four levels (A–D):

- A: self-contained breathing apparatus and gas-tight outer suit.
- B: self-contained breathing apparatus and splash-proof outer suit.
- C: particulate and chemical respiratory filter; this includes the UK military CBRN PPE suit and National Health Service hazardous materials suit.
- D: standard precautions and high-specification particulate filter mask.⁶

Tracheal intubation and potential exposure to bodily fluids and airborne infection dictate that, when possible, minimum PPE should include full-length gown, face mask (high-specification particulate filter mask if airborne infection is expected), eye protection, and

EXHIBIT 46-1

INITIAL INVESTIGATIONS FOR CASUALTIES SEVERELY AFFECTED BY A CHEMICAL, BIOLOGICAL, RADIOLOGICAL, OR NUCLEAR INCIDENT

Conduct the following initial investigations for critical-care patients exposed to chemical agents, where available. Calculation of anion gap may aid diagnosis.

Urea and Electrolytes

- Arterial blood gas analysis with glucose and lactate
- Calcium/phosphate/magnesium
- Liver function
- Amylase/creatinine kinase

Full Blood Count

- Store admission blood sample for later specialist analysis.
- Consider clotting studies/group and hold

Urinalysis

- Store admission urine sample for later specialist analysis

Electrocardiogram

Chest Radiograph

single, disposable gloves (level D). If a chemical incident is suspected, a chemical-resistant coverall with integral hood, respirator, chemically resistant boots, and gloves should be worn. If a casualty is not fully decontaminated from a radiological incident, level D standard precautions with double gloves will suffice.⁷ In an active CBRN environment, all responders should be wearing individual protection equipment (Figure 46-2). Standard-issue individual protection equipment for UK military includes a CBRN respirator, clothing containing reinforced nylon with charcoal-impregnated felt, butyl rubber gloves, and boot coverings, leaving no skin exposed (level C). For chemical incidents in the field, medical personnel should wear level C PPE with surgical gloves instead of butyl and change them every 10 to 15 minutes.⁸

US CBRN respirators come in several models, including the M9, M17, and M40 series. The UK S10 respirator filter canisters provide good protection against particles greater than 0.3 μm .⁹ Military respirators generally provide a level of N95/high-specification particulate filter mask particulate protection (Bland SA, surgeon commander, Royal Navy; personal communication, October 2011). Radiologically contaminated casualties do not generally pose a danger to healthcare workers and first responders; the rare exception to this is when a highly radioactive piece of shrapnel is embedded in a patient presenting for treatment.

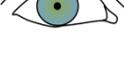
Decontamination

Decontamination after exposure to a CBRN hazard is intended to remove or destroy the contaminant and reduce the risk of harm to the patient, healthcare professionals, and others. Decontamination was the first action before treatment, but this doctrine has recently changed⁸ and decontamination is now incorporated into a modified triage and treatment protocol, meaning syndrome recognition and antidote administration take precedence. The most common antidote, which can be administered to oneself or by a buddy, is the nerve agent ComboPen (produced by the UK Ministry of Defence), which contains 2 mg atropine, 500 mg pralidoxime, and 10 mg avizafone (diazepam equivalent 5 mg). Life-saving interventions (LSIs), including tourniquet application for catastrophic hemorrhage, airway maneuvers, and antidotes via the intraosseous (IO) route, can occur in the “hot,” or contaminated, zone before formal decontamination occurs (see Figure 46-1).^{8,10}

Decontamination may simply involve clothing removal and increased air circulation around the casualty to remove gases and vapors. Physical removal of persistent contaminants should begin as soon as possible by washing with high-flow water with or without detergent.¹¹ Casualties affected by gases such as hydrogen cyanide or vapor of high volatility do not require decontamination. Destruction of the contami-

TABLE 46-1

"QUICK LOOK" CHART: EFFECTS OF MAJOR CHEMICAL AGENTS AND RELATED SUBSTANCES*

Agent	Symptoms and Signs					
	Consciousness Level	Respiration Rate	Eyes	Skin	Secretions	Other/Notes
Carbon monoxide	Confusion, headache	↑↑	Normal 	Pink	Normal	None
Cyanides	LOC, seizures	↑↑ then ↓	Normal or pupils dilated 	Pink, then cyanotic	Normal	Sudden onset of symptoms
Lung-damaging agents	Agitation	↑↑	Normal or red 	Normal, then cyanotic	Pink frothy sputum	None
Vesicants, acids, alkalis	Normal	Normal or ↑	Normal or red 	Red (delayed)	Normal or ↑	With mustard gas, symptoms and signs may be delayed
Nerve agent	Seizures	↑ then ↓	Pinpoint pupils 	Sweaty	↑↑	Fasciculation, bronchospasm
Botulinum	Normal	↓	Dilated pupils 	Dry	↓	Descending paralysis
Opioids	↓	↓↓	Pinpoint pupils 	Normal	Normal	Increased tidal volume
Atropine	Confusion, agitation	↑	Dilated pupils 	Dry	↓↓	None
Methemoglobin	Agitation	↑	Normal 	Cyanotic	Normal	"Chocolate blood," SpO ₂ : 89%

*Clinicians should be alert to the possibility of a combination of agents and coexistence of trauma. Confusion may be the result of head injury, and a pneumothorax could mimic severe bronchospasm.

↑: increased

↑↑: significantly increased

↓: decreased

↓↓: significantly decreased

LOC: loss of consciousness; SpO₂: oxygen saturation in blood

Data source: Bland SA. Chemical, biological and radiation casualties: critical care considerations. *J R Army Med Corps.* 2009;155:122–174.



Figure 46-2. Chemical, biological, radiological, and nuclear personal or individual protective equipment (Level C) will protect you, the casualty, and your colleagues only if selected, worn, and discarded correctly. Hand hygiene and sharps disposal discipline are paramount. Reproduced with permission from: United Kingdom Ministry of Defence; ©UK MOD Crown Copyright 2011.

nant using chemical deactivation through hydrolysis, oxidation, or active decontamination specific to the agent is a secondary goal. In the case of radioactive contamination, LSIs should always be instigated before decontamination.

