Using Screen-Based Computer Simulation to Develop and Test a Civilian, Symptom-Based Terrorism Triage Algorithm

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Learning Objectives: 1) To describe a symptom-based triage algorithm for terrorism victims. 2) To describe a method for testing the algorithm using screen-based simulation. 3) To identify methods for future testing of the algorithm.

Abstract

Educating first-contact health care providers in the care of potential terrorism victims is challenging because of the wide variety of potential presenting symptoms. A civilian, symptom-based algorithmic approach has been developed to aid health care providers in decision-making during the early encounter with these patients. We describe the use of a screen-based bioterrorism simulator as a source of hypothetical patients to test and refine these algorithms. We discuss future methods of potential testing, including paper case scenarios, computer modeling, and testing during field drills.

Chemical, biological, radiological, nuclear, and explosive (CBRNE) events are low-frequency, high-impact events. Emphasis has been placed by the Department of Homeland Security,[1, 2] the Centers for Disease Control,[3, 4] the Occupational Safety and Health Administration,[5] and civilian agencies[6-8] on first responder/receiver preparedness for these potential events. The diversity of possible clinical presentations presents an enormous challenge for first-contact health care providers. A successful symptom-based algorithmic strategy for handling the initial encounter with victims can serve to simplify the educational process and could provide real-time decision-making support for the provider. The theoretical challenge of creating and testing such an algorithmic approach was formidable. In this article, we describe a solution to this challenge by testing a symptom-based algorithmic system using biological and chemical case presentations from a screen-based CBRNE simulator.[9]

One of the authors has commercial and financial interest in a company involved in the production of bioterrorism simulators.

Background on the Algorithms

In the event of a terrorist attack, first-contact health care providers will most likely be faced with symptoms, not known agents, and will have to decide a course of action based on those symptoms. This was the impetus for the development of a civilian, symptom-based algorithmic approach to terror victims. The algorithms were designed to assist with decision-making in regard to the movement of patients through the early encounter with the health care system. The algorithms help to direct health care personnel to employ proper self-protection and to correct early treatment for victims. The algorithms were not designed to arrive at a definitive diagnosis of biological agents, nor were they designed to prioritize casualties for transport at the scene, though they may be of assistance in on-scene decision-making based on symptoms. The complete theory behind the algorithms and the description of the source references have been presented elsewhere.[10]

The algorithms for management of CBRNE casualties were placed into a card format much like an advanced cardiac life support foldout card. The cards are color-coded to assist in moving from the attack card to the appropriate final triage card. The cards are to be used in sequence, moving from the attack card to one of the other four cards. The entry to the algorithms is based on either an overt attack, with a known agent/bomb/blast, or a covert attack that is suggested by epidemiologic criteria and the presence of symptoms. Unstable patients are triaged to the dirty resuscitation area (with the corresponding "dirty resuscitation" card) and stable patients are directed, based on their symptoms, to one of three cards: the chemical agent card, the biological agent card, or the bomb/blast/radiation dispersal device card (Figure 1). The dirty resuscitation area is intended for very limited treatment prior to decontamination, including airway management, hemorrhage control, needle decompression of pneumothorax, and administration of time-critical antidotes. For the sake of simplicity and the limitations inherent to working in the dirty resuscitation environment, the only symptom-based treatment decision happening in this environment is that involving the nerve agents and cyanide (Figure 2).

The stable chemical agent algorithm helps people determine the need for nerve agent antidote based on symptoms (Figure 3). This algorithm also helps identify vesicant and pulmonary agents and warns of the potential need for retriage of patients with pulmonary symptoms who have undergone chemical exposure. The biological agent algorithm deals with four classes of patients: those with fever and flu-like illness, those with fever and other suspicious symptoms such as petechial rash, those with fever and a credible exposure, and those with symptoms of botulism (Figure 4). The bomb/blast algorithm is extremely simple, and the known radiation dispersal device algorithm advocates for treating life/limb/sight-threatening injuries prior to decontamination (Figure 5).

Screen-Based Simulator Development

To understand the usefulness of testing the algorithmic approach with a screen-based simulator, one has to understand the scope and development expertise that went into the screen-based simulator. The screen-based bioterrorism simulator[9] was developed to enable physicians, nurses, and other first responders to review the recognition, diagnosis, and treatment for exposure to biological and chemical agents. The program includes 24 different scenarios in which a patient presents with signs and symptoms consistent with

