Simulation Applications in Emergency Medical Services

Scott Leikin, BA, Pam Aitchison, RN,
Martha Pettineo, RN, Morris Kharasch, MD, FACEP,
and Ernest E. Wang, MD, FACEP

Introduction

Prehospital emergency medical services (EMS) play an important role in the initial stabilization and transport of critically ill patients daily around the world. In the USA, there are an estimated 840,000+ certified first responders and, of these, there are greater than 192,000 EMS providers.[1] These individuals work for a variety of governmental and private organizations such as fire departments, private companies, volunteers, hospitals, and third-party providers. All states require a trained and certified EMS responder to provide emergency medical care in the event of a weapons of mass destruction (WMD) incident and the administration of antidotes as dictated by region.[1] As a response to September 11, comprehensive competency-based curricula for terrorism preparedness have been created.[2]

The hallmark of an expertly trained EMS provider is the ability to recognize rapidly and treat immediate life threats, initiate timely communication with receiving facilities to prepare them for patient arrival, and execute proper protocols in the event of a disaster or mass casualty. EMS providers require a unique skill set to deal effectively with the complexities of the scope of their practice. They are under significant time pressure to triage and initiate treatment for unstable patients. This requires clear thinking and poise. They must be able to think flexibly and cope with an array of environmental factors particular to the scene. Additionally, they need to be able to work effectively while maintaining situational awareness of dangers to their personal safety. Finally, they need to maintain vigilance and be prepared to react to the possibility that their scene response is potentially related to a mass casualty or disaster that they have never

Dis Mon 2011;57:723-733
0011-5029/2011 $36.00 + 0
doi:10.1016/j.disamonth.2011.08.012

experienced. Simulation-based training assists EMS systems and providers prepare for these contingencies.

EMS Training

Simulation-based training for EMS professionals has broad applications. Procedural skills required include cardiopulmonary resuscitation, basic and advanced airway skills, intravenous and intraosseous access techniques, electrocardiogram and telemetry interpretation, and administration of pharmacologic agents. Broader skills include proficiency with standard operating procedures and regional protocols, as well as effective teamwork behaviors.

With the use of airway task trainers, procedures that can be taught include airway assessment, oxygen administration, oral and nasal airway application, noninvasive positive pressure ventilation, endotracheal intubation, laryngeal mask airways and other airway bridge devices, and surgical airways. Cardiopulmonary skills amenable to task training include effective bag-valve-mask ventilation, performance of chest compressions, and intravenous/intraosseous access.

Simulation-based investigation on airway management with prehospital providers has been an area of significant research. Simulation has been used to investigate which difficult airway abnormalities affect success rate of orotracheal intubation in novice intubators.[3] The King LT Supralaryngeal Airway device (Noblesville, IN) may be advantageous in prehospital airway management situations involving multiple patients or hazardous environments and was shown to be performed faster than endotracheal intubation when performed by community EMS providers.[4] Simulation has been used to demonstrate that a paramedic's success in securing a difficult airway may depend on the type of airway device they use.[5] Additionally, in a 2011 usability study of 7 different types of supraglottic airway devices in 41 previously inexperienced paramedics following training on a manikin model, the investigators found that endotracheal intubation success rates by paramedics 3 months after simulation training was significantly less than 5 different supraglottic airway devices (Laryngeal mask unique [LMA] [LMA Company North America, San Diego, CA], Laryngeal tube disposable [King-LT-D, VBM, Sulz, Germany], I-Gel [Intersurgical Ltd, Wokingham, England], Combitube [Covidien, Mansfield, MA], and EasyTube [Teleflexmedical Ruesch, Research Triangle Park, NC]), indicating that simulation may have a role in identifying methods that are more preferable for newer paramedics in the prehospital setting.[6] A just-in-time educational intervention was able to demonstrate retention of skill with LMA placement at

6 months. Fifty-five first-year paramedic students watched a manufacturer's LMA instruction video and practiced insertion in 3 different task trainers. Six months later, subjects were randomized to an intervention (reviewing the video and 10 minutes unsupervised practice) or control group before participating in a high-fidelity simulated clinical scenario. Those in the intervention group displayed significantly shorter insertion times ($P = 0.029$), displayed fewer attempts to achieve success ($P = 0.033$), and had significantly higher LMA skill performance levels ($P = 0.019$) at 6 months.[7]

