

SUSTAINED MECHANICAL VENTILATION OUTSIDE OF TRADITIONAL INTENSIVE CARE UNITS

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Objectives

- Describe the medical response capability needed for mass casualty respiratory failure.
- Summarize the functional requirements of space to be adapted for disaster critical care.
- Identify the essential characteristics of positive pressure ventilation equipment for use in a mass casualty incident.
- Summarize the ancillary respiratory equipment recommended for use in mass casualty critical care.



Case Study

As the head of the critical care committee for your hospital, you have been asked by your medical board to develop and implement a plan for mass critical care in the event of an influenza pandemic. You need to ensure that with only 24 hours' notice your hospital will be ready to handle at least double its usual number of patients with acute respiratory failure.

- What issues need to be addressed to ensure you are adequately prepared?
- What criteria should you use to evaluate additional ventilators that might be purchased for stockpiling?
- What infection-control issues might need to be addressed?

I. INTRODUCTION

Although mass casualty incidents occur frequently worldwide, few have generated hundreds or thousands of casualties with respiratory failure. Most acute disasters result in traumatic injuries rather than critical illness (1-3). Traumatic injuries that are severe enough to cause coma, shock, or respiratory failure are frequently fatal before rescue and stabilization can be achieved (4, 5). Most survivors requiring ventilatory support are able to receive definitive positive pressure ventilation using existing local or regional capabilities (6-8). Even events associated with higher proportions of critically injured survivors, such as explosions in enclosed spaces or structure fires, usually result in relatively small numbers of victims who develop acute respiratory failure (8-12). Consequently, in nations with widespread critical care capabilities, there has been minimal need for delivery of mechanical ventilation outside of traditional intensive care units (ICUs) for extended periods of time.

Concerns about the emergence of novel respiratory pathogens, as occurred during the severe acute respiratory syndrome (SARS) epidemic of 2002 to 2003; the growing possibility of an intentionally created catastrophe; and the threat of an influenza pandemic have generated increased awareness that disaster planning must include preparation for delivery of sustained mechanical ventilation by means other than usual practice. Much recent attention has been focused on events that would cause large-scale, survivable respiratory failure but limit patient evacuation due to concerns about infection control challenges or other concerns. Inhalation of toxic chemicals, epidemics, detonation of nuclear fission devices, and natural disasters that cause aspiration pneumonia and septic shock are among the scenarios likely to result in mass respiratory failure. In such cases, the demand for mechanical ventilatory support could far exceed routine critical care capacity. Careful pre-event planning is essential to ensure that the numerous victims of such events have access to the potentially life-saving critical care that they need.

In this chapter, we discuss the key elements of planning for response to mass respiratory failure, including evaluation and use of appropriate treatment space, selected medical equipment, and professional staff. All 3 of these aspects must be carefully considered in the development of an effective plan for responding to mass respiratory failure. This chapter updates and extends the authors' previous paper on this topic, "Mass casualty respiratory failure" (*Curr Opin Crit Care*. 2007;13(1):51-56).

II. SPACE REQUIREMENTS FOR TREATING MASS RESPIRATORY FAILURE

On average, 65.5% of the 87,500 total US, nonfederal critical care beds are occupied (13), and larger hospitals tend to have even higher ICU occupancy rates (14). In the event of mass respiratory failure, routine critical care treatment space is likely to be rapidly overwhelmed. Planning response to such a scenario must address the use of alternative space, given the prohibitive cost of maintaining significant numbers of fully equipped local or regional ICU beds exclusively for use during disasters (15).

In the initial stages of response, postanesthesia care units, emergency department critical care beds, and monitored beds in endoscopy suites can provide some surge space. That approach, however, does not provide extensive additional critical care treatment space, and occupying those areas with critical care inpatients may adversely affect other core hospital functions (eg, emergency department throughput). Once those areas are occupied, additional alternative space will need to be utilized. General inpatient care may be delivered in non-hospital settings, such as gymnasiums (16). However, the need for supplemental oxygen, suction, monitoring equipment, and diagnostic facilities, and the potential need for specialized infection-control measures make treatment of mass respiratory failure outside the hospital impractical.

! Alternative space used for treating mass respiratory failure must be able to support needs for supplemental oxygen, suction, monitoring, and effective infection control. !

