

Health Care Worker Protection in Mass Casualty Respiratory Failure: Infection Control, Decontamination, and Personal Protective Equipment

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Maintenance of a safe and stable health care infrastructure is critical to an effective mass casualty disaster response. Both secondary contamination during chemical disasters and hospital-associated infections during epidemic illness can pose substantial threats to achieving this goal. Understanding basic principles of decontamination and infection control during responses to chemical and biologic disasters can help minimize the risks to patients and health care workers. Effective decontamination following toxic chemical exposure should include both removal of contaminated clothing and decontamination of the victim's skin. Wet decontamination is the most feasible strategy in a mass casualty situation and should be performed promptly by trained personnel. In the event of an epidemic, infection prevention and control measures are based on essential principles of hand hygiene and standard precautions. Expanded precautions should be instituted as needed to target contact, droplet, and airborne routes of infectious disease transmission. Specific equipment and measures for critical care delivery may serve to decrease risk to health care workers in the event of an epidemic. Their use should be considered in developing comprehensive disaster response plans. Key words: decontamination, infection control, personal protective equipment, respiratory failure, chemical disaster, epidemic. [Respir Care 2008;53(2):201–212. © 2008 Daedalus Enterprises]

Introduction

Although hundreds of catastrophes occur each year,¹ only a few types of disasters have the potential to cause

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mass respiratory failure associated with substantial secondary risk to health care workers. Conventional explosions and natural disasters, such as earthquakes or tsunamis, may result in varying numbers of critically injured victims,²⁻⁴ but these types of disasters are not usually associated with substantial secondary exposures. Chemical exposures and epidemics, however, are particularly likely to result in both large numbers of critically ill victims and

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substantial risk of secondary exposure of health care workers. Maintenance of a safe and stable health care infrastructure is critical to effective mass casualty disaster response. Minimizing the risk of secondary contamination or infection of patients and health care workers is essential to achieving that goal.

Planning for effective health care worker protection is particularly important in light of 3 facts:

1. Concerns about current workforce shortages
2. Estimates of increased demands on the workforce during a disaster
3. Increased risk posed specifically to critical care practitioners during disaster response

Recent reports have suggested that as many as 12% of hospitals have closed beds due to nursing shortages.⁵ Data analyzed by Mathews and colleagues suggest that a shortage of respiratory therapists is likely to develop in the next 10–20 years,⁶ and others have raised similar concerns about possible shortages of critical care physicians in the near future.⁷

Estimates for an influenza pandemic, one type of disaster with the potential to cause mass respiratory failure, emphasize the potential scope of the workforce capacity problem. The United States Department of Health and Human Services has estimated that a severe influenza pandemic could result in nearly 1.5 million individuals who require critical care and over 700,000 who require mechanical ventilation over the course of 12–16 weeks.⁸ This level of demand on a health care system with approximately 87,000 critical care beds at baseline⁹ is unprecedented. Thus, failure to protect workers in the event of a mass casualty disaster could cripple an already stretched critical care workforce at the time when they are most needed.

In addition to major increases in demand for critical care practitioners, those caring for the critically ill are likely to be at higher risk for secondary exposures. During response to the sarin gas release in Tokyo in 1995, intensive care unit (ICU) staff experienced secondary exposures at more than twice the rate of staff working on the general wards. This difference was probably due to ICU staff contact with those more severely ill patients who were initially exposed to higher levels of toxin.¹⁰ Further, procedures common to ICU care have been associated with increased risk of secondary infection of health care workers. Data from the severe acute respiratory syndrome (SARS) experience and elsewhere demonstrate that intubation, bronchial suctioning, and bronchoscopy pose a substantial increased risk of secondary infection,^{11–16} probably due to aerosolization of pathogens. Other studies suggest that increased risk may extend to noninvasive ventilation, nebulizer administration, and manual ventilation.^{11,17–19}

Thus, the expected increased demands on the health care system's critical care personnel coupled with the increased risk associated with delivery of critical care during disasters, require that response plans carefully consider

health care worker protection. If a sufficient number of health care workers become ill and unable to care for patients, an otherwise well-conceived response plan may be crippled.

This paper reviews basic principles of decontamination and infection control during responses to chemical and biologic disasters. It provides overviews of both hospital-based decontamination procedures following a chemical event and infection control measures for outbreaks based on known routes of infectious disease transmission. Finally, it reviews equipment and measures specific to critical care delivery that may serve to decrease health care worker risk in the event of epidemic or pandemic respiratory illness.

Chemical Exposures and Decontamination

Although chemical disasters may be caused by numerous agents, response planning categorizes these agents into one of 4 groups: asphyxiants, cholinesterase inhibitors, respiratory tract irritants, and vesicants.²⁰ Regardless of the type of chemical exposure, effective response to all classes of chemical agents is based on the initial key component of decontamination. This step is essential both to prevent ongoing exposure of the affected patient and secondary exposure of health care workers and to maintain safe ongoing hospital operations. Although in some situations primary decontamination may be undertaken in the field, concerns about incomplete decontamination and persistence of the toxic agent necessitate careful planning for effective hospital-based decontamination.