All casualties should ideally be decontaminated at the scene before transfer to the emergency department (ED) or next-level medical facility; however, in a civilian scenario, some contaminated casualties may self-present to the ED, increasing the risk to other patients and staff. In this scenario, the fire service or ED staff may have to decontaminate patients at the ED.¹¹ In the 1995 Tokyo subway sarin attack, 20 physicians were exposed to the 3,227 patients who were treated at local hospitals. Although many of these physicians experienced varying signs and symptoms of nerve

agent exposure (dim vision, miosis, rhinorrhea, and dyspnea), including six who actually received atropine, none was forced to abandon patient-care responsibilities. Recent studies conducted in the United States suggest that hospitals are not prepared for a biological or chemical event in an urban area, including the resultant mass decontamination and medical response.¹² In the UK civilian environment, the Ambulance Service and the Fire and Rescue Service carry out emergency decontamination of the injured.¹³ All clothing and foreign bodies (eg, jewelry, hearing aids, and contact lenses) are removed and the casualty is rinsed with warm soapy water, wiped, then rinsed again without heavy abrasion of skin or extremities.⁷

UK forces use Fuller's earth, a highly adsorbent, clay-like powder consisting of hydrated aluminum silicates, and US forces use the M291 carbonaceous resin kit. Both powders are highly adsorbent to chemical agents present on clothes, respirators, and skin, and aid personal decontamination in the field.¹⁴ In 2009, the United States replaced the M291 with Reactive Skin Decontamination Lotion (First Line Technology, LLC, Chantilly, VA) to decontaminate skin but not wounds or eyes. Reactive Skin Decontamination Lotion is a mixture of potassium 2,3-butanedione monoximate and free oxime.¹⁵ For both biological and chemical agents, UK and US forces fully decontaminate casualties by washing exposed areas with dilute warm sodium hypochlorite solution (0.5%), pH 10 to 11, for 10 to 15 minutes and removing and containing contaminated clothing.⁹ Sodium hypochlorite is not to be used in eye, exposed brain, spinal cord, or abdominal injuries.¹⁴

Abdominal and thoracic cavity wounds should be washed out with saline; however, doing so may be hazardous if there is a chemical agent present. Irrigation fluid should be sucked out with a large-bore suction apparatus and disposed of in a hypochlorite solution.¹⁴ Vesicant (blistering agent) decontamination requires water and saline (0.9%) or sodium bicarbonate (1.26%), if available, for the eyes and mucous membranes.¹⁵

Triage and Hot-Zone Treatment

Triage during a CBRN event involves not only prioritizing patient treatment based on the condition severity but also factoring in responder safety. This makes an already stressful and difficult process resource dependent. Peacetime civilian exercises indicate casualty decontamination time is currently unacceptable.¹⁰ Life-saving first aid, akin to care under fire, can be administered during extraction⁸ to save time. The time involved in decontamination may cause casualties to self-select; those able to evacuate the hot zone

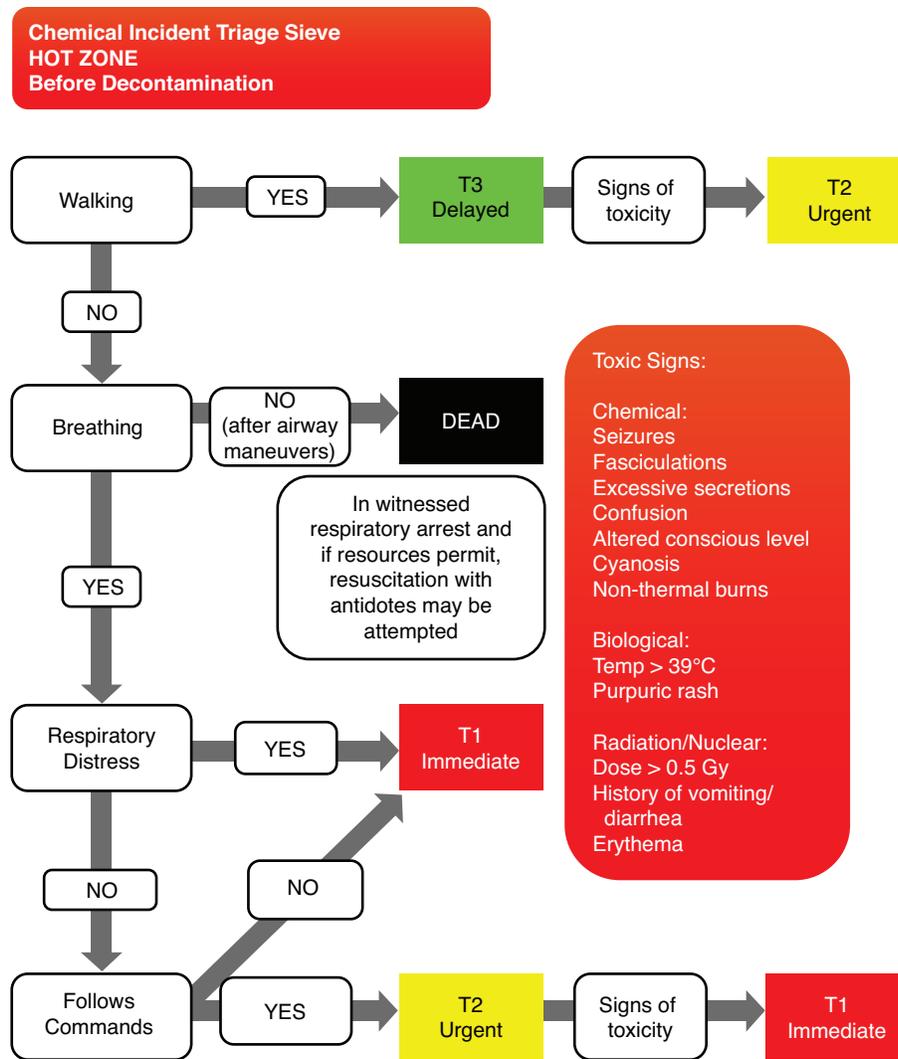


Figure 46-3. Chemical incident triage flowchart, hot zone before decontamination. Extraction to avoid further intoxication is a logical priority; when casualties are numerous, clinical input in the hot zone is useful. While casualties await extraction, the early administration of antidotes and other life-saving interventions may enhance survival. Toxidrome recognition can lead to identification and early supply of possible antidotes from the supply chain. Determining deaths promptly will reduce waste of limited resources.

Data source: UK Ministry of Defence. *Clinical Guidelines for Operations*. London, England: MOD; 2 Feb 2011. Joint Doctrine Publication 4-03.1.

are likely to profit from medical intervention more than those with a combination of trauma and intoxication, who are likely to face a poor prognosis. Despite this grim reality, a small subset of patients requires immediate, life-saving medical treatment prior to decontamination.

Prehospital trauma care still follows the <C>ABCD (catastrophic hemorrhage, airway, breathing, circulation, disability) paradigm, with the addition of antidotes, LSIs, and analgesia where appropriate in the hot zone. LSIs include rolling casualties on their sides or

fronts to improve airway patency and tourniquet application. While casualties await evacuation from the hot zone, rapid triage may be performed (Figure 46-3).