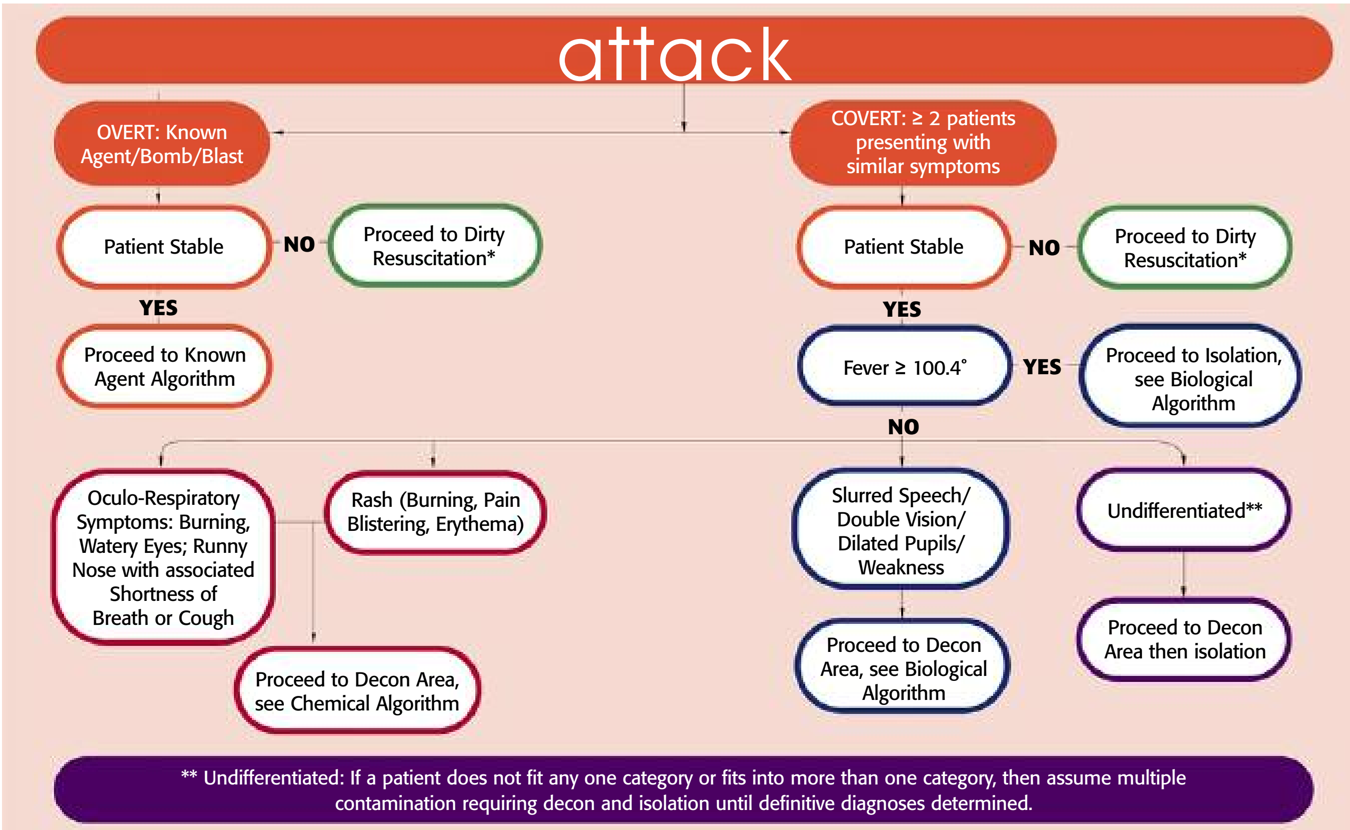

Figure 1. Attack algorithm. (From Subbarao et al.[10] Reprinted with permission of *Prehospital and Disaster Medicine*.)