Perhaps the most well-known recent chemical disaster is that of the 1995 sarin gas release in the Tokyo subway. In that event, 5,500 individuals sought medical care and 12 died.²¹ 640 affected individuals were taken to nearby St Luke's International Hospital for treatment. None of those patients underwent primary decontamination prior to arrival at St Luke's, nor did the hospital initially implement its own decontamination procedures. As a result, 23% of all hospital staff reported symptoms of secondary exposure to sarin. Further, ICU staff experienced such symptoms at a significantly higher rate (39%) than did emergency department personnel (17%).¹⁰ This difference was attributed both to the well-ventilated emergency department and to the concentration in the ICU of patients with higher initial toxic exposures.

In a smaller but nonetheless alarming incident, 3 Georgia health care workers became severely ill after caring for a patient who ingested a large amount of an organophosphate agent in a suicide attempt. All three required antidotal therapy, one was intubated for 24 hours, and another was admitted overnight for observation. Importantly, the patient was not decontaminated and the health care workers did not use personal protective equipment (PPE).²²

Although hospital-based decontamination is most often performed by emergency medical responders or emergency department personnel,²³ critical care providers should be aware of the principles of decontamination for 2 reasons. First, in a mass casualty situation they may be reassigned to emergency response areas of the hospital. Second, they must be aware of the possibility of inadequate decontamination of patients being transferred to critical care areas. In such situations, critical care practitioners must know how to acquire the appropriate PPE and complete the decontamination process.

There is some debate about the appropriate level of PPE to be worn by “first receiver” personnel who are carrying out hospital-based decontamination. PPE levels range from Level A, an entirely encapsulated suit with a self-contained breathing apparatus, to Level D, which includes routine work clothes with standard precautions, including gloves and splash protection.²² It has been generally agreed that Level C PPE is adequate for most hospital decontamination scenarios.²² Level C PPE includes a nonencapsulated, chemical-resistant suit, gloves, boots, and a full-face air-purifying respirator²⁴ (Fig. 1).

Effective decontamination requires 2 principle steps: removal of the victim’s contaminated clothing and decontamination of the victim’s skin. Only emergency life-saving interventions, such as intubation or major hemorrhage control, should be initiated prior to decontamination.²³ Other medical management should be delayed until the toxic agent has been effectively removed. Removal of contaminated clothing generally results in an 85–90% reduction in the amount of the offending agent associated with the victim.²⁰ Clothing should be cut off rather than pulled off to avoid either aerosolizing the agent or exposing the face and mucous membranes to an agent that has contaminated the shirt.²³ Once clothing has been removed, either wet or dry decontamination of the victim’s skin may be performed.

Although dry decontamination with resins/clays to absorb toxic agents may be appropriate in some scenarios, wet decontamination is generally the only practical means of decontamination in a mass casualty setting with large numbers of nonambulatory victims.²³ Wet decontamination is performed using copious amounts of water alone, or, if available, soap and water. Water serves both to dilute and to remove most offending agents. Although a few agents react with water, timely removal with water is safer than delaying decontamination until specialized decontamination can be performed. For victims who are ambulatory, showering in a decontamination area set up for this purpose is the most efficient. Nonambulatory victims should undergo wet decontamination on stretchers in a dedicated area by trained health care workers using appropriate PPE. As mentioned previously, Level C protection is adequate for most scenarios, unless suspicion of a specific agent demands a higher level of protection.



Fig. 1. Level C personal protective equipment: chemical-resistant suit, gloves, boots, and a full-face air-purifying respirator. (Photograph courtesy of John A Schaefer, Department of Health, Safety, and Environment, Johns Hopkins University, Baltimore, Maryland.)

Advance planning is critical to successful hospital-based decontamination. The disaster plan must provide for adequate space for pre-decontamination waiting areas, decontamination tents with capacity to care for both ambulatory and nonambulatory victims, replacement clothing for decontaminated victims, and adequate post-decontamination shelter for those awaiting medical assessment. The best plans will also incorporate a means to assess for adequacy of decontamination and will provide training for health care workers to assess when a patient they have received has been inadequately decontaminated. Further, the plan must facilitate ongoing communication as patients transfer from one station to the next (eg, disaster site, decontamination, triage, emergency department, and subsequent patient care areas). Such communication would include what, if any, decontamination has been performed prior to each

transfer, as well as feedback on adequacy of decontamination from “downstream” care areas. Finally, the plan must be practiced repeatedly in advance so that personnel are fully aware of their responsibilities and how to protect themselves with appropriate PPE.

Decontamination may also be required in cases of exposure to infectious agents, such as in a deliberate release of anthrax powder. However, decontamination to prevent secondary exposure is generally less critical for biological agents than for chemical agents,²⁴ particularly since most biologic agents have a long enough incubation period that victims will have showered and changed their clothing prior to presentation.