Casualty decontamination begins in the “warm” zone (see Figure 46-1). Further LSIs are applied to tier 1 (immediate) casualties at this stage, then casualties are passed over the clean-dirty line and out of the inner cordon to the “cold” zone. Tier 2 (urgent) cases are given antidotes, if available, and decontaminated; tier 3 (delayed) cases are decontaminated and transferred to the cold zone without intervention unless they

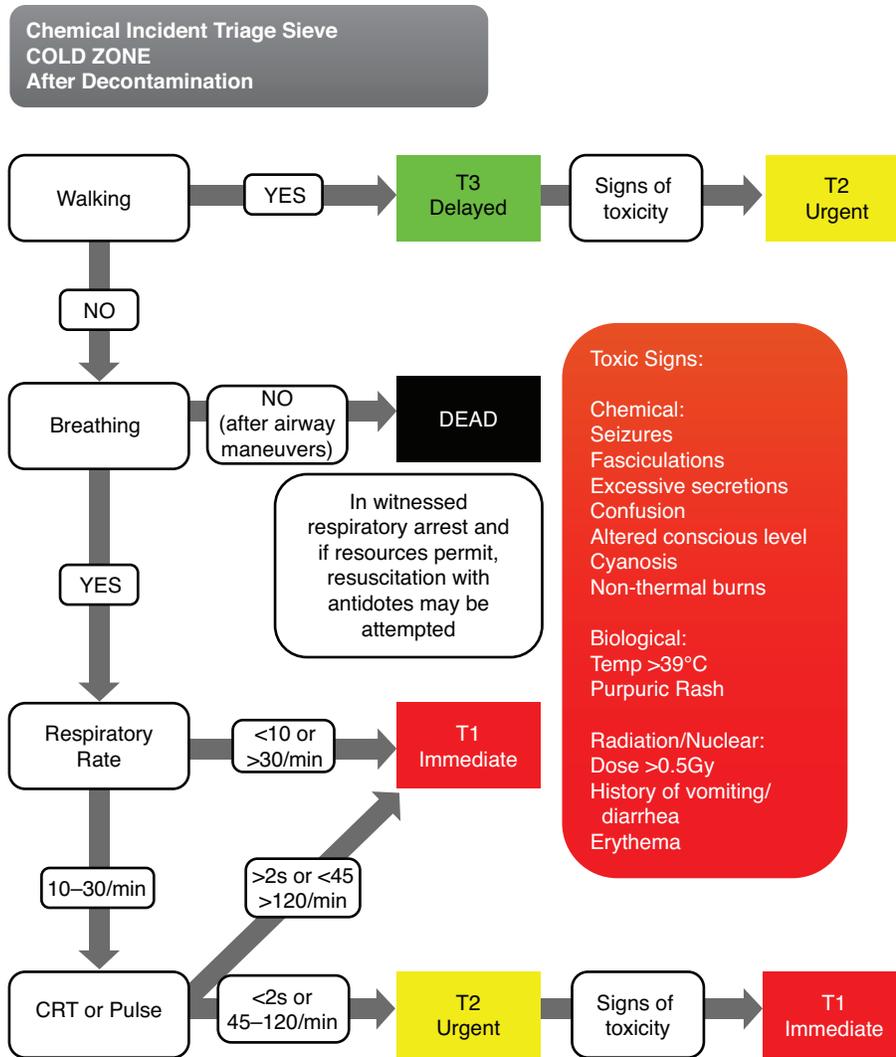


Figure 46-4. Chemical incident triage flowchart, cold zone after decontamination. After decontamination, casualties can be triaged more accurately in the cold zone. If, at any time, a casualty develops signs of toxicity, their triage category becomes a higher priority.

Data source: UK Ministry of Defence. *Clinical Guidelines for Operations*. London, England: MOD; 2 Feb 2011. Joint Doctrine Publication 4-03.1.

deteriorate. Once in the cold zone, triage is repeated and a formal primary survey is performed (Figure 46-4). In conjunction with chemical countermeasures,

problems found during the primary survey are treated if imperative for survival to the next echelon of medical care.

AIRWAY ISSUES

Airway Devices

Assessing airway patency in an unconscious casualty while wearing CBRN PPE is difficult, but can be accomplished by placing a surgical glove with one finger cut off over the primary speech module of a UK military respirator (Figure 46-5). This allows assess-

ment of airway patency and respiratory rate, success of airway maneuvers, and ability to triage effectively while avoiding contamination.¹⁶

Laryngeal mask airway (LMA) insertion by anesthesiologists dressed in CBRN PPE is prolonged but possible,¹⁷ but tracheal intubation with an endotracheal tube carries an increased risk of failed intuba-



Figure 46-5. A glove with one finger removed and placed over the primary speech module can act as a marker for breathing. A valve ensures that gas flows through the primary speech module in one direction only, from the wearer to the atmosphere; therefore, it is a safe and effective means of showing apnea or inspiration (a) or exhalation (b). Photographs courtesy of E Hulse.

tion.¹⁸ Failed intubation rates are also increased when intubating the casualty on the ground rather than a trolley or litter while wearing CBRN PPE.¹⁹ This can be overcome by using the LMA, but casualties with bronchospasm and increased airway secretions will be more prone to aspiration, laryngospasm, and high ventilating airway pressures, making the LMA undesirable. The LMA should be considered a rescue adjunct for casualty evacuation to a more permissive environment. The potential difficulty in securing an airway within a CBRN environment may suggest a role for video-assisted intubation devices, but this is probably unrealistic given the large footprint, financial costs, and limited field durability of these devices.

Chemical Casualties

Nerve agents, cyanides, pulmonary agents, vesicants, burns, vomiting, and riot-control agents can all adversely affect the airway.

Nerve Agents

Sarin, tabun, soman, and methylphosphonothioic acid can be absorbed via many routes, depending on their physical properties, and act swiftly by irreversibly inhibiting the acetylcholinesterase enzyme within the body. This leads to excessive acetylcholine levels at both muscarinic and nicotinic receptors, resulting in cholinergic toxidrome (Figure 46-6).² Clinically, excessive acetylcholine levels cause excessive miosis, salivation, rhinorrhea, and bronchoconstriction

with copious bronchial secretions, which may make tracheal intubation impossible before atropine administration.¹

Central cholinergic effects can depress levels of consciousness and the respiratory center, with nicotinic effects causing muscle paralysis and convulsions. Death is from respiratory failure due to airway obstruction by secretions, bronchospasm, paralysis of the respiratory