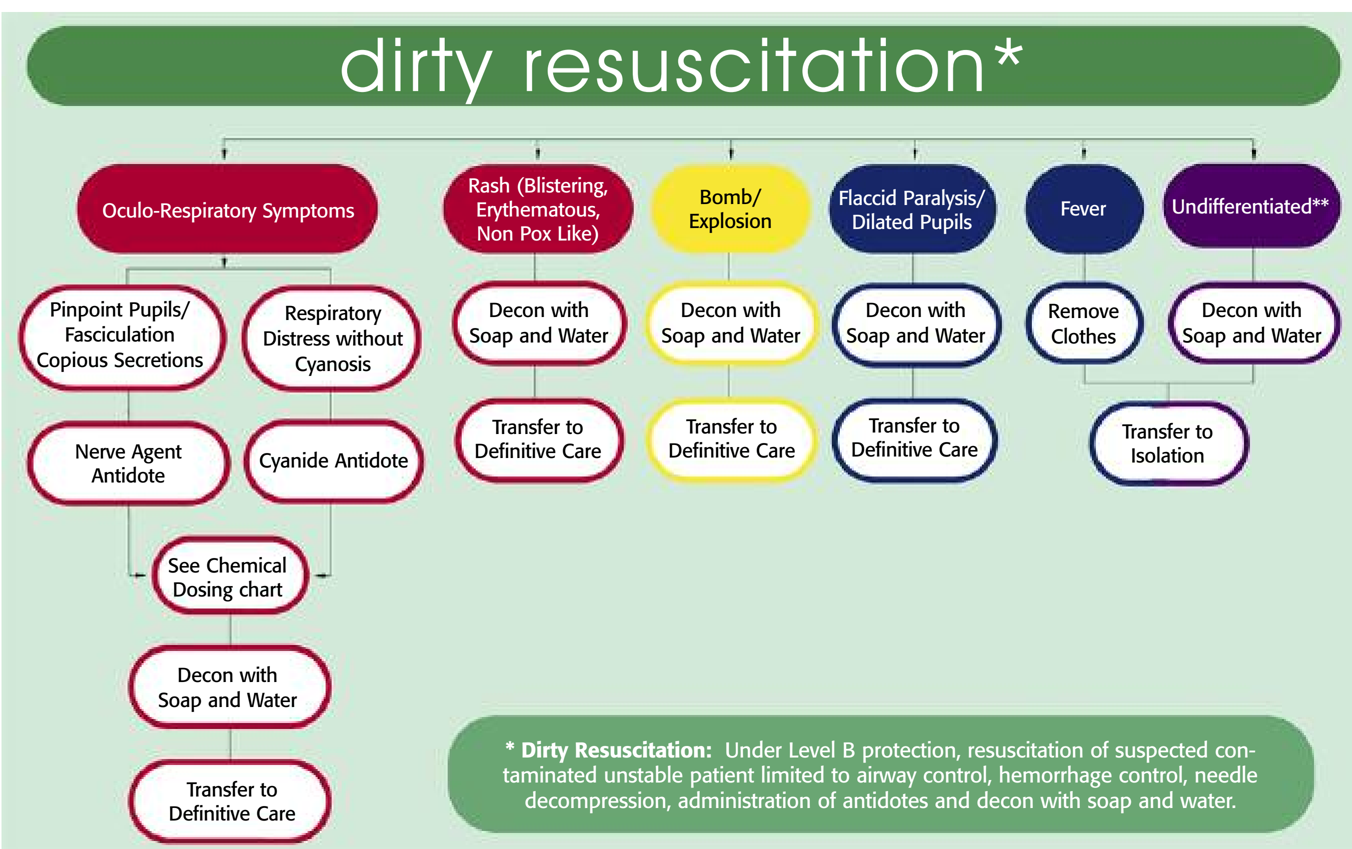

Figure 2. Dirty resuscitation algorithm. (From Subbarao et al.[10] Reprinted with permission of *Prehospital Disaster Medicine*.)