Biologic Events and Health Care Worker Safety

Infection prevention and control are key components of health care worker protection during mass casualty biological events. During the SARS epidemic of 2003, over 8,000 infections were reported worldwide.²⁵ Of the 351 cases reported in Canada, 72% were infected in a health care setting and 45% were among health care workers.²⁶ These findings underscore the considerable risk to unprotected workers from infectious agents in a health care setting. A critical lesson of the SARS experience was also that use of PPE to control spread of infectious agents can be highly effective, even in settings where knowledge about the infecting agent is limited.²⁷

An effective disaster infection control plan must include several key components. First, infection control interventions should be targeted against specific pathogens or groups of pathogens as much as possible. Second, the plan should include provisions not only for adequate training in the use of specific types of PPE for all potentially involved health care workers, but also for appropriate quality control checks. Third, it should include appropriate environmental controls to maximize containment of potentially infectious material. Fourth, it should account for providing appropriate PPE to all vulnerable health care workers for a sustained period. Although a complete discussion of stockpiling issues is beyond the scope of this paper. Here are discussed the use of PPE targeted at specific modes of transmission, the correct use of PPE, and the development of expanded environmental controls, including critical care-specific devices that may enhance containment efforts. It should be noted that choice between types of PPE with similar protection factors should be informed by the ease of delivering patient care and performing procedures while using the equipment.

Routes of Transmission and Personal Protective Equipment

In general, infection-control efforts are targeted against 3 modes of transmission: contact (both direct

and indirect), droplet, and airborne transmission. Contact transmission occurs when an infectious microorganism is transferred to a susceptible host, either via direct body surface contact with an infected individual or via contact with a contaminated intermediate object. Droplet transmission occurs when an infected person generates microorganism-containing droplets ($\geq 5 \mu\text{m}$) by coughing or sneezing, which are transmitted over short distances (1–2 m) and deposited on the mucous membranes of a susceptible host. Airborne transmission occurs when contaminated droplet nuclei $< 5 \mu\text{m}$ are inhaled by a susceptible host. These smaller droplet nuclei may remain suspended in the air for long periods, and infection via this mode may occur over long distances in the absence of environmental controls.²⁸ After evaluation of the various modes of transmission of SARS during the 2003 epidemic, a classification scheme was proposed for types of airborne transmission. Under this scheme, airborne transmission may be obligate, preferential, or opportunistic. Obligate airborne transmission, as is seen with tuberculosis, causes infection only through aerosols deposited in the distal lung. Preferential airborne transmission occurs in diseases such as measles, which can be transmitted through multiple modes but are most frequently transmitted through the deposition of infected aerosols in the distal airways. Finally, opportunistic airborne transmission is associated with diseases that are preferentially transmitted via other modes but may become airborne under specific environmental conditions.²⁹ Strategies to prevent and control contagious infections should account for circumstances that may alter the mode by which a particular pathogen is spread. Such variability will probably require ongoing risk assessment by infection control personnel to guide PPE choices.

The Healthcare Infection Control Practices Advisory Committee (HICPAC) of the Centers for Disease Control and Prevention has developed guidelines for both standard precautions and transmission-based precautions, based on the modes of transmission outlined above. Standard precautions apply to all health care interactions, regardless of whether a patient is presumed to be infected. One or several types of expanded, transmission-based precautions may be added to control the spread of specific pathogens. The newly updated HICPAC guidelines for both standard and transmission-based precautions are summarized in Table 1.^{28,30}

Correct Personal Protective Equipment Use

Essential to the success of any infection control program is effective implementation through education and quality control. As the Institute of Medicine pointed out in its assessment of one type of PPE:

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Table 1. HICPAC Guidelines for Standard and Transmission-Based Precautions

Precautions	Scenario	Hand Hygiene	Gowns/ Gloves	Mask and Eye Protection	Environmental Controls
Standard	Use for all patients, regardless of confirmed or suspected presence of an infectious agent.	Should be performed before patient contact, after touching blood, body fluids, and contaminated items, immediately after removing gloves, and between patient contacts.	Gown should be worn when contact of clothing or exposed skin with blood or body fluids is anticipated. Gloves should be worn for touching blood, body fluids, contaminated items, mucous membranes or non-intact skin.	A surgical mask and eye protection should be worn during procedures and patient care activities likely to generate splashes or sprays of blood or body fluids, especially suctioning and endotracheal intubation.	Routine care, cleaning, and disinfection of environmental surfaces.
Contact*	Use for infectious agents that are spread by direct or indirect contact with the patient or his/her environment (eg, vancomycin-resistant enterococcus, <i>Clostridium difficile</i> , respiratory syncytial virus).	As above	Gown and gloves should be worn for all interactions that involve contact with the patient or contaminated areas of the patient's environment. Gown and gloves should be donned on room entry for pathogens known to be transmitted through environmental contamination.	As above	Single-patient room is preferred. When single-patient room is not available, consultation with infection control practitioners is recommended to assess other options, such as cohorting.
Droplet*	Use for infectious agents that are spread through close respiratory or mucous-membrane contact with respiratory secretions (eg <i>Bordetella pertussis</i> , influenza, <i>Neisseria meningitidis</i>).	As above	As per standard precautions	A mask should be donned on room entry. Eye protection should be used as per standard precautions.	As above. Curtains should be drawn between beds in shared patient rooms, and the patient should wear a mask when transported out of the hospital room.
Airborne*	Use for infectious agents that remain infectious over long distances when suspended in air (eg, <i>Mycobacterium tuberculosis</i> and varicella and rubeola viruses).	As above	As per standard precautions	A fit-tested N95 respirator or a powered air-purifying respirator should be worn whenever entering the patient room.	Patients should be placed in a monitored airborne infection isolation room, maintained with 6–12 air exchanges per hour and negative pressure relative to surrounding areas.