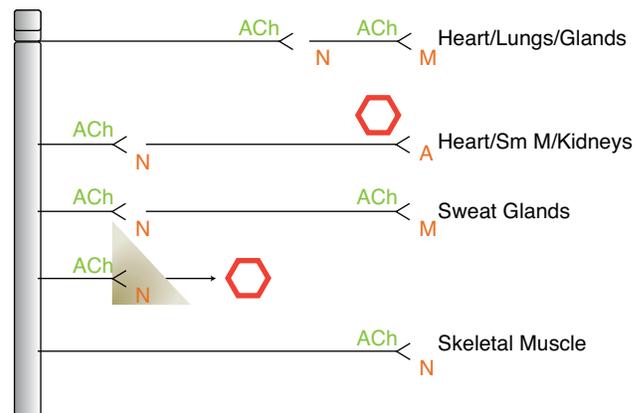


Figure 46-6. Acetylcholine use by the autonomic nervous system and neuromuscular junction. The parasympathetic effects at the top show pre- and postganglionic fibers stimulated by acetylcholine at nicotinic and muscarinic receptors. Shorter preganglionic sympathetic fibers use acetylcholine to stimulate nicotinic receptors. The postganglionic sympathetic fibers release catecholamines (red hexagons) acting visceraally and hormonally from the adrenal gland (brown triangle). The sympathetic control of sweat glands is mediated by acetylcholine acting on muscarinic receptors.

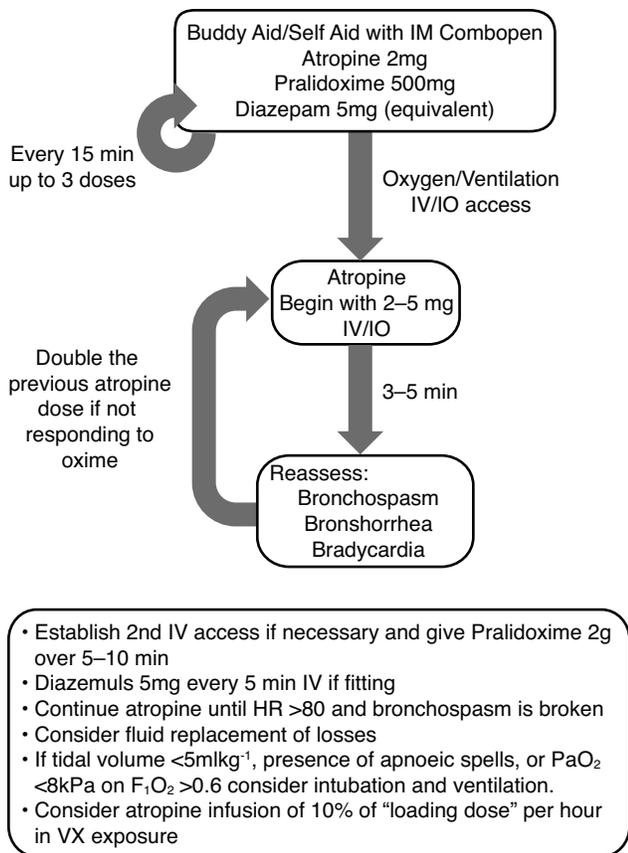


Figure 46-7. Nerve agent treatment algorithm. Atropine dose may need to be doubled in patients who do not respond to oxime. When continued absorption is anticipated, an atropine infusion may be employed. If suxamethonium is used, its action will be greatly prolonged.

Data sources: (1) Eddleston M, Buckley NA, Eyer P, Dawson AH. Management of acute organophosphorus pesticide poisoning. *Lancet*. 2008;371:597-607. (2) Bland SA, surgeon commander, Royal Navy; personal communication, 2010.

muscles, and central respiration depression (Figure 46-7).^{20,21}

Vesicants (Blister Agents)

Mustard agents, Lewisite (arsenical), and phosgene oxime can burn and blister the eyes, mucous membranes, lungs, and skin. Onset can be delayed by hours for mustard agents, which can irritate and congest the mucous membranes in the nasal cavity, throat, and trachea. Symptoms include rhinorrhea, burning in throat, hoarseness of voice, and dyspnea. Mustard agents can damage the vocal cords. Additionally, airway secretions and necrotic tissue may obstruct the bronchial tree. Respiratory complications occur in more than 70% of mustard victims (Exhibit 46-2).²²

EXHIBIT 46-2

TREATMENT AIMS: VESICANTS

- Laryngitis and tracheitis can be treated with humidified oxygen
- Mustard injuries should be treated as thermal burns and can cause bone-marrow suppression and carcinogenesis. Fluid resuscitation is less aggressive than that for thermal burns. Aim for urine output > 0.5 mL/kg/h
- Severe exposure results in pulmonary hemorrhage and edema with respiratory failure requiring intubation and ventilation
- Early antibiotic treatment of suspected bronchopneumonia

Severe pulmonary edema can occur with Lewisite and is treated with intramuscular dimercaprol, 10% British anti-Lewisite 3 mg/kg four times daily, or the oral chelating agent dimercaptosuccinic acid 30 mg/kg/day.

Data sources: (1) Bland SA. Chemical, biological and radiation casualties: critical care considerations. *J R Army Med Corps*. 2009;155:122-174. (2) UK Ministry of Defence. *Clinical Guidelines for Operations*. London, England: MOD; 2 Feb 2011. Joint Doctrine Publication 4-03.03.1.

EXHIBIT 46-3

TREATMENT AIMS: PULMONARY AGENTS

- Emergency treatment of laryngospasm may be required, including rapid sequence induction or application of continuous positive airway pressure.
- Bronchodilators and nebulized steroids for bronchospasm may be beneficial.
- Oxygen, intubation, and ventilation with sufficient positive end-expiratory pressure may be required in moderate to severe cases of pulmonary edema. It is logical to limit the fraction of inspired oxygen only to maintain adequate partial pressure of arterial oxygen.
- Observation of asymptomatic exposed individuals for 24 hours is mandatory.
- There is limited in-vitro evidence for nebulized N-acetylcysteine.