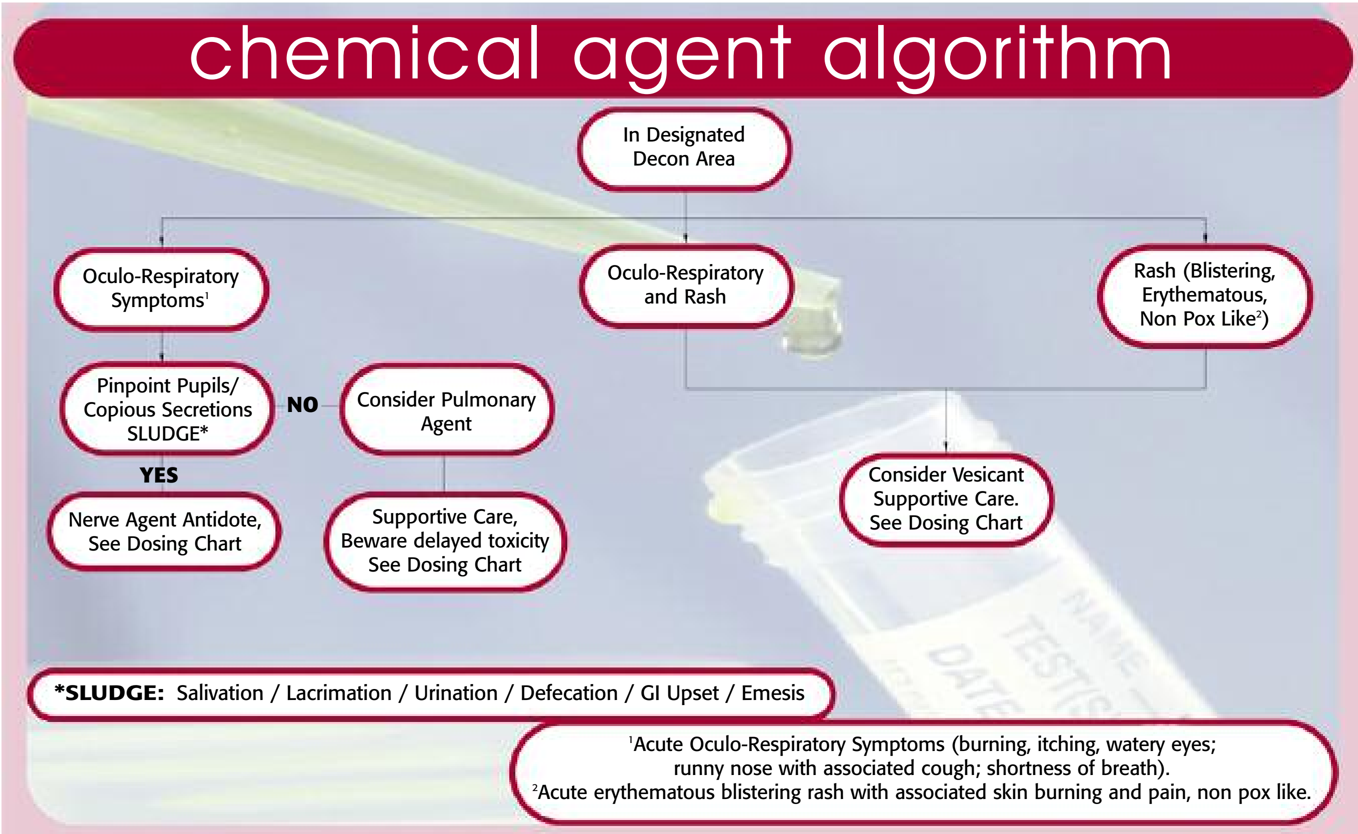

Figure 3. Chemical agent algorithm. (From Subbarao et al.[10] Reprinted with permission of *Prehospital Disaster Medicine*.)

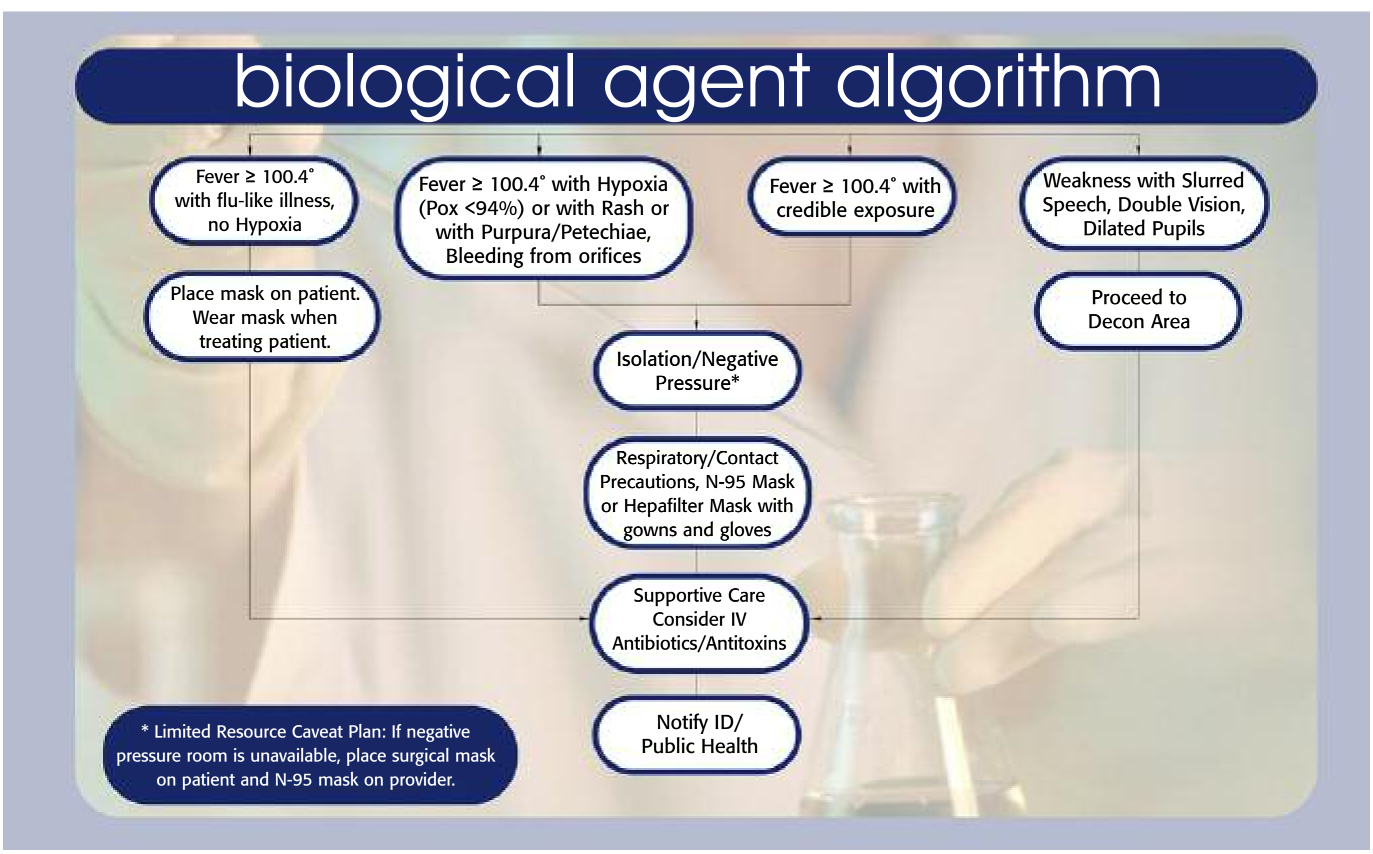

Figure 4. Biological agent algorithm. (From Subbarao et al.[10] Reprinted with permission of *Prehospital Disaster Medicine*.)