* Transmission-based precautions (always used in addition to standard precautions).
HICPAC = Healthcare Infection Control Practices Advisory Committee
(Adapted from Reference 30.)

Previous efforts to improve infection control in the hospital and elsewhere have demonstrated that the efficacy of an intervention alone does not guarantee its success. The best respirator or medical mask will do little to protect the individual who refuses, or who misunderstands how and when, to use it correctly.³¹

Effective protective technique requires use of both correct PPE donning and removal sequences and consistent hand hygiene before and after PPE use. The gown should be donned first and tied in back, followed by the mask or respirator. The mask nose piece should be fit snugly over the bridge of the nose, and any respirator should be fit-checked. Ties should be adjusted and secured at the back of the head. Goggles or eye-shield should then be secured over the head and gloves should be donned last. Gloves should extend over the cuffs of the isolation gown.³² If available, tape may be used to secure gloves to gown. Correctly donned contact, droplet, and airborne isolation PPE are shown in Figures 2 through 4. PPE should be



Fig. 2. Contact and droplet precautions.

removed at the doorway before leaving the patient room or in an anteroom. If wearing a respirator or powered air-purifying respirator, it should be removed outside the room



Fig. 3. Contact and airborne precautions with powered air-purifying respirator.



Fig. 4. Contact and airborne precautions with powered air-purifying respirator. Note that the powered air-purifying respirator belt is worn under the gown, to avoid contamination.

after the door has been closed. When ready to remove PPE, it is critical to recall which areas of the equipment are contaminated. In general, the outside front of the gown is considered contaminated, and the inside, outside back, and ties on the head are considered clean. It is essential to

avoid cross-contamination by touching contaminated parts of PPE.³²

When removing PPE, gloves should be removed first and hand hygiene performed. The face shield or goggles should be removed next, followed by the gown and, lastly, the mask or respirator. If gloves have been secured to the gown using tape, gloves and gown should be removed together as one piece. Eye protection and masks should be removed by grasping the ties at the sides or back of the head, rather than touching the contaminated front of the mask or goggles. Hand hygiene should be performed following removal of all PPE.³²

Table 2 outlines recommended precautions for specific representative biologic agents, and Table 3 compares types of respiratory protection that may be used for care of patients in airborne infection isolation.

Environmental Controls and Devices

In addition to PPE, environmental controls play a critical role in effective infection control during certain mass casualty response situations (eg, smallpox or epidemic/pandemic respiratory illness). Just as other resources are likely to be overwhelmed, a major epidemic caused by an airborne pathogen may overwhelm the usual airborne infection isolation capacity. Minimizing health care worker risk through environmental control necessitates planning for both cohorting of infected patients when airborne infection isolation is unavailable and expanding airborne infection isolation through repurposing non-airborne infection isolation spaces. When private rooms are overwhelmed, it will be necessary to cohort infected patients in separate areas from those without known or suspected disease.³⁶ Plans must also be made to minimize risk of exposing multiple staff or staff cross-contamination by careful patient care assignment. Those health care workers caring for infected individuals should not care for both infected and uninfected patients at the same time, and they should be carefully screened for symptoms of infection before and after each shift.

Environmental control planning also involves the expansion of negative-pressure rooms/areas for airborne infection isolation. Several authors have suggested ways to rapidly expand effective negative-pressure care areas. Gomersall and colleagues have outlined a method to increase ICU negative-pressure capacity by installing industrial exhaust fans in external windows of individual rooms or cubicles within an open unit to generate negative pressure.³⁷ Mead and colleagues developed and tested means to convert conventional hospital rooms into effective negative-pressure isolation rooms using portable high-efficiency particulate air (HEPA) filters.³⁷ In that study multiple configurations were tested that could be set up within a few hours, and the most effective format achieved

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Table 2. Recommended Precautions for Specific Biologic Agents