Pulmonary Agents (Choking Agents)

Phosgene, chlorine, oxides of nitrogen, and per-fluoroisobutene can cause pronounced irritation of the upper and lower airways. Irritation of the larynx by high concentrations of agent may cause laryngeal spasm and death. More commonly, it causes acute lung injury and pulmonary edema. Airway secretions and pulmonary edema can be severe in phosgene toxicity and are sometimes delayed up to 24 hours, suggesting

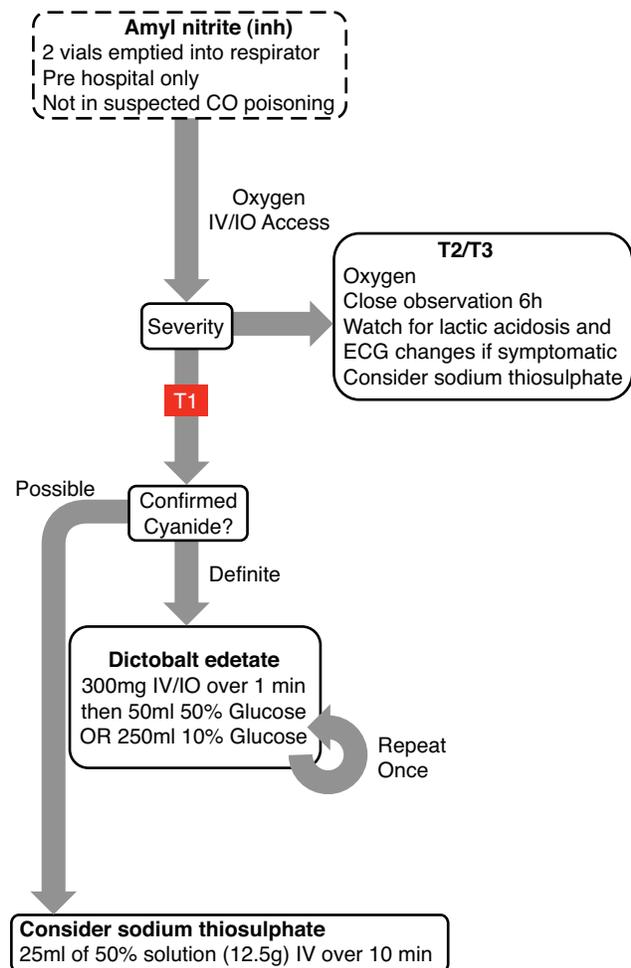


Figure 46-8. Management of cyanide poisoning. Diagnosis is dependent upon an index of suspicion in the absence of a confirmed release. Severe cases will demonstrate a raised central venous oxygen saturation and hyperlactatemia. Oxygen is the mainstay of treatment, with supplementation of sulphur donors with sodium thiosulphate. Sodium nitrite can be considered, inducing a methemoglobinemia to preferentially bind cyanide, but may not be appropriate if oxygen-carrying capacity is to be preserved. Give 10 mL of 3% sodium nitrite solution (300 mg) intravenously over 5 to 20 minutes once only with sodium thiosulphate.

EXHIBIT 46-4

TREATMENT AIMS: BURN AND INHALATIONAL INJURIES

- Senior anesthetologist should intubate patient early, especially in the presence of stridor or hoarseness.
- In a conscious patient, consider an inhalational induction (this may be painful with a mask on raw tissue).
- Ensure surgical tracheostomy is immediately available if tracheal intubation via laryngoscopy fails.
- If using suxamethonium, use during the first 24 hours to avoid severe hyperkalemia.
- Leave the endotracheal tube uncut to provide room for facial-tissue swelling.
- Consider securing the tube with wire to the upper teeth, or be prepared to adjust tube ties in proportion to swelling (which may be rapid).
- Bronchodilators and a protective ventilatory strategy with good bronchial hygiene will be useful.
- Aim for an adequate urine output (0.5 mL/kg/h) using the Parkland formula (amount of fluid required in 24 hours [ml] = 4 × patient's weight [kg] × body surface area burned [%]).
- Hydrofluoric acid burns can cause hypotension and arrhythmias due to hypocalcemia. Treat with topical calcium gluconate gel and intravenous calcium chloride.
- Early enteral feeding for catabolic state is essential.

some inflammatory mechanism and possible pathology related to acute respiratory distress syndrome (ARDS; Exhibit 46-3).

Riot Control Agents

Mace (2-chlorobenzalmalononitrile [CS] or 2-chloro-1-phenylethanone [CN]) is commonly used by law-enforcement agencies for riot control and training. CS and CN are solids dispersed as fine particles or in solution exerting their alkylating effect by inhibiting enzymes and increasing bradykinin release.²³ They are irritants affecting mainly the eyes, nose, mouth, airways, and skin. Airway burning and irritation cause coughing, bronchorrhea, and dyspnea, and should cease within 15 to 30 minutes once removed from the source. If the casualty has preexisting lung disease, such as asthma

or chronic obstructive pulmonary disease, bronchospasm and respiratory distress may be triggered by riot-control agents. CN can cause burns and tracheo-bronchitis and form laryngeal pseudomembranes. CN has also been associated with some deaths; it is not used in the United Kingdom but is permitted in the United States.²⁴

Cyanides

Cyanides exist in many forms, including smoke from fires. They are also used extensively in industry. Electron-transport-chain poisoning, specifically of cytochrome c, results in tissue hypoxia and lactic acidosis from forced anaerobic metabolism, which can cause nausea, agitation, hyperventilation, confusion, loss of consciousness, seizures, coma, respiratory arrest, and death (Figure 46-8).

Airway Burns

Airway burns represent a huge spectrum of illness, depending on duration of exposure and the concentration, composition, and temperature of the smoke. House fires may generate toxic chemicals such as carbon monoxide, hydrogen cyanide, inorganic acids, and nitrogen oxides, which have lung-damaging properties. Obvious burns or carbonaceous deposits around the mouth and nose and singed nasal and eyebrow hairs with dyspnea, cough, and wheeze should alert a provider to a possible airway problem. Hoarseness or stridor may indicate impending airway obstruction and require urgent assessment and intervention by a senior anesthesiologist (Exhibit 46-4).

Biological Casualties

Recognizing the characteristically nonspecific clinical features of a biological casualty is both difficult and critical. Therefore, a high index of suspicion must be maintained and steps should be taken to protect medical personnel and first responders physically, chemically, and immunologically. Physical protection takes the form of PPE and protective masks, whereas chemical protection against bacterial agents (eg, brucellosis, plague, tularaemia, and Q fever) comes from antibiotics either before or after exposure. Immunologic protection, typically immunization, helps protect against biological agents such as anthrax and smallpox. This heightened awareness and active protection enables healthcare workers to immediately provide potentially life-saving airway maneuvers prior to decontamination and definitive diagnosis.

Radiological Casualties

Airway management is rarely necessary, even in the most severely exposed radiological casualty. Instead, the medical management of acute radiation sickness focuses dose-dependently on the hematopoietic, gastrointestinal, neurovascular, and integumentary systems. With severe blast injury following a nuclear incident, airway issues, such as pneumothorax and pulmonary failure secondary to barotrauma, may require airway intervention. Additionally, although patients exposed to higher doses of radiation may be triaged into an expectant category, they will likely experience increased episodes of nausea and vomiting, which may impact a provider's decision on how and when to secure the patient's airway.