Because EMS providers infrequently encounter seriously ill and injured pediatric patients, simulation can be useful for training and assessing the skill level of prehospital providers in the area. Lammers et al. conducted manikin-based pediatric simulations on 3 core topics---infant cardiopulmonary arrest, sepsis/seizure, and child asthma/respiratory arrest. Two hundred twelve paramedics from 5 EMS agencies in Michigan participated in this prospective, observational study. Performance deficiencies included lack of airway support or protection; lack of support of ventilations or cardiac function; inappropriate use of length-based treatment tapes; and inaccurate calculation and administration of medications and fluids.[8]

Another area of research with prehospital providers is patient safety. High-fidelity manikin scenarios have been used to identify gaps in patient safety[9] and to improve providers' communication skills.[10] Zimmer et al. used several prehospital scenarios involving advanced life support, asthma, pulmonary embolus, and multiple trauma to identify and quantify specific communication breakdowns or errors that led to unsafe acts. They noted that the paramedics committed an average of 7.4 unsafe acts per scenario and transmitted only 53.7% of their interventions to the emergency physicians. The most common unsafe acts were observed in the areas of respiratory management, physical examination, and circulatory management.[9]

Developing immersive EMS simulation environments often requires more creativity than in any other field of medical simulation. For EMS providers, their mobile intensive care units are usually ambulance or helicopters. Immersive simulation environments can be designed to replicate the space, equipment, and functionalities of these vehicles (Fig 1). This allows for the providers to use familiar equipment and practice providing care within the confines of their spaces. For novices, it helps develop awareness of the limitations and capabilities of the vehicle. It can help them practice to look for the clues of an impending problem (monitor or physical examination findings that are associated with pneumothorax), prevent complications, improve assessment in a noisy environment, improve anticipatory skills, and increase situational awareness. A study

(Tober-Pollack Emergency Simulation Center at the Michael S. Gordon Center for Research in Medical Education, Miami, FL. Photo courtesy of S. Barry Issenberg, MD, FACP)

FIG 1. EMS Ambulance simulation environment. (Tober-Pollack Emergency Simulation Center at the Michael S. Gordon Center for Research in Medical Education, Miami, FL. Photo courtesy of S. Barry Issenberg, MD, FACP.) (Color version of figure is available online.)

involving emergency medicine residents participating in a high-fidelity simulated flight medicine experience reported significantly improved understanding of the obstacles to patient care in a helicopter. The reported cost for such a session included a monetary cost of $440 and a time cost of 22 hours of skilled instructor time.[11]

Unique to prehospital medicine is the infinite variability of the scene responses to which paramedics must respond. Their ability to provide care is often dictated by the circumstances they encounter. Simulation environments can be created to resemble a home environment, a work environment, or a crime scene. Motor vehicle collisions can be created using old cars, and victim extrication exercises can be performed (Fig 2). These simulations can help with protocol testing or new equipment testing or help providers develop the ability to think creatively and develop workarounds for unanticipated contingencies.

Disaster Preparedness

Disaster preparedness for a possible mass casualty incident or bioterrorism event is a great concern for EMS and the associated hospitals

(Northeastern Illinois Public Safety Training Academy, Glenview, IL. Photo: Ernest Wang, MD, FACEP)

FIG 2. Motor vehicle collision victim extrication simulation training exercise. (Northeastern Illinois Public Safety Training Academy, Glenview, IL. Photo: Ernest E. Wang, MD, FACEP.)

within the catchment area. Disasters can be categorized into several types: 1. natural disasters (eg, fires, floods, droughts, hurricanes, landslides, tornadoes, earthquakes, heat waves, winter storm events such as blizzards, and cold-related emergencies); 2. human-caused or technological disasters (eg, dam failures, hazardous material accidents, aviation accidents, accidents involving nuclear reactors); or 3. national security disasters (terrorism associated with WMD, such as nuclear/biological/chemical attacks).[12] Domestic preparedness for such events relies on capable and properly trained prehospital personnel as well as effectively integrated hospitals within the local community. Despite this, it is estimated that only 4% of the US Homeland Security funding for public safety terrorism preparedness is allotted to EMS.[1]