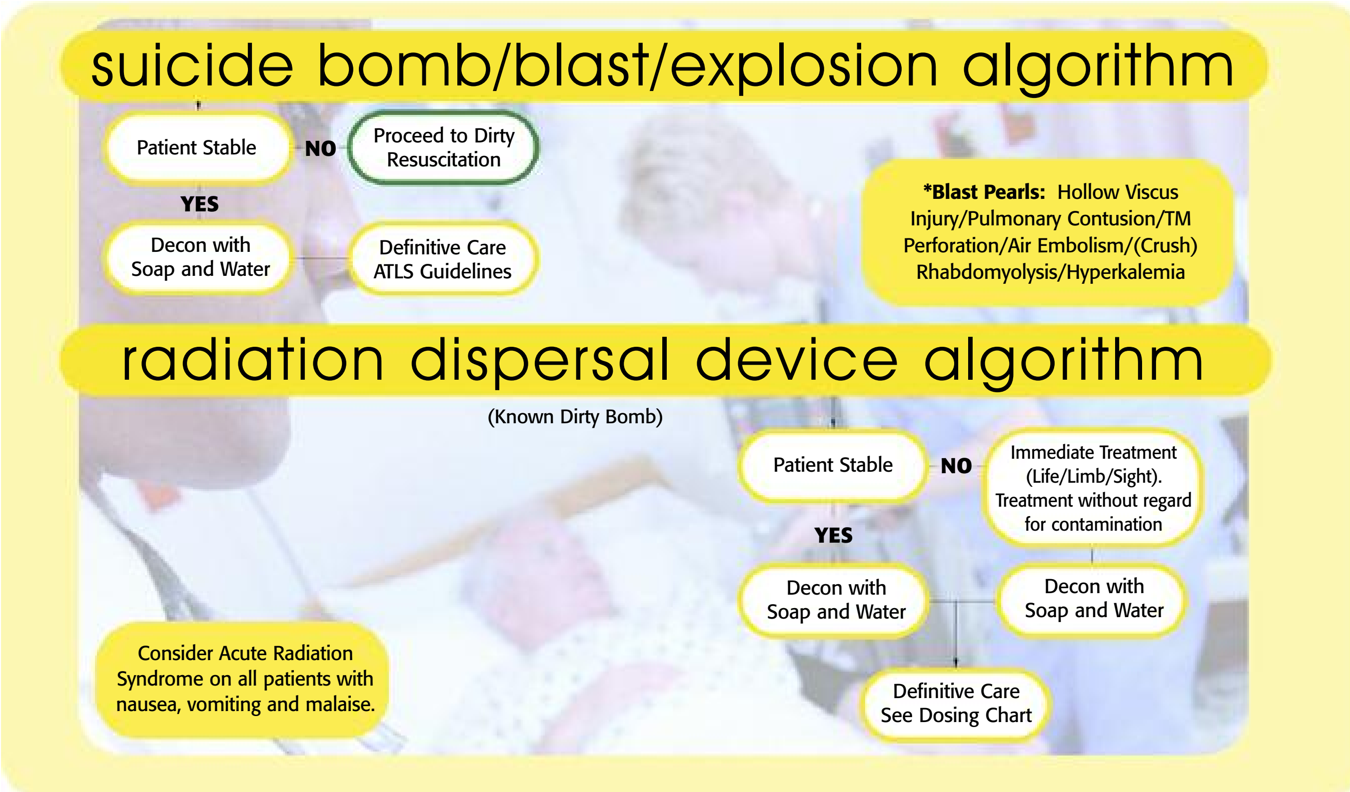

Figure 5. Bomb/blast explosion and radiation dispersal device algorithm. (From Subbarao et al.[10] Reprinted with permission of *Prehospital Disaster Medicine*.)