BREATHING ISSUES

All chemical warfare agents, biological agents, and TICs have a direct or indirect effect on the respiratory system. Radiological casualties rarely exhibit breathing difficulties. Lung injury manifests diversely, with compounds exhibiting effects at different times and sites within the bronchial tree. Preoxygenation and uptake of volatile anesthetic agents is likely to be adversely affected. Currently there are no specific therapies for toxic lung injury, and supportive care remains the cornerstone. Protective lung ventilation strategies may limit further damage; however, in carbon monoxide poisoning, a high fraction of inspired oxygen (FiO_2) should be maintained. Carboxyhemoglobin has a half-life dependent on FiO_2 ; therefore, severely poisoned patients should breathe an FiO_2 of 1.0 for 5 half lives, or 3.5 hours,² before titrating to partial pressure of arterial oxygen.

Direct-Acting Agents

Pulmonary agents such as phosgene and chlorine; biological agents such as staphylococcal enterotoxin type B, plague, tularemia, and inhalational anthrax; and some TICs fall into the category of direct-acting agents. Vesicants such as mustard predominantly affect the upper airway, but in higher or more prolonged exposures can cause lung damage. Phosgene and mustard have delayed effects on the lungs, and a 24-hour period of observation is mandatory for casualties with mild symptoms and a history of exposure. Chlorine may also exhibit delayed effects. Deterioration during anesthesia is a possibility that anesthesiologists must rapidly diagnose and treat. Many direct-acting agents are oxidizing and proinflammatory, prompting studies of antioxidant and

antiinflammatory compounds. There is in-vitro and small-animal-model evidence to suggest that N-acetylcysteine may be effective as oral prophylaxis or in nebulized form following mustard exposure, but less so in phosgene exposure. N-acetylcysteine has also been used topically. The effectiveness of moderate-dose intravenous (IV) steroids is still debated and, when combined with immunosuppression from mustard, may not be appropriate; however, the early use of steroids may have a role in phosgene exposure.²⁵ There is little evidence for steroid use in chlorine exposure²⁶; however, nebulized bronchodilators are recommended for bronchospasm following chlorine exposure. Treatment for exposure to aerosolized staphylococcal enterotoxin type B is primarily supportive and consists of humidified oxygen and steroids. Treatment for direct-acting toxins is escalated from supplementary oxygen to maintain saturation of peripheral oxygen above 94% through noninvasive, continuous positive airway pressure, to invasive ventilation as dictated by the patient's condition. Phosgene and chlorine injured patients should be ventilated using the National Heart, Lung, and Blood Institute's ARDS Network protocol²⁷ to prevent progression to ARDS. Oxygen toxicity from continued free-radical cycling is minimized by increasing positive end expiratory pressure rather than FiO₂. Large-animal studies of phosgene demonstrate an increased mortality from immediate oxygen therapy and benefit from delay until symptomatic; however, no oxygen therapy carried a higher mortality.²⁵ Tidal volumes should be limited to 6 mL/kg ideal bodyweight.^{25,27}

Inhalation injury is rare because the airway has efficient heat exchange mechanisms, so attention should be directed to the management of airway burn. (see

Exhibit 46-4). A protective ventilatory strategy (ARDS Network protocol²⁷) should be adopted and other measures considered, such as nebulized bronchodilators, N-acetylcysteine, heparin, and bronchoscopic lavage with 1.26% sodium bicarbonate.²

Indirect-Acting Agents

Certain incapacitants have opioid- or benzodiazepine-like effects and, in sufficient doses, may result in respiratory failure, but ventilation is usually the most effective treatment until consciousness is regained.

Nerve agents cause bronchoconstriction, bronchorrhea, and ventilatory failure. Bronchoconstriction may be so severe that ventilation is unachievable without an antidote (see Figure 46-7) and tracheal intubation may not be possible because of secretion volume. Atropinization takes priority when resuscitating nerve-agent casualties; once achieved, bag-valve mask ventilation becomes considerably easier. Although there has been concern that atropine given to hypoxemic patients may precipitate tachyarrhythmias, there is no evidence to deny its use in cases of organophosphorus pesticide poisoning.²¹ Atropine is titrated until a desired effect on bronchorrhea, bronchospasm, and bradycardia is achieved. After adequate dosing, ventilation is significantly easier and tracheal intubation may be possible. Capnography and airway-pressure monitoring will allow close titration of atropine infusion to effect, especially if supplies are limited. Oximes will reduce the atropine requirement and can be given as a bolus or as an infusion (see Figure 46-7). An infusion is indicated in cases where continued absorption occurs, (eg, dermal absorption of methylphosphonothioic acid, which continues after decontamination).

CIRCULATION ISSUES

Types of Access

Initial treatment of nerve-agent exposure involves self or buddy administration of an intramuscular ComboPen. This may be sufficient in the short term, but casualties with compromised circulation due to trauma or chemical poisoning will ultimately require timely vascular access. In these patients, IO devices may be life saving in the field.

A study using a manikin model found that when medical operators and casualties were dressed in CBRN PPE, they inserted the IO device EZ-IO (Vidacare Corporation, San Antonio, TX) more quickly than trying to obtain peripheral IV access.²⁸ The casualty may be in CBRN PPE when vascular access is required. After limited decontamination and exposure in the

hot zone, access to the sternum may permit use of the sternal IO device FAST1 (First Access for Shock & Trauma, Pyng Medical Corporation, Vancouver, British Columbia; Figure 46-9). A study using advanced patient simulators and the Bone Injection Gun (BIG, Waismed Ltd, Migdal Tefen, Israel), a spring-driven, trigger-operated, IO injection device, enabled nerve-agent antidotes to be administered within 3.5 min. This technique has an insertion success rate of 89% by physicians wearing full CBRN PPE.²⁹

Chemical Casualties

Nerve Agents

Nerve-agent casualties can show an early transient

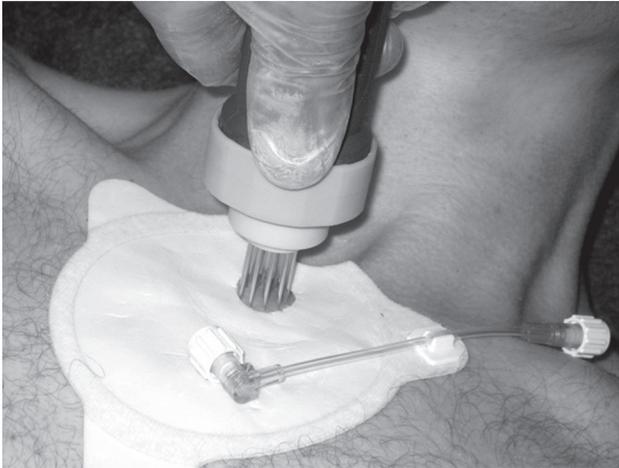


Figure 46-9. Insertion of FAST 1 (First Access for Shock & Trauma, Pynq Medical Corporation, Vancouver, British Columbia) intraosseus, sternal access.