Agent	Mode of Transmission	Patient Placement	Type and Duration of Precautions
Smallpox	Inhalation of droplets or aerosols	Patients should be placed in airborne infection isolation whenever possible. In a mass-exposure situation, cohorting may be appropriate.	Standard, contact, and airborne precautions should be used until all scabs have separated (3–4 weeks). Only immune health care workers should care for infected patients. Nonimmune individuals who are exposed should receive post-exposure vaccination within 4 days.
Anthrax	Person-to-person transmission does not occur with respiratory or gastrointestinal tract anthrax. Person-to-person transmission of cutaneous anthrax is extremely rare.	No restrictions	Standard precautions. If presence of aerosolized powder or environmental exposure is suspected, airborne precautions should be used and exposed persons should be decontaminated.
Pneumonic plague	Inhalation of respiratory droplets. Risk of transmission is low during the first 20–24 hours of illness.	Patients should be placed in private rooms whenever possible, and cohorted if private rooms are unavailable.	Use standard precautions. Droplet precautions should be used until the patient has received at least 48 hours of appropriate therapy.
SARS	Droplet and contact transmission. Opportunistic airborne transmission possible.	Airborne infection isolation	Standard, droplet, and airborne precautions with eye protection should be continued for the duration of potential infectivity.
Pandemic influenza	Presumed transmission primarily via large respiratory droplets, but opportunistic airborne transmission also possible.	Airborne infection isolation	Standard, droplet, and airborne precautions with eye protection should be continued for 14 days after onset of symptoms or until an alternative diagnosis is made.

SARS = severe acute respiratory syndrome
(Adapted from References 30 and 33.)

an 87% reduction in estimated health care worker exposure to the infectious agent. In another study, Rosenbaum and colleagues outlined a method for converting a large hospital space, as opposed to individual patient rooms, into a negative-pressure patient care area capable of accommodating approximately 30 patients.³⁸ Although establishing such units has not been tested in the presence of actual patients, the suggested methods appear to be capable of rapidly providing negative-pressure space with the Centers for Disease Control and Prevention requisite 12 air exchanges per hour,^{30,39} which would vastly enhance the safety of both workers and other patients. Hospital air-conditioning systems may also be modified to eliminate recirculated gas or filter it through HEPA filters in high-risk situations.³⁶ Finally, based on early studies in tuberculosis patients,⁴⁰ some

have suggested that ultraviolet light may have a role in environmental infection control in the setting of infections with potential for airborne spread.⁴¹ This strategy, however, remains untested.

In addition to environmental controls and PPE, the high risk of critical care delivery demands utilization of best practices to control spread of contagion at its source. A comprehensive review of devices that might be used or developed to limit environmental contamination in an epidemic or pandemic is extensive and beyond the scope of this paper. Here, however, are reviewed several devices potentially useful to the infection control armamentarium of the critical care practitioner for source containment in patients across the spectrum of illness severity. These include protective devices for patients using face-mask oxygen and protective devices for mechanically ventilated

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Table 3. Types of Respiratory Protection With Patients in Airborne Infection Isolation

Respirator Type	N95 Filtering Face Piece	Elastometric Air-Purifying Respirator (APR)	Powered Air-Purifying Respirator (PAPR)
Filter efficiency (%)	95	95–100	99.97 (HEPA filter)
Assigned protection factor	10	10 (half mask) 50 (full mask)	25 (loose-fitting face piece)
Fit-testing	Annual fit-testing required by OSHA standards. Not appropriate for use with facial hair. Seal check required with each use.	Annual fit-testing required by OSHA standards. Not appropriate for use with facial hair. Seal check required with each use.	May be used with facial hair. Fit testing not required.
Ease of use	Lightweight Minimal interference with patient care	Lightweight May interfere with communication.	More comfortable than tight-fitting negative-pressure respirators and associated with lower breathing resistance. May be bulky, noisy, and interfere with communication.
Storage and maintenance	Disposable Most do not require specific cleaning or maintenance	Requires routine inspection, cleaning, and repair. Durable and requires only replacement of filters as needed.	Requires routine inspection, cleaning, and repair. Batteries must be charged.
Cost (\$)	1–5	17–30	450–650

HEPA = high-efficiency particulate arrestor

OSHA = Occupational Safety and Health Administration

(Adapted from References 34 and 35.)

patients. In addition, special problems with high-frequency oscillatory ventilation (HFOV) are briefly addressed.

As has been outlined above, the SARS experience revealed that a number of critical care procedures may be significantly associated with increased risk of infection by respiratory viruses.¹¹ Among them is the manipulation of an oxygen mask. Several authors have since examined the dispersal of respiratory droplets with the use of standard open oxygen delivery masks, including both an air-entrainment type mask and a standard nonrebreather mask.^{42–44} One study compared the use of the standard masks with side vents to a nonrebreather that could be used with a filter on the expiratory port, the Viasys Hi-Ox 80 (Fig. 5).⁴² This study demonstrated that the visible plume of exhaled droplets was reduced with use of this filter, but change in measurable particle dispersal was not tested. It should be noted that although use of a Hi-Ox mask may reduce environmental contamination by an infected patient, it should not be expected to reduce a patient's exposure to a potentially contaminated environment.