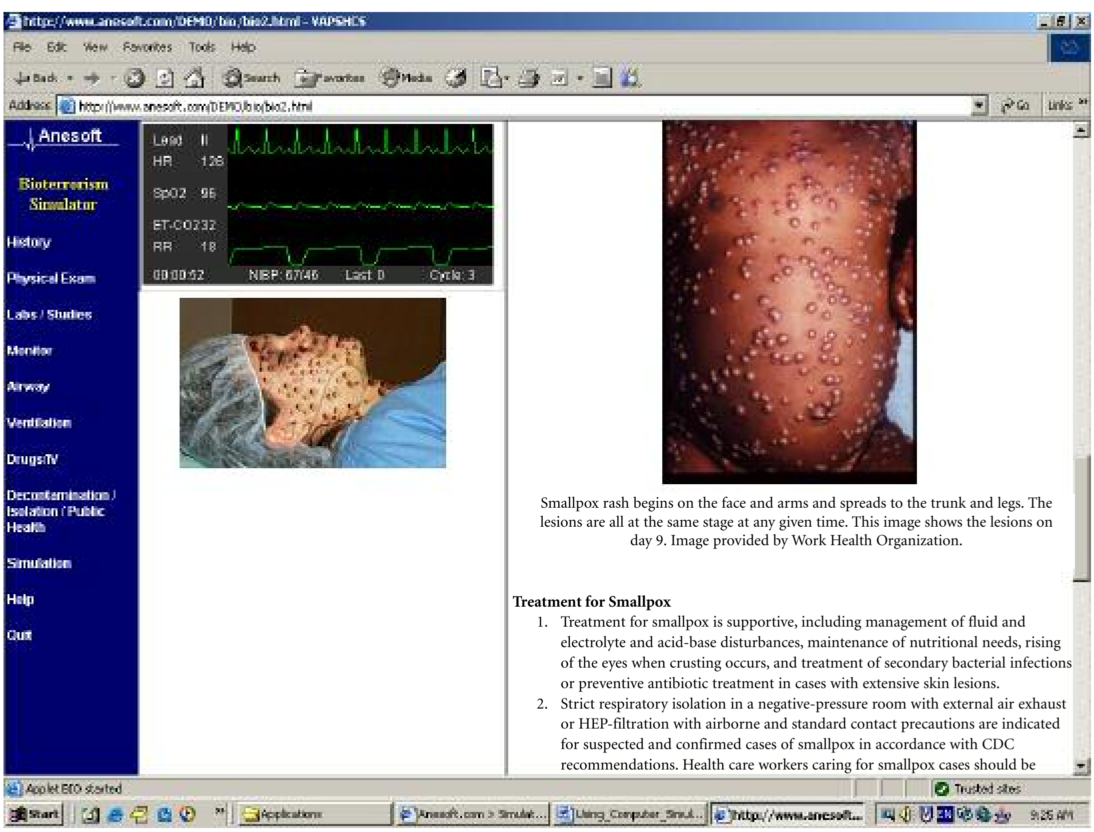

Figure 6. Screen shot of the bioterrorism simulator. (From www.anesoft.com. Used with permission.)

possible exposure, but an unknown diagnosis. As the simulated scenario unfolds, the health care professional learns to recognize the signs and symptoms of each illness, and orders appropriate isolation, decontamination, diagnostic tests, and treatment. Just as in real life, slow response or improper decisions lead to worse patient outcomes.

The bioterrorism simulator uses Sun Java (version 1.5) technology, making it accessible using an Internet browser such as Internet Explorer. The program is freely accessible on the World Wide Web at www.anesoft.com. The bioterrorism simulator uses a graphical user interface to make the program easy to use and clinically realistic (Figure 6). The patient and physiologic monitors are continuously displayed. Because many of the clinical scenarios involve airway and ventilation management, the patient image reflects the state of the airway. The bioterrorism simulator is a real-time, mathematical model-driven simulator, which means that the condition of the patient changes as it would in a real-life situation. For example, if the simulated patient hypoventilates and then becomes apneic, the physiologic consequences in the simulator would follow the same time course as in a real patient. The bioterrorism simulator also includes an extensive on-line help system so that at any point during the simulated case, the trainee can call for an "expert" to review the appropriate case management. In addition, the program produces a detailed case record so that the trainee can receive later debriefing, document competency for institutional review, or use the program to earn AMA Category 1 CME credits.

An experienced educational team at the University of Washington created the bioterrorism simulator. A select group of CBRNE experts in infectious disease, toxicology, public health, and critical care from around the globe created and critiqued the scenarios to verify accuracy and realism. The scenarios selected for inclusion in the bioterrorism simulator were believed by the expert consultants to represent the most likely terrorist threats. The biological agents selected were the Category A agents: anthrax, botulism, plague, tularemia, smallpox, and viral hemorrhagic fever. The four anthrax scenarios involved an anxious patient with possible exposure and flu-like illness, cutaneous anthrax, as well as mild and severe inhalational anthrax. The four botulism cases represented the spectrum of presentations from new onset of weakness, to cranial nerve involvement, to full-fledged respiratory failure. Severely ill cases of plague, tularemia, and viral hemorrhagic fever are presented. The four smallpox cases varied in severity and involved differentiating chickenpox from smallpox. The four nerve agent cases presented various levels of exposure with a spectrum of symptoms from eye burning and respiratory distress to seizures and respiratory failure. The other toxic gas scenarios included exposure to vesicants, cyanide, and benzilate, an anticholinergic agent that can cause mass delirium. In all of these scenarios, the simulated patient presents much the same as a real patient would, with dynamically changing vital signs that improve or decline depending on the trainee's management of the simulated scenario.