Photograph reproduced with permission from: [trauma.org; http://www.trauma.org/images/image_library/11181942171FAST_RSI_photo.JPG](http://www.trauma.org/images/image_library/11181942171FAST_RSI_photo.JPG)

tachycardia or hypertension through stimulation of the adrenal medulla, followed by muscarinic-induced bradycardia and hypotension, which may abolish the compensatory mechanisms necessary to combat hypovolemia. Intense parasympathetic activity may also mask awareness during anesthesia. Other arrhythmias, QT prolongation, and decreased cardiac ventricular contraction occur in severe poisoning.³⁰ Raised serum creatine kinase was observed in cases from the sarin release in Matsumoto, Japan, in 1994 and is likely due to prolonged muscle contraction.³¹ Nerve agents typically require IV fluids to expand circulation, offsetting loss from secretions and atropine to increase heart rate. Inotropes are occasionally required alongside clonidine and magnesium to control cholinergic symptoms (see Figure 46-7).³⁰

Chemical Burns

Chemical burns may not need such an aggressive fluid-management strategy as thermal burns, and maintenance of an adequate urine output (0.5–1 mL/kg/h) is an acceptable indicator of fluid levels.⁵ Hydrofluoric acid burns can cause intense pain, liquefactive necrosis, hypotension, and fatal arrhythmias due to hypocalcemia, hyperkalemia, and hypomagnesemia. For cutaneous exposure, treatment is frequent application

of topical 10% calcium gluconate gel, which may be followed by local infiltration of 10% calcium gluconate until the pain has settled; local and regional anesthesia should be avoided because of this significant clinical endpoint. Calcium and magnesium are aggressively replaced to maintain levels within the normal range, empirically before results are known and especially if symptomatic.³² An intraarterial infusion, proximal to the burn, of 10 mL 10% calcium gluconate diluted in 40 mL glucose or saline over 4 to 5 hours may be required for severe peripheral burns.³² Calcium chloride is only given IV because it will otherwise cause tissue necrosis.

Atropine Overdose

Over-atropinization may be observed after inadvertent treatment with the military-issue ComboPen, which is self-administered intramuscularly by military personnel during nerve-agent poisoning scenarios. In the absence of nerve-agent poisoning, the ComboPen would produce antimuscarinic toxicity with the typical features of mydriasis, tachycardia, thirst, absence of sweating, hyperthermia, and confusion. Supportive treatment should suffice and may include the use of benzodiazepines.

Biological Casualties

Victims of biological attacks typically present with nonspecific clinical features, which can be extremely difficult to diagnose and treat. Intravascular volume depletion should be anticipated in the setting of many biological agents, such as those that often present clinically as pneumonia (plague, tularemia, and staphylococcal enterotoxin B), or those that present with febrile illness (Q-fever, Venezuelan equine encephalitis, or brucellosis).

Radiological Casualties

Victims of severe radiation events with acute radiation sickness can exhibit significant circulatory compromise or collapse. Within hours after an event, early symptoms may include severe nausea, vomiting, and watery diarrhea. Severe diarrhea and vomiting may progress clinically to shock, renal failure, and, ultimately, cardiovascular collapse. Other predictable circulatory issues observed in these patients include malabsorption of nutrients, significant fluid and electrolyte shifts, gastrointestinal bleeding, and sepsis.

NEUROLOGICAL ISSUES

Many agents act on the nervous system, resulting in airway, breathing, and circulation issues. Agents that

act on the central nervous system include cyanide, opioids, carbon monoxide, and novel incapacitants.

Those that act on the peripheral nervous system include nerve agents, botulinum toxin, and other neurotoxins. The management of each varies in complexity; incapacitants and other novel agents may require airway attention and administration of benzodiazepines for agitation, but nerve-agent poisoning is a multisystem disease.

Carbon Monoxide

Carbon monoxide poisoning usually presents with nonspecific symptoms and signs after inhalation of incomplete combustion products (eg, house fires or poorly maintained heaters or burners). The following are important points to remember about carbon monoxide poisoning:

- Respirators do not filter carbon monoxide.
- Measured carboxyhemoglobin does not cor-

relate with poisoning severity.

- Smokers will have carboxyhemoglobin concentration up to 10%.
- Do not induce methemoglobinemia if concomitant cyanide poisoning is suspected.

Carbon monoxide poisoning is a common cause of death from poisoning in the United Kingdom and can present with neurological signs in severe cases. Injury to watershed areas of the brain, such as basal ganglia, is possible, as is myocardial injury.² The mechanisms are complex and involve extreme left shift of the oxy-hemoglobin dissociation curve.

Unconscious patients should be maintained on a high FiO₂ (see Breathing Issues in Chemical, Biological, Radiological, and Nuclear Exposure). Attention to raised intracranial pressure must include head-up tilt, maintenance of normotension and normocapnia, care with tracheal tube ties, and regular pupil assessment.²

EXHIBIT 46-5

NEUROMUSCULAR EFFECTS OF NERVE AGENTS

After exposure to nerve agents, parasympathetic activity predominates to the extent that tachycardia is unusual, and hypovolemia should be excluded first. The effects on the autonomic nervous system will abolish the compensatory response to hypovolemia and mask a fixed dilated pupil in head injury. Multiple factors combine to cause death from respiratory failure.

Different types of effects are as follows:

Central Nervous System (Nicotinic and Muscarinic Effects)

- Confusion
- Agitation
- Coma
- Respiratory failure

Autonomic Nervous System

- Parasympathetic Nervous System (Muscarinic Effects)
 - Bradycardia, hypotension
 - Bronchospasm, bronchorrhea
 - Salivation, vomiting, diarrhea
 - Miosis, lacrimation, urination
- Sympathetic Nervous System (Nicotinic Effects)
 - Tachycardia, hypertension
 - Sweating
 - Mydriasis

Neuromuscular Junction (Nicotinic Effects)

- Muscle weakness
- Paralysis
- Respiratory failure
- Fasciculation

Data source: Eddleston M, Buckley NA, Eyer P, Dawson AH. Management of acute organophosphorus pesticide poisoning. *Lancet*. 2008;371:597-607.

Nerve Agents

Nerve agents have central and peripheral effects secondary to overwhelming acetylcholine concentrations after inhibition of acetylcholinesterase (Exhibit 46-5). The peripheral nicotinic effects are fasciculation, which may be mistaken for seizures, followed by paralysis. The muscarinic effects are eased by atropine.

The peripheral nicotinic effects are managed supportively until function returns; magnesium and clonidine may decrease presynaptic acetylcholine release.³⁰ The central effects of seizures are more common in nerve-agent poisoning than in their agricultural organophosphorus cousins and should be managed aggressively with benzodiazepines (see Figure 46-7).