In a mass casualty situation, patients with possible infection may need to share rooms with patients who are known to be infected. In that event, a mask to provide protection of the patient from the environment, in addition to source containment and supplemental O₂ for the in-



Fig. 5. Hi-Ox 80 mask with (left) and without (right) available nebulizer. (From Reference 42 with permission)

fectured patient, would be needed. Although such a device is not currently available, Mardimae and colleagues have demonstrated that an N95 mask may be modified to permit supplemental oxygen administration without loss of filtration and isolation efficacy.⁴⁵ An N95 nonrebreather mask,



Fig. 6. ISO-O₂ oxygen mask. (Courtesy of Viasys.)

the ISO-O₂ oxygen mask, has been approved for use by both Health Canada and European licensing bodies (Fig. 6). The United States Food and Drug Administration evaluation of this device should be completed in the near future (personal communication, Alex Stenzler, SensorMedics, 2007).

For the patient who requires mechanical ventilation, several strategies may prove important in containment of infection. As previously outlined, aerosol-generating procedures frequently associated with mechanical ventilation, such as intubation and suctioning,¹¹ have been associated with increased risk of infection. Procedures such as intubation and bronchoscopy, which require immediate access to the airway, are not readily amenable to the use of specific devices to limit spread of contagious material. For such procedures, correct PPE use is the best line of defense. However, strategies for both ventilator-circuit maintenance and endotracheal suctioning have been suggested that may minimize infectious risk to the health care worker.

In his review of the impact of SARS on filter use in Canada, Thiessen suggested that, in addition to those procedures outlined above, several other commonly performed critical care procedures are likely to pose threats.⁴⁶ Of specific concern are other procedures that require breaks

in the breathing system, including circuit changes, filter changes, and open-circuit suctioning. Maintaining the integrity of the breathing circuit probably decreases the risk to the health care worker by minimizing exposure. Neither minimizing routine changes in ventilator circuits nor extended use of closed-circuit suction catheters increases the risk to the patient of ventilator-associated pneumonia.⁴⁷⁻⁵⁰ Therefore, minimizing such procedures to reduce health care worker risk can be accomplished without adding risk to the patient.

No data are available that compare the use of heated humidifiers and heat-and-moisture exchangers (HMEs) in a mass casualty situation. However, in most mass casualty respiratory failure patients, HMEs are preferable, given their low cost and small size.⁵¹ Heated humidifiers may be reserved for selected patients (eg, those with copious secretions or requiring high minute ventilation).⁵¹ In patients with whom HMEs are used, device changes should be minimized when possible, to avoid breaking a potentially infectious ventilator circuit. It has been demonstrated that HMEs may be used from 3 to 7 days without decrease in performance.⁵²⁻⁵⁵ However, they should be carefully observed for evidence of occlusion by blood or secretions, which increases airways resistance and necessitates more frequent changes.

The addition of filters to ventilator circuits, alone or in combination with an HME, has been suggested.⁴⁶ It is unknown whether exhaled gas from mechanical ventilation poses a substantial infectious risk to health care workers or other patients.⁵¹ Nevertheless, strategies that target maximum source containment may include gas filtration, either by placing filters in the inspiratory and expiratory limbs of the patient circuit on the ventilator side or by adding a filter between the endotracheal tube and the circuit, in the form of an HME filter. A key problem with HME filter use is that buildup of condensation and associated increased airways resistance require frequent device changes. Such frequent changes could significantly increase the number of high-risk health care worker exposures. There is data to suggest that composite HME filter devices with separate filter and heat-and-moisture-exchanging elements are more likely to be associated with excessive work of breathing than are HME filters that are designed with a pleated ceramic membrane that acts as both a filter and an HME.^{56,57} However, both types require careful monitoring for blockage by accumulated secretions and therefore may be impractical for use in a mass casualty setting.

Those who decide on the use of filtration systems for their mechanically ventilated patients should be aware that, unlike for medical respirators, no current National Institute of Occupational Safety and Health guidelines require minimum efficiency ratings for breathing system filters. Once a strategy for filtration is chosen, the individual planner must ensure

that the expected efficiency testing has been performed on the selected filter.⁵⁸ It is also important to note that no matter how effective the devices and strategies discussed here may prove to be, their use does not diminish the central role of consistent hand hygiene and PPE use.

The use of HFOV poses additional infection control challenges in the event of epidemic or pandemic respiratory illness.^{46,59} HFOV use involves constant venting of unfiltered, aerosolized gas out of the mean airway pressure-control diaphragm into the patient room. The entire system includes 1 exhalation valve and 2 high-pressure dump valves whose design prevents filtration. Further, effective scavenging of exhaled gas from all 3 valves would probably be impractical. Although HFOV has not been demonstrated to increase risk in the same way that intubation does, data on its use in the setting of febrile respiratory illness are limited.⁶⁰ Until additional data are available, HFOV should be used cautiously in the setting of mass respiratory failure due to an infectious agent with the potential for secondary transmission.