Algorithm Development Using Screen-Based Simulation

During the process of developing the algorithms, the algorithms required alpha testing. The algorithms had been devised based on symptomatic presentation and they needed to be tested with a variety of patients. This called for a source of cases and a method that would test the logic of the algorithms. There was a need for case presentations that were diverse in both cause and symptoms. This diversity had to encompass patients who were stable and unstable, patients with a variety of agents, patients who had infectious risk, and patients who may be stable with credible exposure. The impact of dynamically changing vital signs that highlight the need for possible retriage as well as the amount of early intervention that a patient might require could be assessed.

The first step in algorithm development was to find symptoms that would be expected with the different agents. The second step was to find commonality in the symptoms so that certain symptom complexes might be originally brought together on the algorithm. The goal was to have as few branches as possible. This led to the initial draft of the algorithms that was then tested via an iterative process with the screen-based simulator. The patients in the screen-based simulator were managed by the algorithm development team using the algorithms. As logic flaws were uncovered, the algorithms would be changed and the scenario repeated. At times, the changed algorithm would then conflict on another simulation case and would be revised again. This change process was at times as simple as a branch point and at times as complex as reorganizing the entry symptoms for the beginning of the algorithm. Some case examples are noted here with a discussion of the flow of the patient via the algorithms.

Biological Agents. One example of a biologic case involved a 6-year-old child with possible smallpox exposure. The scenario of "fever with credible exposure" was one that was believed to be extremely important, but was not initially adequately addressed in our symptom-based approach. Although a large outbreak would be accompanied by guidelines from the Centers for Disease Control and public health departments, these may not yet be widely disseminated or easily accessible early in an outbreak. These patients are managed with a conservative approach that recommends negative pressure isolation or the use of masks on both provider and patient when negative pressure is not available. The simulator also demonstrates the patient with a credible exposure and the need for antibiotic prophylaxis. Specifically, this is a case of a possible pulmonary anthrax exposure, but without symptoms. This topic is extremely important, but is not addressed in the algorithms because the patient is not a threat to the health care worker, and the decision to treat with antibiotic prophylaxis can be made in hours to days rather than minutes.

Several scenarios presented with cases of fever and flu-like illness. The first simulator case involving possible anthrax is that of a gentleman with a flu-like illness who is already on antibiotics for prophylaxis. If this patient has the flu, he may actually present more risk to health care workers or other patients than if he has pulmonary anthrax. This case brings to the forefront one of the most common potential early biological weapon presentations in addition to an exceedingly common clinical scenario. These cases were debated at length because of the issue of resource use that might come with over-triage of such patients. Because the syndrome of fever and cough or fever and flu-like illness without hypoxia could represent anthrax (little threat to health care workers), smallpox (definite threat to unimmunized workers), pneumonic plague (threat to health care workers), or pandemic influenza (threat to health care workers), the decision was made to handle this with simple masks for both provider and patient until more information is known. This is a low-cost method to reduce the spread of droplet-mediated agents and to slow the spread of aerosolized agents.

Botulism. Another screen-based simulator case involved a young man presenting with new onset of weakness and double vision. This was a concerning case with stable vital signs and brought up the issue of whether or not botulism would need to be addressed with decontamination in the algorithms. Botulism victims tend to present to health care providers 12 hours after the exposure, with more rapid symptoms given larger exposures. The toxin poses little risk to health care workers unless it is reaerosolized during clothing removal. Because the toxin persists in the environment for approximately 24 hours, the decision was made to write the algorithms such that botulism patients would need to be decontaminated in both stable and unstable cases. Another case in this module highlighted the symptoms of cranial nerve weakness that occur with botulism. These are rare clinical presentations in the developed world and, for that reason, the symptoms "slurred speech, double vision, dilated pupils, weakness" are listed on the attack card. Any case of botulism in the developed world should prompt awareness and a public health search for a cause.

Nerve Agents—Dirty Resuscitation. One critical care example involved a nerve agent victim from the screen-based simulator who presented with respiratory failure and seizure. These first two symptoms could be a presentation of cyanide or nerve agent. The first order of business should be to protect the health care worker by meeting the patient in the dirty resuscitation area with proper protective equipment.[5] This decision is directed by the attack card. The dirty resuscitation environment allows for airway support and early treatment with antidotes prior to decontamination. A patient such as this may pose a threat to health care workers if liquid nerve agent is still present on the body or clothing. The unstable patient is the patient most likely to be off-gassing such potentially hazardous materials. Treatment prior to decontamination may be this patient's only chance for survival. In fact, within the simulation she dies quickly if she does not receive airway management. The screen-based simulator brings to life the physiology of the case, the details of airway management, and the dosing of antidotes; the debriefing material contains added didactics. The algorithms provide logic as to where this patient fits into the scheme of other patients with similar, but perhaps less severe, symptoms. It also provides a guideline for movement of the patient through the mass casualty treatment system.