First responders need to be able to identify a mass casualty situation, recognize the potential causes based on the presentation, and trigger alerts to initiate containment protocols. Because bioterrorist events will likely occur without warning and the cause will not be known, symptom-based, all-hazards, decision-making algorithmic approaches have been proposed to improve providers' ability to predict the cause and initiate rapid treatment. Bond et al. studied the use of this type of algorithm on the ability of health care providers to correctly choose the proper triage and management for 26 unknown terrorism scenarios.[13] Each required that one make a triage choice on the "attack" algorithm (the trunk algorithm) and then proceed to 1 of 4 other branch algorithms (dirty resuscitation, chemical agents, biological agents, bomb/blast/radiation dispersal device) to make a final triage choice. The authors found that the 110 physicians and nurses who participated in the study performed substantially better than would have been expected by chance alone. The overall total score was 45% correct for all participants, whereas the conditional probability of guessing both the attack algorithm and the final card correct ranged from 4.7% for the biological, chemical, and bomb/blast algorithms to 2.4% for the dirty resuscitation algorithm.[13] The algorithms described by Bond et al. have been implemented in an Advanced Bioterrorism Training Course at our NorthShore Center for Simulation and Innovation Highland Park Hospital Simulation Campus in Highland Park, IL to extensively disseminate this training to EMS providers throughout Lake County, IL (Fig 3).

Using the Simple Triage and Rapid Treatment (START) triage system, triage accuracy in one large urban study was documented at 78%.[14] During a disaster drill (train collision with blast injury and chemical release), the accuracy and speed of triage of 130 patient-actors by the Fire Department of New York City EMS personnel was evaluated using the START triage system. All EMS personnel had been previously trained in START, but refresher training was not administered before the drill. Overall triage accuracy was 78%. In patients who had additional changes in their status during the triage process (injects), 62% were retriaged appropriately.[14] Triage/treatment began 40 minutes after the drill began; the average time from start of triage to transport was 1 hour and 2 minutes, and the scene was completely cleared in 2 hours and 38 minutes.[14]

Likewise, natural disasters pose similar potential for injury and death while exposing first responders to environmental hazards as well. In the Asia-Pacific region, where over one-half of the world's natural disasters occur, manikin-based simulations have been effectively conducted in multiple countries to treat traumatic injuries and life threats: (1) leg wound (hemorrhagic shock/immediate); (2) chest wound (tension pneumothorax/immediate); (3) head wound (traumatic brain injury/expectant); and (4) limb trauma (leg fracture/delayed).[15]

Disaster drills differ from manikin-based simulations because these scenarios test the systems' response to disaster and have broader scope

(Advanced Bioterrorism Training Course conducted at NCSI CSTAR Highland Park Hospital, Highland Park, IL. Photo: Ernest Wang, MD, FACEP)

FIG 3. Bioterrorism dirty resuscitation simulation. (Advanced Bioterrorism Training Course conducted at NorthShore Center for Simulation and Innovation CSTAR Highland Park Hospital, Highland Park, IL. Photo: Ernest E. Wang, MD, FACEP.) (Color version of figure is available online.)

and costs associated with mobilizing simulated patients, money, resources, time, and number of personnel it takes to correctly coordinate a proper disaster drill.[12] Because of this, they are only performed periodically and do not often address the "what if" variables associated with the uncertainties of a particular scenario. Examples of "what if" variables were described by Christie and Levary and include the following: How much time would it take, given the number of ambulances in the city, to transport the injured to hospital? How long must the injured wait for ambulances to arrive? What is the longest waiting time for a patient? How many ambulances are needed to transport the injured? If two patients are transported in an ambulance instead of one patient, how much does it reduce the transportation time? What strategy should be followed to transport the injured, first to nearby hospitals and later to hospitals that are further away? What would the change in average waiting time be for the injured or what would the total time be for transporting all patients to hospitals if variables such as arrival rate, weather, type of disaster, availability of beds, availability of trauma centers, and ambulances were changed?[12]

Computer simulation has been suggested to assist with these. Advantages of computer simulation include the ability to repetitively test scenarios while changing variables, lowering operational costs, and providing a risk-free environment for medical personnel to develop critical thinking and medical decision-making skills quickly.[12] Transient modeling approaches using programming simulation and exponential functions have been devised. The model can represent transient, patient waiting times during a disaster and allows real-time capacity estimation of hospitals of various sizes and capabilities.[16] Web-based training models have been studied to teach EMS providers to recognize and treat ocular injuries associated with WMD attacks.[17]