Summary

Infection control, decontamination, and health care worker protection issues surrounding the delivery of mass casualty mechanical ventilation are myriad and complex. However, despite the challenges posed, it is critical that preparedness and planning efforts include careful consideration of these aspects of effective response. Thoughtful planning for health care worker safety during a mass casualty respiratory failure event can minimize the morbidity of such a disaster, protect individual health care workers, and help maintain the stability of the health care system.

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Discussion

Sandrock: I have a question about equipment and environmental decontamination. Influenza and SARS, for example, are partly spread by contact. In a mass casualty setting, because resources will be limited, there will be a lot of shared resources, so aggressive equipment decontamination will be very important, particularly if a clinician is moving from patient to patient.

We had a *Stenotrophomonas* outbreak in a long-term-ventilation hospital I work at; about 40 of the patients are on long-term ventilation. We don't have pulse oximeters in every room, and we traced the *Stenotrophomonas* to the respiratory therapists, who were doing their best but carrying the bacteria from room to room on the pulse oximeters, which they had not been decontaminating between patients.

We also have an issue with *Clostridium difficile*, which is obviously a big issue in the hospital. Some of the basic things we use to eradicate this disease don't always work, because the clostridium form spores. The CDC [Centers for Disease Control and Prevention] often recommends bleach for environmental decontamination. We have tried to move to using bleach wipes rather than diluting concentrated bleach down to the appropriate level. The respiratory therapists didn't like having to walk back to the central decontamination area, spray their equipment with bleach, and then smell like bleach the rest of the day. These bleach wipes have some scent and they don't smell as strong.

Daugherty: In our institution we use the standard quaternary ammonium hospital disinfectant solution for routine cleaning of medical equipment and bleach if there is concern about spore-forming organisms. Our Hospital Epidemiology and Infection Control office has not made a move to the bleach wipes, to my knowledge. Your point is certainly important. Effectively decontaminating shared equipment in a mass casualty situation will be essential for infection prevention and control.

Sandrock: These wipes are on the order of 10 times more expensive than bulk bleach, so that really changes things, but they might reduce spread. Regarding PAPRs [powered air-purifying respirators] and N95 masks, yesterday I talked with some people from the audience and—obviously—industrial hygienists view the issues very differently than do infection-control clinical people.

My hospital switched from N95s to PAPRs, mainly because it's probably going to be cost-effective in a couple of years and we think they provide better protection. But another issue is the limited supply and production of N95s. In our modeling at UC [University of California] Davis we calculated that we would need millions of N95s during the first phase of a pandemic. Do we need these large numbers or masks and/or respirators? Are there alternatives?

Daugherty: A move towards PAPRs and away from N95s is certainly one option. At the hospital where I work we routinely use PAPRs. My concern

is that it can be challenging to deliver quality patient care while wearing a PAPR. Auscultation and communication with the patient can be quite difficult. It is not unreasonable to wonder if health care workers will be less compliant with PAPRs than they should be, because of the perceived interference with patient care. PAPRs won't offer much better protection if compliance is poor.

But I think institutions will probably need to incorporate both PAPRs and N95s in their response plans. Unfortunately, an institutional shift toward PAPR use can result in gaps in routine fit-testing, and at times PAPR training is minimal. Although fit-testing and PAPR training are not all that time-consuming, it may be very difficult to ensure these goals are accomplished once a pandemic has already begun.

Sandrock: You're right. We're not looking at fit testing; we're looking at the regular training and function in the PAPRs, and then not fit-testing, so that will be an issue, although just-in-time fit testing is not too difficult.

Daugherty: I think that largely that depends on the scale of the event.

Rubinson: Can I pose a question to the audience? By a show of hands, how many of you would come to work—be as honest as you can—if there was a disease out there that we don't know how it's spread, for which there is no treatment, and that seems to put at high risk people doing airway management, given the equip-

ment and training you have now? . . . Excellent!

Daugherty: That's great.

Rubinson: But if members of your staff, whom you trust and know as folks who probably use equipment quite well, got sick and ended up in your ICU, how many of you would still come to work? The prior question was for an unknown situation, which is scary enough. But this second question is about a situation where people you have a lot of respect for got sick using the same equipment that you would use. Would you continue to work?

That was the scenario in various countries that were affected by SARS, and you can imagine the heroic nature of those folks to show up every day in the risk of a disease that they didn't know really how it was transmitted or how to treat it.

With PAPRs, how many people are taught how to test for adequate flow and make sure that they can put it on and take it off without self-contaminating? The equipment is only good if there is adequate training to use it properly, and a PAPR's protection goes down substantially if you are self-contaminating with diseases that can be transmitted via contact. If you self-contaminate, you have a device that has a high protection factor for a droplet nuclei, but you actually may be self-contaminating more frequently than if you were to just use an N95 mask. Don't think that just buying something gives you protection. It's buying something for an intended purpose and knowing how to use it.