Some mobile medical facilities have treatment areas that are designed and equipped for critical care delivery. These facilities may have a role in the management of critical care surge, but they must provide sufficient additional capability to make their benefits outweigh the logistic challenges of their maintenance and deployment. Mobile options are most appealing for geographically isolated disasters (eg, tornadoes) in which regional ICU infrastructure is destroyed and rebuilding will take some time. Hence, they may be best used for replacing previously existing capacity rather than providing surge capacity.

For large events, most communities will need to utilize general hospital rooms to meet surges in critical care demand. Approximately 20% of general hospital beds have been made available within 24 hours during past disasters, and if critically ill patients are admitted preferentially, hospitals can quickly realize a significant increase their critical care capacity (17). During ongoing disasters, much of a hospital can be adapted for critical care delivery if adequate staffing and equipment are available. Because the field of disaster critical care is rapidly evolving, it is essential that those involved in emergency mass critical care remain abreast of developing recommendations for augmenting critical care surge capability.

III. MEDICAL EQUIPMENT REQUIRED TO TREAT MASS RESPIRATORY FAILURE

In a disaster that causes mass respiratory failure, it is likely that many patients will die without the benefit of mechanical ventilatory support, either for hypercarbic or hypoxemic respiratory failure or for airway protection. Although manual ventilation of patients in respiratory failure may be appropriate in the short term, its use on an ongoing basis will be severely limited by staffing requirements, lack of oxygen-conserving capability, delivery of inconsistent minute ventilation to patients with serious lung pathology, and potentially high infectious risk to staff. Ways of obtaining additional equipment include using vendors' rental supplies, adapting anesthesia machines and noninvasive ventilatory equipment, and accessing preplanned ventilator stockpiles.

The stockpiling of full-feature ventilators by hospitals, hospital systems, or even states is, however, likely to be cost prohibitive. For this reason, Rubinson and colleagues have suggested the stockpiling

of sophisticated portable ventilators (18). To be useful, such ventilators should have a minimum set of necessary features. They should be inexpensive to purchase and maintain, easy to use, and equipped with adequate alarms. The equipment should perform well in at least 1 basic ventilatory mode, and it should function using either high- or low-pressure oxygen sources. It should also be capable of running on battery power and of providing both adult and pediatric ventilation (18, 19) (see **Table 14-1**).

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Portable ventilators that are stockpiled for use in emergency mass critical care should meet specific minimum requirements.

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Table 14-1. Suggested Characteristics for Stockpiled Surge Mechanical Ventilators^a

Ventilator Criteria	Mandatory Characteristics	Beneficial, Optional Characteristics
Operating Characteristics		
Power source	AC with battery backup and ability to run without gas source; ≥4-h duration using standard evaluation of battery duration based on patient requirements for ARDS ^b should be at least 4 h in duration at the following: assist-volume control, 16-L minute ventilation; 35 breaths/min; 15 mL/cm H ₂ O compliance; 20 cm H ₂ O/L/s resistance; 10 cm H ₂ O PEEP; low-flow oxygen source at 4 L/min and 10 L/min; not 50 to 55 psi of oxygen or medical air source; and 1:2 I:E	Pneumatic operable (as additional power source option); external battery option >10 h on defined battery settings and total weight of kitted material remains <30 pounds; can recharge battery from null to full charge by AC current source within 4 h; demonstrated range of external and internal power tolerances Voltage: AC, -25% to +15% of nominal value; DC, -15% to +25% of nominal value Frequency: AC, -5% to +5% of nominal value
US Food and Drug Administration-approved for pediatric use	Pediatric and infant approved	
Modes of ventilation	Volume control (assist-control and synchronized intermittent mandatory ventilation)	Pressure control (only in addition to volume control) continuous positive airway pressure (for spontaneous breathing trial), but T-piece spontaneous breathing trial acceptable for noncontagious disease
Control of settings	Respiratory rate; PEEP; tidal volume; flow or I:E ratio; Fi ₂ (on source oxygen of 50 to 55 psi)	Trigger sensitivity; mode of ventilation; flow waveform; certain controls unavailable except for more experienced user levels (remain at default setting for usual user)
Range of flow	Minimum ≤10 L/min; upper limit ≥80 L/min	
PEEP	Internal PEEP; PEEP compensation ^c	PEEP upper limit ≥20 cm H ₂ O
Oxygen titration	Room air to Fi ₂ of 1.0 on oxygen source of 50 to 55 psi	
Operate without oxygen source of 50 to 55 psi	Able to operate on oxygen concentrator or low-flow oxygen source	
Measurements	Measure and display inspiratory tidal volume; peak inspiratory pressure	Inspiratory plateau pressure (static pressure); auto-PEEP; expired tidal volume
Pulse oximeter		Built-in pulse oximeter