Disaster simulations can expose system weaknesses and identify targets for improvement. A study performed to assess EMS systems' effectiveness in response to possible chemical, biological, radiological, nuclear, explosive (CBRNE) units examined the "after-action" reports from the Office of Domestic Preparedness, Chemical Weapons Improved Response.[1] They discovered that only 6 of 70 after-action reports reported the use of level C or higher personal protective equipment (PPE). Forty-four (63%) reported no additional PPE other than their regular work uniform. Twenty (28.6%) of the 70 after-action reports made no comment regarding the use of the PPE gear used by EMS providers at all.[1]

Hospital preparedness has been assessed with simulated exercises and training has been shown to improve topical knowledge.[18] These types of exercises usually involve alerting the hospital with a hypothetical scenario and delivering moulaged patients of varying degrees of severity to the emergency department (ED). Each patient undergoes real-time triage and registration followed by compressed time treatment and disposition.

Patient disposition and management is beyond the ED and is often conducted as a tabletop exercise.[18]

Subbarao et al. report the use of a combination of high-fidelity manikin simulations and video clinical vignettes to create a curriculum to train first responders and receivers (attending emergency physicians, emergency medicine residents, nurses, physician assistants, medical students, paramedics, and ED technicians) in the acute management of victims of an unknown CBRNE event. Statistically significant improvement was noted in all learner groups post training.[19]

Future Roles of Simulation in EMS Training

In addition to manikin-based simulation and full-scale disaster drill simulation, other potential simulation-based applications show promise. "Gaming" simulation has been shown to improve students' knowledge of a bioterrorism and emergency readiness curriculum.[20] Web-based curricula may become more prominent because of improved feasibility of distance learning and because web-based applications can allow for real-time virtual networking between regional hospitals. Citywide disaster drills will likely incorporate Access Grid-like technologies (Chicago, IL) for real-time coordination of every hospital from a central command center.

Another promising tool in the future of EMS training is the use of virtual worlds. A 2008 study used 3D virtual environments to evaluate and train teamwork behaviors with emergency medical technicians, emergency physicians, and emergency nurses in two virtual scenarios: a sarin gas attack and a trauma victim from a radioactive dirty bomb explosion. Each participant was assigned an online character and interacted with the other members through the virtual world. Evaluation of these virtual world simulation exercises demonstrated that trainees found the exercise adequately realistic to "suspend disbelief." The participants were able to learn quickly to use Internet voice communication and user interface to navigate their online character/avatar to work effectively in a critical care team. Sixty-two percent thought multiplayer game-based training was as effective as or more effective than traditional methods. The utility of the game environment was felt to be better suited for initial training (56%) and for refresher training (75%). Self-efficacy scores were improved after participation in these exercises as well.[21]

Andreatta et al. compared disaster triage performance using full-immersion virtual reality simulation and standardized patient (SP) simulation. Although the results showed an effect in favor of the SP group performance on the posttest, no significant differences were found with respect to triage performances. The authors conclude that virtual reality should be considered as a viable alternative training tool for disaster triage and has the benefits of increased flexibility, repeatability, and availability relative to SP exercises.[22]

Conclusions

The skills required of EMS providers are complex and can be difficult to master. They need to be skilled with emergent interventions to stabilize patients with acute conditions in a variety of situations dictated by the environment, to effectively work in micro- and macrounits as part of a larger EMS system, and to be situationally aware of CBRNE threats.

Emergent procedures are now being taught using simulation so that EMS providers can apply superior skills to actual clinical care and improve outcomes for the patients they encounter.

The key to disaster preparedness is providing first responders with the best possible training modalities to simulate the experience of a mass casualty event so that they have a working knowledge of the general principles for effectively managing the situation.

Effective periodic simulation exposure and contemporaneous debriefing are necessary to foster teamwork and communication with receiving facilities and to improve pre-hospital providers' ability to perform emergent procedures effectively. Additionally, simulation can help them perform rapid cognitive processing and act effectively in high-pressure, highly variable, and possibly dangerous environments. In this way, simulation can help make poise under pressure a learned behavior.