Daugherty: I agree.

O'Laughlin: Are you aware of anybody who's looked at the way we use N95s or PAPRs now versus the way that we would have to try to use them when we don't have much in the way of supplies coming our way anymore? Typically, you would toss out an N95

after one use. Would we ever save N95s that aren't grossly contaminated, and try to reuse them because something is better than nothing?

Daugherty: I sat in on some meetings of the Institute of Medicine's 2006 committee on the reusability of face masks during a pandemic, which evaluated reuse of N95s, among others. The committee suggested that an individual user could potentially reuse his or her own filtering face piece, if absolutely necessary, provided that (1) it is protected from external surface contamination, (2) it is carefully stored, and (3) hand-hygiene is used before and after removal of the mask. The committee's report¹ affirmed that there are important gaps in our knowledge base on this issue, and they included an important research agenda with their findings. I believe some work from that agenda is going on at NIOSH [National Institute for Occupational Safety and Health], but I'm not aware of any data on the topic.

1. Committee on the Development of Reusable Face Masks for Use During an Influenza Pandemic, Institute of Medicine, Board on Health Sciences Policy, and National Academies Press (United States). *Reusability of face masks during an influenza pandemic: facing the flu*. National Academies Press, Washington DC; 2006.

Ritz: What about the hospital's air-handling system that gathers all this potentially contaminated environmental gas and exhausts it out onto the hospital roof? Should that gas be conditioned or filtered before it's exhausted outside the hospital?

Daugherty: The CDC recommends that (1) HVAC [heating, ventilation, and air conditioning] air exhaust outlets be located at least 25 feet from air intakes, (2) intakes be located at least 6 feet above the ground or 3 feet above roof level, and that (3) exhaust from contaminated areas be located above roof level to minimize air recirculation.¹ The CDC also recommends HEPA [high-efficiency particulate ar-

restor] filtering of air from airborne-isolation areas if that air cannot be effectively exhausted to the outside and must be recirculated through the hospital.²

1. National Fire Protection Association. Report of the Committee on Health Care Facilities, Technical Correlating Committee. NFPA 99, November 2001 ROC. Standard for Health Care Facilities. Regulation 5.1.3.6.7.2. <http://www.nfpa.org/assets/files/pdf/rop/99-f2001-roc.pdf>. Accessed November 16, 2007.
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Ritz: You're right; it depends upon whether the system has to exhaust this. It's 10 feet from the nearest window. There are a lot of building regulations, but I guess the question is, What is the transmission radius for droplet precautions for these things? How far away? One would assume that the exhaust for vacuum-handling and room-handling systems would be hundreds of feet away from the patient, and so would that be outside the transmission radius? Would filtering be necessary to provide droplet precautions? My understanding is that you could put HEPA filters in the systems, but that adds another level of complexity and maintenance to the system.

Daugherty: The main pathogens we are concerned with in terms of HEPA filtering and effective HVAC systems are airborne pathogens. Pathogens that are spread via droplet transmission generally don't travel more than 3 to 6 feet. It may be a major challenge in the face of an epidemic, however, to clearly define a pathogen's predominant route of transmission. This is particularly true when considering the question of obligate versus preferential versus opportunistic airborne spread of pathogens.

Ritz: In my institution we adopted a technique, mainly to prevent lung derecruitment, that when we disconnect the patient from the mechanical ventilator (which is as infrequently as possible), if the patient has an endotracheal tube in place, we clamp that tube prior to disconnecting, which prevents the patient from spewing aerosols out on us. Most ventilators are designed to limit the amount of gas output during a disconnect. They'll deliver a single gas burst and then shut off the flow. In your opinion, is that a useful technique to prevent environmental contamination?

Daugherty: That sounds like a reasonable approach, but its impact on environmental contamination has not been studied, to my knowledge. At

my institution we use a similar procedure, particularly with patients on HFOV [high-frequency oscillatory ventilation], to prevent derecruitment, but not for limiting environmental contamination. One of the challenging things about infection control is that, though some things are known to be effective, there is so much research that is still needed.

Hanley: How does facial hair affect the efficacy of masks that we wear for aerosol protection? Also, do you know what was the rate of staff absenteeism in Toronto during the SARS epidemic?

Daugherty: With an N95 filtering face piece, facial hair can prevent establishment of an adequate seal be-

tween the edge of the mask and the skin. If this happens and the fit-test cannot be completed satisfactorily, an alternative protection mode, such as a PAPR, must be used. This can pose a problem in institutions that routinely use N95s rather than PAPRs. Often PAPRs are difficult to find in these places. I think the absenteeism during the SARS outbreak in Toronto was fairly low, but I don't have the numbers.

Sandrock: Tom Stewart said that the absentee rates were extremely low. If anything, they had a difficulty with too many staff showing up for work during that time.¹

1. Hawryluck L, Lapinsky SF, Stewart TE. Clinical review: SARS: lessons in disaster management. *Crit Care* 2005;9(4):384-389.