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Table 14-1. Suggested Characteristics for Stockpiled Surge Mechanical Ventilators^a (continued)

Ventilator Criteria	Mandatory Characteristics	Beneficial, Optional Characteristics
Performance		
Ease to set up/ set ventilation settings/ troubleshoot	Ability to read screen at a distance and in sunlight and low ambient light; clear, easily understood, instructions in plain language in hard copy and electronically (Internet and stored within ventilator) are recommended. Novice users will need to be able to work with the ventilators without additional help.	Color coding of connections; unique connections for equipment with specific functions; laminated quick reference/troubleshooting guide; software interface to assist operator setup device
Oxygen consumption	Time to empty 680-L E tank: assist-volume control, 16-L minute ventilation; 35 breaths/min; 15 mL/cm H ₂ O compliance; 20 cm H ₂ O/L/s resistance; 10 cm H ₂ O PEEP; FiO ₂ of 1.0 and 0.5; 1:2 I:E ratio; >38 min FiO ₂ = 1.0; >104 min FiO ₂ = 0.5 Time to empty 680-L E tank: assist-volume control, 6-L minute ventilation; 12 breaths/min; 30 mL/cm H ₂ O compliance; 20 cm H ₂ O/L/s resistance; 5 cm H ₂ O PEEP; FiO ₂ of 1.0 and 0.5; 1:2 I:E ratio; >100 min FiO ₂ = 1.0; 280 min FiO ₂ = 0.5	
Sustained use	Documented evidence of sustained performance for: 2,000 h; assist-volume control, 16-L minute ventilation; 35 breaths/min; compliance 15 mL/cm H ₂ O; resistance 20 cm H ₂ O/L/s Documented evidence of sustained performance for 2,000 h: assist-volume control, 8-L minute ventilation; 60 breaths/min; compliance 3 mL/cm H ₂ O; resistance 200 cm H ₂ O/L (may be a separate machine for both 2,000-h evaluations); reference contacts for 3 or more clinical institutions where equipment is used ≥2 wk continuously	
Standards		Meets standard specification for ventilators intended for use in critical care (ASTM F1100-90); meets Lung Ventilators for Medical Use; Part 3 Emergency and Transport Ventilators (ISO 10651-3)
Safety		
Alarms	Audible and visible alarms; disconnect, apnea, high pressure, low-source gas pressure	Wireless fidelity or similar wireless technology included and demonstrated to reliably communicate through common hospital patient room walls (at least 1 receiver per 10 ventilators); receiver is capable of interfacing with any third-party pulse oximeter using standard wireless communication; visible alarm remains lit until reset by operator; multiple types of audible alarms denoting different severity of problems

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Table 14-1. Suggested Characteristics for Stockpiled Surge Mechanical Ventilators^a (continued)

Ventilator Criteria	Mandatory Characteristics	Beneficial, Optional Characteristics
Stockpiling Issues		
General durability	Fluid spill resistance; mechanical shock (similar to 4-foot drop, military standard); mechanical vibration; electromagnetic compatibility and electrical safety testing; storage temperature and humidity (-20°C to 60°C, 0% to 95% relative humidity); operating temperature and humidity (5°C to 40°C, 0% to 95% relative humidity)	
Recalls	Vendor must disclose all recalls on ventilator and equipment in the last 3 yr	
Vendor and support contract	Company will continue to produce ventilator model until at least 2012 and continue to support model 10 yr after order is completed; able to produce all ventilators within 18 mo from order; if unable to meet this criterion, estimated ramp-up/surge period and timeframe for delivery must be stated; 24-h, 7 d/wk direct telephone access to senior-level technician (vendor responsible for maintaining call coverage); warranty; provide any storage life data if available	Warranty period starts at first contact with patient; ability to produce all ordered ventilators within 9 mo from order
Maintenance	≥1 yr for battery and all equipment interval maintenance; also include battery replacement if needed	All usual maintenance activities can be performed with ventilator in kit; all usual maintenance activities can be performed with kits in stockpiled configuration
Purchasing costs	≤\$10,000; cost must include kitted ventilator, end-user training program, maintenance, and all necessary equipment (ancillary supplies) to ventilate 1 patient on both 50 to 55 psi and low-flow oxygen	
End-user training program	Interactive training via Internet or digital video disk with data demonstrating training effectiveness (subject to evaluator review for merit of data)	
Kit	Rigid case; weight of kit with ventilator and all ancillary equipment needed to ventilate 1 patient ≤30 pounds; wheels provided on case	Weight of kit with ventilator and all ancillary equipment needed to ventilate 1 patient ≤20 pounds
Additional approvals/clearances		Food and Drug Administration-approved closed-loop technology included with the ventilator (eg, oxygen conservation, ventilator-patient interaction feedback, and automated setting modification); full joint air worthiness certificate; full fleet air worthiness release; aeromedical certification letter from US Army