Biological Agents

Numerous biological agents evoke neurologic symptomatology. Inhalational anthrax can present as hemorrhagic meningitis with a dramatically widened mediastinum on chest radiograph. Initial presenting signs and symptoms of inhaled botulinum include progressive ocular, pharyngeal, respiratory, and mus-

cular weakness and paralysis. Other biological agents with neurological symptoms include Ebola hemorrhagic fever, Crimean-Congo hemorrhagic fever, and Venezuelan equine encephalitis. Medical management includes isolation, antibiotics, and supportive care.

Radiation Exposure

Acute neurovascular syndrome, the third of the three subsyndromes (hematopoietic, gastrointestinal, and neurovascular) seen in acute radiation sickness, typically emerges when a victim has experienced extremely high external doses of ionizing radiation. Expected clinical symptoms include an immediate burning sensation, emesis, hyperpyrexia, prostration, hypotension, and neurologic signs (ataxia and delirium). Death is inevitable and frequently occurs within 48 hours. Another condition, early transient incapacitation, is characteristic of very high exposures to radiation that only occur during plutonium and enriched uranium fuel reprocessing accidents. Similar to acute neurovascular syndrome, early transient incapacitation portends a grim prognosis, including a deteriorating level of consciousness, vascular instability, and death.

DRUG INTERACTIONS, CONTRAINDICATIONS, AND HAZARDS

Nerve agents act on a number of different enzymes and receptors. Inhibition of butyrylcholinesterase results in prolonged action of drugs hydrolyzed by it, namely suxamethonium and mivacurium. Metabolism of remifentanyl and esmolol by other esterases is unaffected in butyrylcholinesterase deficiency³³; however, nerve agents affect many esterases and it is unclear whether the metabolism of these drugs would be prolonged.

The interaction between nerve agents and cholinesterases can be disrupted by oximes, which are used to reactivate affected enzyme. A process called “aging” affects the nerve agent bound to cholinesterase, whereby the interaction becomes stronger with time due to loss of a radical. Once aged, oximes are no longer effective. Aging is particularly rapid with soman, which has an aging half-life of 1.3 minutes.³⁴ To mitigate against this process, pyridostigmine is used as pretreatment, preventing the enzyme from binding to nerve agent and enhancing subsequent treatments (eg, ComboPen). After exposure, pyridostigmine is discontinued, unbound nerve agent undergoes spontaneous hydrolysis, and cholinesterase bound to pyr-

idostigmine dissociates. This unaffected cholinesterase may be sufficient to restore normal neuromuscular function due to redundancy in the mechanism.³⁵ Where absorption of nerve agent is likely to continue (eg, in cutaneous methylphosphonothioic acid exposure), oxime infusion should be maintained.

If suxamethonium is required for tracheal intubation, expect its action to be prolonged, and nondepolarizing muscle relaxants will require an increased dose in pyridostigmine pretreated casualties. There may even be a role for nondepolarizing muscle relaxants in shielding nicotinic receptors from acetylcholine in severe nerve-agent poisoning.³⁶ Anesthesia use for nerve-agent-poisoned casualties is limited; clinicians will need to judge neuromuscular function by the standard clinical indicators, including “train-of-four” count. Ultrasound-guided regional anesthesia must also be considered.^{2,36} The evidence base for drug interactions in toxicology stems from case reports, limited animal studies, and theoretical interpretations. Providers should be aware of pharmacological concerns when using antidotes and anesthetic agents in the presence of toxic injury (Exhibit 46-6).

EXHIBIT 46-6**COMMON ANESTHETIC DRUGS AND ANTIDOTES**

Listed below are some commonly used anesthetic drugs and antidotes, and some of their more important interactions and contraindications. Volatile anesthetic agents probably do not have serious interactions, although titration to an autonomic response in mild to moderate nerve agent poisoning may result in unintended intraoperative awareness.

Cyanide Antidotes

- **Amyl nitrite.** Used to oxidize hemoglobin to methemoglobin, generally used prehospital. Do not induce methemoglobinemia if carbon monoxide poisoning is suspected.
- **Dicobalt edentate.** Use only in confirmed cyanide exposure as a chelator. Administer 300 mg followed by 50 mL of 50% glucose or 250 mL of 10% glucose. Can cause anaphylactoid reaction with pulmonary edema in the absence of cyanide.
- **Sodium thiosulphate.** Use in moderate to severe poisoning. Administer 25 mL of 50% solution (12.5 g) over 10 min. Relatively free of side effects.
- **Alternatives**
 - Sodium nitrite can be used to induce methemoglobinemia in severe cyanide poisoning without carbon monoxide.
 - Cyanokit (hydroxycobalamin 5 g) can be considered if cyanide inhalation from combustion products is suspected.¹

Induction agents. Familiar induction agents are most suitable. In nerve agent poisoning, atropinization must be achieved prior to induction if anesthesia is required. It is not known whether ketamine will cause excess secretions and bronchodilation in this situation, or whether such effects are clinically relevant.

Methylene blue.² To reduce methemoglobin in compromised patients (> 30% methemoglobin), give 1–2 mg/kg over 5 min. Can be repeated after 30–60 min. If this treatment fails, consider ascorbic acid and exchange transfusion. Methylene blue should be avoided in patients with glucose-6-phosphate dehydrogenase deficiency.

Nondepolarizing muscle relaxants. May not be required in surgery for nerve-agent-poisoned casualties. Dose increase is required for nerve agent poisoning and in burns after 24 h.

Oximes. Used to reactivate cholinesterase. Do not delay atropine therapy. Give 2 g pralidoxime over 5–10 min.

Suxamethonium

- **Burns.** Use causes severe hyperkalemia >24 h postburn. Can be used acutely.
- **Nerve agent poisoning.** Suxamethonium's action is prolonged in patients with mild to moderate toxicity requiring surgery and possibly in pyridostigmine use. Not required for severe intoxication.

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SUMMARY

The addition of CBRN considerations to the care of trauma casualties completely transforms incident management. The high risk of secondary exposure for first responders must be balanced against the risk of over-decontamination or unnecessary decontamination of casualties. To inform the decontamination process, due attention must be paid to agents' physical properties. Severely poisoned individuals may be minimally exposed to further contamination to enable lifesaving interventions prior to decon-

tamination. Trauma and CBRN exposure conspire synergistically to yield a grave prognosis possibly resulting from delays caused by decontamination and chemical resuscitation. To make the best use of possibly limited resources, expectant casualties should be identified and triage guidelines followed. Adverse outcomes can be minimized with the timely application of specific therapies and antidotes where available, in concert with damage control resuscitation for trauma.

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