Bomb/Blast/Radiologic Dispersal Device. It was necessary to fabricate patients in addition to those in the simulator to test the algorithms. For example, the screen-based simulator did not have trauma cases. Therefore, we looked at the presenting patterns of blast injury from a theoretical perspective[11-13] and from the perspective of actual data,[14-22] and from this we created our own hypothetical patients who required triage. Examples included patients with head injury requiring intubation, patients with blast lung and progressing dyspnea, and patients with potential intra-abdominal injuries. The simulator did not address the dirty bomb issue, so again the algorithm development team had to consider the presentations, whether they would be subacute or acute, and whether or not they would pose a threat to health care workers. The theory behind the handling of dirty bomb cases was derived from the "Medical Effects of Ionizing Radiation" course handbook.[23]

Future Directions

The details of any mass casualty management strategy should be tested as much as possible before their real-world application. However, because of the significant logistical and cost barriers to arranging drills, new and practical approaches are needed for testing CBRNE strategies. The algorithms presented here are currently undergoing beta testing with a series of paragraph-length paper scenarios. This is important for several reasons. The paper scenarios may reveal places where users have difficulty following the flow or logic of the algorithms. They may identify areas of the algorithms that can be clarified or simplified. The algorithms will be tested in those who have attended a training course and those who have not. The lower the amount of training needed for the use, the greater their utility will be in terms of educating large numbers of providers. Their potential for just-in-time education and as a real-time decision-making aid depends on their clarity to the untrained or the not-recently trained. Paper scenarios with poor triage success rates can also be used to identify targeted areas for training. Testing across different levels of learner may reveal that the algorithms are suitable for physicians but not suitable for paramedics or other provider levels.

In addition to paper case scenarios to simulate hypothetical individual cases, there is also a potential role for a different type of simulation that can be used to test the algorithms on a broader and more complex scale. Computerized event simulation, or perhaps for clarity what could be termed "computer modeling," is a potentially powerful tool to consider when developing approaches to disaster preparedness. Computer modeling of complex scenarios has been used in various industries for years.[24] A branch of computer science referred to as "discrete event simulation" provides a structure that allows the development of a representative model of a system of interest. Given recent advances in computer processing speed and capacity, models as complex as an emergency medical system, a mass casualty scene, or an emergency department are possible.[25-29] Importantly, the nature of this process allows for probabilistic or "best-guess" input into the development of the model. This is particularly important when developing a representative model that will incorporate rare or even purely hypothetical events.

Once developed, an event model of a given system can be used to analyze a multitude of "what if" scenarios. In the context of the current discussion, the various input variables might be the numbers of critical, ambulatory, and noncritical nonambulatory patients. They may even include a broader scope of inputs such as the number of cities or counties affected. The output metrics may include throughput times, proportion of patient outcome categories, and overall resource use. These outcomes can be analyzed with respect to various resource constraints such as the presence or absence of decontamination stations. Importantly, many software packages that are currently used for such modeling are also able to perform optimization analyses that will search for ways to maximize the performance metric of choice (i.e., shorten transport, treatment, or waiting times). Such optimization techniques have recently been applied to the study of mass casualty triage.[30] Additionally, dynamic modeling techniques have been used to define surge capacity during bombing incidents.[31] Ultimately, the concept of computer modeling relies on the construct of a sufficiently detailed model that will then allow subsequent manipulation of variables (i.e., resources) to estimate downstream effects. The development of a robust discrete event simulation model of a given system can allow for an intermediate level of analysis of complex or rarely occurring scenarios that would otherwise be impossible or impractical to perform.

The final arbiter of any triage system will most likely be the performance of the system during field drills. Studying their performance during real-time events would be extremely difficult, though small-scale opportunities may arise. The study of field drills is labor-intensive because each point of entry requires trained observers to assess the success or failure of triage decisions. The algorithms' performance could be tested with markers, such as the number of casualties or the amount of contamination that slips through during a mass casualty drill involving a chemical exposure. Ideally, such drills would be announced initially so that first-contact providers would be ready and trained to use the system. Unannounced drills would assess the readiness of the system and the ability for the algorithms to serve as a cognitive aid, perhaps months after the training. We recommend that any system of triage or a triage decision aid such as that described here be used by the end-user in drills prior to real-world application.

Conclusions

We have presented a method for using a screen-based bioterrorism simulator in the testing and development of triage algorithms for CBRNE casualties. Future testing of these algorithms may take the form of hypothetical paper cases, computer modeling, and mass casualty triage drills.

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