Abbreviations: AC, alternating current; ARDS, acute respiratory distress syndrome; ASTM, American Society for Testing and Materials; DC, direct current; FiO₂, fraction of inspired oxygen; I:E, inspiratory/expiratory ratio; ISO, International Standards Organization; PEEP, positive end-expiratory pressure; psi, pounds per square inch.

^a Reprinted with permission from Rubinson L, Hick JL, Curtis JR, Branson RD, Burns S, Christian M. Definitive care for the critically ill during a disaster: medical resources for surge capacity. *Chest*. 2008;133(suppl 5):32S-50S.

^b Brower RG, Lanken PN, MacIntyre N, et al. Higher versus lower positive end-expiratory pressures in patients with the acute respiratory distress syndrome. *N Engl J Med*. 2004;351(4):327-336.

^c Austin PN, Campbell RS, Johannigman JA, et al. Imposed work of breathing during ventilator failure. *Respir Care*. 2002;47(6):667-674.

One proposed solution to limited ventilator supply is the use of a single mechanical ventilator to support multiple patients (20, 21). Such a strategy, however, is problematic for a number of reasons, including the need to match patients with similar static compliance, oxygen and minute ventilation requirements, and risk for dynamic hyperinflation. Further, infection-control issues, inability to control patient-ventilator dyssynchrony, and variability in individual minute ventilation are likely to limit this approach's usefulness for patients with airway obstruction or acute lung injury.

A. The US Example

The number of mechanical ventilators currently available in the United States is a subject of debate, with estimates ranging from 53,000 to 105,000 (22). In any case, the vast majority of the full-feature mechanical ventilator supply is required to support even small surges in respiratory failure, as seen with seasonal influenza (22). Although in theory vendors' rental supplies could be utilized in a disaster, a recent drill in 1 region revealed that vendors had only 16 available ventilators to support as many as 3,500 potential surge critical care beds (23).

The Centers for Disease Control's Strategic National Stockpile (SNS) currently maintains approximately 4,500 ventilators for deployment to disaster areas. Distribution will depend on the event. For national events, the SNS will distribute the ventilators pro rata to states and territories, where officials will decide how to distribute them within their jurisdiction. Planners who want to know how many SNS ventilators may be available to them in a disaster should contact their state SNS official for the most up-to-date policies regarding the probable allocation of ventilators to their region. The SNS-managed inventory includes the Impact Univent Eagle 754, a limited-feature but sophisticated portable ventilator, and the Puritan Bennett LP-10, which has traditionally been used for the home care of patients with chronic respiratory disease (**Figures 14-1** and **14-2**). In 2009, the Department of Health and Human Services will purchase additional ventilators for the SNS. The recommended features of a surge ventilator were developed through consensus of several expert panels (24).

Delivery of mass ventilatory support is dependent on more than the ventilators themselves. Ensuring availability of adequate amounts of medical grade oxygen is also essential to an effective response. Because oxygen will not be delivered with SNS equipment and supplies, oxygen-conserving strategies will be vital if infrastructure for commercial oxygen delivery is damaged.

Oxygen systems include bulk liquid supplies, compressed gas cylinders, and oxygen concentrators. Both liquid and compressed gas cylinders can provide gas at 50 pounds per square inch or at low flows (25). Bulk liquid is the main source of oxygen for hospitals and is the best option for supporting mass mechanical ventilation. One cubic foot of liquid oxygen produces 860 cubic feet of oxygen at room temperature, allowing a typical bulk liquid system to meet demands for several weeks. Compressed gas cylinders, including the commonly used E-cylinder (644 L) or H-cylinder (6900 L), can meet short-term oxygen needs (eg, patient transport). However, given cost and storage constraints, most hospitals maintain only enough cylinders to cover short-term disruptions of the bulk liquid system.