REFERENCES

1. Phelps S. Mission failure: Emergency medical services response to chemical, biological, radiological, nuclear, and explosive events. Prehosp Disast Med 2006;22(4):293-6.
2. Markenson D, DiMaggio C, Redlener I. Preparing health professions students for terrorism, disaster, and public health emergencies: core competencies. Acad Med 2005;80(6):517-26.
3. Thomas F, Carpenter J, Rhoades C, et al. The usefulness of design of experimentation in defining the effect difficult airway factors and training have on simulator oral-tracheal intubation success rates in novice intubators. Acad Emerg Med 2010;17(4):460-3.
4. Burns Jr, JB Branson R, Barnes SL, et al. Emergency airway placement by EMS providers: comparison between the King LT supralaryngeal airway and endotracheal intubation. Prehosp Disaster Med 2010;25(1):92-5.
5. Nasim S, Maharaj CH, Butt I, et al. Comparison of the Airtraq and Truview laryngoscopes to the Macintosh laryngoscope for use by Advanced Paramedics in easy and simulated difficult intubation in manikins. BMC Emerg Med 2009;9:2.

6. Ruetzler K, Roessler B, Potura L, et al. Performance and skill retention of intubation by paramedics using seven different airway devices---a manikin study. Resuscitation 2011;82(5):593-7.
7. Hein C, Owen H, Plummer J. A training program for novice paramedics provides initial laryngeal mask airway insertion skill and improves skill retention at 6 months. Simul Healthc 2010;5(1):33-9.
8. Lammers RL, Byrwa MJ, Fales WD, et al. Simulation-based assessment of paramedic pediatric resuscitation skills. Prehosp Emerg Care 2009;13(3):345-56.
9. Zimmer M, Wassmer R, Latasch L, et al. Initiation of risk management: incidence of failures in simulated Emergency Medical Service scenarios. Resuscitation 2010;81(7):882-6.
10. Batchelder AJ, Steel A, Mackenzie R, et al. Simulation as a tool to improve the safety of pre-hospital anaesthesia. J Assoc Anesth Gt Br Irel 2009;64:978-83.
11. Wright SW, Lindsell CJ, Hinckley WR, et al. High fidelity medical simulation in the difficult environment of a helicopter: feasibility, self-efficacy and cost. BMC Med Educ 2006;6:49.
12. Christie PM, Levary RR. The use of simulation in planning the transportation of patients to hospitals following a disaster. J Med Syst 1998;22(5):289-300.
13. Bond WF, Subbarao I, Kimmel SR, et al. Testing the use of symptom-based terrorism triage algorithms with hospital-based providers. Prehosp Disaster Med 2008;23(3):234-41.
14. Schenker JD, Goldstein S, Braun J, et al. Triage accuracy at a multiple casualty incident disaster drill: the Emergency Medical Service, Fire Department of New York City experience. J Burn Care Res 2006;27(5):570-5.
15. Vincent DS, Berg BW, Ikegami K. Mass-casualty triage training for international healthcare workers in the Asia-Pacific Region using manikin-based simulations. Prehosp Disast Med 2009;24(3):206-13.
16. Paul JA, George SK, Yi P, et al. Transient modeling in simulation of hospital operations for emergency response. Prehosp Disast Med 2006;21(4):223-36.
17. Gershon RR, Canton AN, Magda LA, et al. Web-based training on weapons of mass destruction response for emergency medical services personnel. Am J Disaster Med 2009;4(3):153-61.
18. Bartley BH, Stella JB, Walsh LD. What a disaster?! Assessing utility of simulated disaster exercise and associated educational process. Prehosp Disast Med 2006;21(4):249-55.
19. Subbarao I, Bond WF, Johnson C, et al. Using innovative simulation modalities for civilian-based, chemical, biological, radiological, nuclear, and explosive training for the acute management of terrorist victims: A pilot course study. Prehosp Disast Med 2006;21(4):272-5.
20. Olson DK, Scheller A, Larson S, et al. Using Gaming simulation to evaluate bioterrorism and emergency readiness education. Public Health Rep 2010;125:468-77.
21. LeRoy Heinrichs W, Youngblood P, Harter PM, et al. Simulation for team training and assessment: case studies of online training with virtual worlds. World J Surg 2008;32:161-70.
22. Andreatta PB, Maslowski E, Petty S, et al. Virtual reality triage training provides a viable solution for disaster-preparedness. Acad Emerg Med 2010;17(8):870-6.