Figure 14-1. Impact Univent Eagle 754^a



^aReprinted with permission from Daugherty EL, Branson R, Rubinson L. Mass casualty respiratory failure. *Curr Opin Crit Care.* 2007;13(1):51-56.

Figure 14-2. Puritan Bennett LP-10^a



^aReprinted with permission from Daugherty EL, Branson R, Rubinson L. Mass casualty respiratory failure. *Curr Opin Crit Care.* 2007;13(1):51-56.

Oxygen concentrators produce 1 to 6 L/min of 90% to 100% oxygen using an electric compressor to force gas through a sieve, which allows the movement of oxygen while restricting the passage of nitrogen (26). Oxygen concentrators cannot generate pressurized gas for a pneumatically powered ventilator but can provide low flows to be entrained into ventilator circuits. Because concentrators provide a lower F_{IO_2} at higher flow rates and can be quite expensive, their inclusion in stockpiled equipment is not recommended. They may, however, be incorporated into a disaster plan if they are already among routine equipment supplies.

Although oxygen for nonventilated patients may be conserved using reservoir cannulas or pulsed-dose technology (27), no data are available on the use of these devices during a disaster. A closed loop controller that adjusts F_{IO_2} to maintain SpO_2 between 92% and 96% has recently been shown to result in markedly reduced oxygen usage compared to clinician-adjusted F_{IO_2} in ventilated trauma patients (28). A controller-based system may prove useful in minimizing oxygen consumption during disasters if it becomes routinely available at reasonable cost.

Recommendations for routine monitoring in ICUs include use of pulse oximetry for patients receiving supplemental oxygen (29). In a mass casualty incident, hospitals may not have enough pulse oximeters to provide continuous monitoring for all ventilated patients. Intermittent pulse oximetry may be an acceptable alternative. There is insufficient data to compare outcomes with continuous versus intermittent monitoring, but episodic hypoxemia may be missed more often with the latter. Episodic hypoxemia has been well documented in patients undergoing anesthesia, in surgical ICUs, or patients admitted to a general medical service (30); and intermittent hypoxemia has been shown to result in poorer outcomes in head-injured patients (31). Clinical monitoring (eg, respiratory frequency and use of accessory muscles) can identify patients in need of more frequent monitoring, although this approach has not been validated.

Ancillary equipment such as ventilator circuits, humidification devices, and suction equipment must also be considered. Both ventilator circuits and closed-circuit suction catheters may be used in a single patient for the duration of ventilation, as long as they remain functional. There is limited, if any, risk of ventilator-associated pneumonia with prolonged use of these devices (32, 33). Humidification of inspired gases in the intubated patient is accomplished either via heated humidifier or heat and moisture exchanger (HME). In a mass casualty situation, passive operation, small size, and low cost make the HME the device of choice. Studies have demonstrated that a single HME can be used for the same patient from 3 to 7 days without decreasing performance, but these devices should be inspected for occlusion with blood or secretions and changed if obstruction is present. Available heated humidifiers should be reserved for patients with thick and copious secretions or with high minute ventilation requirements (34-37).

Additional equipment that should be considered in planning for mass mechanical ventilation includes airway supplies, respiratory medication delivery adapters, and pulse oximeter probes. Airway supplies should include manual ventilators, intubation equipment, endotracheal tubes with securing devices, closed-circuit suction catheters, single-use suction catheters for postextubation, suction traps, regulators, and hoses. A project of the American College of Chest Physicians Critical Care Collaborative titled “Definitive Care for the Critically Ill During a Disaster” recently provided more comprehensive guidance about equipment needed to ventilate patients outside traditional ICUs (38).

IV. PROFESSIONAL STAFF REQUIRED TO TREAT MASS RESPIRATORY FAILURE

A disaster that requires mass mechanical ventilation will dramatically increase the need for specially trained nurses, respiratory care professionals, physician assistants, acute care nurse practitioners, and physicians. In a recent analysis of US ICUs, Groeger and colleagues reported that 12% of ICUs responding to their survey had been forced to close beds owing to a shortage of nurses (39, 40). Even in the absence of a mass casualty incident, respiratory care practitioners, pharmacists, and physicians trained in critical care are in short supply (41-44). Establishing local or regional memoranda of understanding to share staff and to cross-credential clinicians across facilities can help if some hospitals are more affected than others by the shortages. Alternative strategies must be employed if a facility is geographically isolated or if many hospitals are simultaneously overwhelmed.

Two-tiered staffing, as recommended by the Working Group on Emergency Mass Critical Care, would increase the ability of critical care practitioners to oversee the care of vastly increased numbers of patients. This model calls for critical care specialists and nonspecialists to work collaboratively to care for the critically ill and injured (15). Both the Agency for Healthcare Research and Quality and the Department of Health and Human Services' Office of Preparedness and Emergency Operations are working on projects to augment staffing in the event of a disaster that results in mass casualty respiratory failure. Project Xtreme, an Agency for Healthcare Research and Quality-sponsored program, aims to provide just-in-time cross-training in respiratory care so that professionals from other areas will be ready to assist therapists in caring for surges of ventilated patients (45). The Office of Preparedness and Emergency Operations is collaborating with the American Association of Respiratory Care to train a total of 200 respiratory care professionals for disaster deployment (46), although deploying such teams may be logistically infeasible during a serious epidemic that affects multiple geographic areas concurrently.

! Tiered staffing can effectively extend the capabilities of critical care providers in a disaster. !

V. INFECTION CONTROL REQUIRED BY MASS RESPIRATORY FAILURE

Certain biologic disasters with the potential for secondary transmission of infection add the challenge of large-scale infection control (47). Infection-control measures will play an essential role in a successful response to an outbreak of a highly transmissible virulent pathogen. The risk of secondary transmission may be higher in critical care delivery than in other settings due in part to the number of interventions that could potentially cause aerosolization of infectious material. Procedures such as endotracheal intubation (48, 49), open-circuit suctioning (48), and bronchoscopy (50-53) have been associated with increased risk of secondary transmission.

The risk associated with procedures such as noninvasive positive-pressure ventilation (48, 54), administration of nebulized medication (48, 55), and manual ventilation (48, 56) remains controversial. Some experts advocate higher levels of respiratory protection during the performance of high-risk procedures, such as the use of powered air-purifying respirators during bronchoscopies (50).

The SARS experience demonstrated that correct use of recommended personal protective equipment among healthcare workers can be highly efficacious in limiting disease spread (57). However, ensuring correct use of personal protective equipment, especially during a protracted response, remains a significant challenge. Data from the SARS outbreak reveal compliance as low as 56% to 67% among Hong Kong and US healthcare workers caring for infected patients (55, 58).

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Delivery of emergency mass critical care during a biologic disaster requires that special attention be given to infection control.
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The use of filters for inspired gases, expired gases, or within the HME is a subject of debate. Ventilators that draw air from the room for delivery to the patient should have a filter on the inspiratory inlet, particularly if there is a risk of secondary spread of disease in a biologic disaster. Filters are routinely used in the expiratory portion of the ventilator circuit to protect the flow and pressure-monitoring components rather than to decrease environmental contamination. Caregivers' risk for secondary infection from expired gas from intubated patients has not been documented, and the use of an HME with filter has not been shown to reduce either rates of ventilator-associated pneumonia or environmental contamination. The inclusion of a filter in the HME tends to increase the risk of obstruction. If used, expiratory filters should therefore be inspected frequently to avoid potential complications, including increased expiratory resistance, air-trapping, and pneumothorax (59, 60).

Key Points

SUSTAINED MECHANICAL VENTILATION OUTSIDE OF TRADITIONAL INTENSIVE CARE UNITS

- Planning for sustained mechanical ventilation outside ICUs requires consideration of space, equipment, and staffing issues.
- Mass critical care should not be delivered outside a hospital setting due to demands for compressed gas, suction, and diagnostic capabilities.
- Equipment planning should address the use of alternative ventilatory equipment as well as integration of stockpiles from federal or other sources.
- Decisions by individual hospitals, localities, or regions to stockpile ventilators should be guided by a set of minimum requirements related to cost, maintenance, ease of use, functionality, and versatility.

- Because oxygen is a key resource for response to mass respiratory failure, ensuring adequate supplies is essential to effective planning.
- Meeting needs for expanded staffing is likely to require both pre-event training of essential personnel and the use of tiered staffing.
- Infection-control issues must be carefully addressed in planning for delivery of critical care during an outbreak of a virulent, highly transmissible pathogen.



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