Definitive Care for the Critically Ill During a Disaster: Medical Resources for Surge Capacity*

From a Task Force for Mass Critical Care Summit Meeting, January 26–27, 2007, Chicago, IL

Lewis Rubinson, MD, PhD; John L. Hick, MD; J. Randall Curtis, MD, MPH, FCCP; Richard D. Branson, MS, RRT; Suzi Burns, RN, MSN, RRT; Michael D. Christian, MD; Asha V. Devereaux, MD, MPH, FCCP; Jeffrey R. Dichter, MD; Daniel Talmor, MD, MPH, FCCP; Brian Erstad, PharmD; Justine Medina, RN, MS; and James A. Geiling, MD, FCCP†

Background: **Mass numbers of critically ill disaster victims will stress the abilities of health-care systems to maintain usual critical care services for all in need. To enhance the number of patients who can receive life-sustaining interventions, the Task Force on Mass Critical Care (hereafter termed the *Task Force*) has suggested a framework for providing limited, essential critical care, termed *emergency mass critical care* (EMCC). This article suggests medical equipment, concepts to expand treatment spaces, and staffing models for EMCC.**

Methods: **Consensus suggestions for EMCC were derived from published clinical practice guidelines and medical resource utilization data for the everyday critical care conditions that are anticipated to predominate during mass critical care events. When necessary, expert opinion was used.**

Task Force major suggestions: **The Task Force makes the following suggestions: (1) one mechanical ventilator that meets specific characteristics, as well as a set of consumable and durable medical equipment, should be provided for each EMCC patient; (2) EMCC should be provided in hospitals or similarly equipped structures; after ICUs, postanesthesia care units, and emergency departments all reach capacity, hospital locations should be repurposed for EMCC in the following order: (A) step-down units and large procedure suites, (B) telemetry units, and (C) hospital wards; and (3) hospitals can extend the provision of critical care using non-critical care personnel via a deliberate model of delegation to match staff competencies with patient needs.**

Discussion: **By using the Task Force suggestions for adequate supplies of medical equipment, appropriate treatment space, and trained staff, communities may better prepare to deliver augmented essential critical care in response to disasters.** ***(CHEST 2008; 133:32S–50S)***

Key words: disaster medicine; influenza pandemic; mass casualty medical care; medical surge capacity

Abbreviations: CDC = Centers for Disease Control and Prevention; EMCC = emergency mass critical care; IMCU = intermediate care unit; NIPPV = noninvasive positive pressure ventilation; PPV = positive pressure ventilation; RT = respiratory therapist

The severe acute respiratory syndrome epidemic of 2002–2003, recent natural disasters, burgeoning concern about industrial and intentional catastrophes, and the looming threat of a severe influenza pandemic have stimulated much recent debate about how to care for a surge of critically ill people.[1–12] Still, most countries, including those with widely available critical care services, lack sufficient quantities of specialized staff, medical equipment, and ICU space to provide timely, usual critical care for a large

influx of additional patients (see "Definitive Care for the Critically Ill During a Disaster: Current Capabilities and Limitations"). Provision of essential rather than limitless critical care will be needed to allow many additional community members to access key life-sustaining interventions during disasters.

Without pre-event critical care surge planning, the quantities and types of medical resources that remain available will dictate which elements of critical care can be maintained. There is no guarantee that effective critical care interventions will be provided. Alternatively, critical care professionals could decide prior to an event what constitutes essential critical care practices and the associated staffing, medical equipment, and treatment space requirements. Critical care disaster preparedness efforts can then be focused to ensure that these crucial resources remain available in sufficient quantity during disasters in order to maximize delivery of essential critical care.

The Task Force for Mass Critical Care (hereafter referred to as the *Task Force*) was convened in January 2007 and defined emergency mass critical care (EMCC) as a circumscribed set of key critical care therapeutics and interventions, as well as the necessary supporting medical resources required to maintain continuity of sufficient critical care services during a catastrophe (Table 1 and "Definitive Care for the Critically Ill During a Disaster: A Framework for Optimizing Critical Care Surge Capacity"). The Task Force suggests that hospitals with ICUs plan to provide modified but sufficient critical care for a daily patient census triple their baseline ICU capacity for up to 10 days without adequate external assistance (see "Definitive Care for the Critically Ill During a Disaster: A Framework for Optimizing Critical Care Surge Capacity"). Additional details regarding the Task Force are summarized elsewhere (see "Summary of Suggestions From the Task Force for Mass Critical Care Summit"). This current document suggests quantities of essential medical equipment, treatment space expansion concepts, and staffing models to assist emergency planners, clinical staff, and public health officials to meet these capacity goals.

Development of Task Force Suggestions for Medical Resources

The majority of the 15 US Department of Homeland Security national planning scenarios have clear potential to cause mass critical illness and injuries.[13] These scenarios are likely to require additional medical supplies for the response, but at the same time they have a high potential to interrupt the supply of medical equipment at multiple points along the path from manufacturer to distributor to local health-care facilities. Current hospital reliance on "just-in-time" and stockless material management systems to reduce storage and inventory costs[14] leave institutions with vulnerably low reserves of key consumables and durable medical equipment.[15] Critical care equipment is no exception (Lewis Rubinson, MD, PhD; unpublished data; December 2007), so the quantity of additional critically ill patients a hospital can care for without resupply is impressively small. (See "Definitive Care for the Critically Ill During a Disaster: Current Capabilities and Limitations.")

Avoiding preparation to increase the availability of key medical resources will profoundly limit the capabilities of hospitals to offer many victims life-sustaining care when needed during a mass critical care event. Nevertheless, expecting all hospitals to stockpile multiples of every conceivable piece of critical care consumable and durable medical equipment for use only during low-frequency/high-consequence events is unrealistic and perhaps even reckless.[14] Optimal critical care disaster preparedness calls for a resource strategy between these two extremes. The limited scope of care suggested for EMCC (see "Definitive Care for the Critically Ill During a Disaster: A Framework for Optimizing Critical Care Surge Capacity") affords

*From the University of Washington (Dr. Rubinson), Seattle, WA; Hennepin County Medical Center (Dr. Hick), Minneapolis, MN; Harbor View Medical Center (Dr. Curtis), Seattle, WA; University of Cincinnati (Mr. Branson), Cincinnati, OH; University of Virginia (Ms. Burns), Charlottesville, VA; Mount Sinai Hospital/University Health Network (Dr. Christian), Toronto, ON, Canada; Sharp Coronado Hospital (Dr. Devereaux), Coronado, CA; Presbyterian Hospital (Dr. Dichter), Albuquerque, NM; Beth Israel Deaconess Medical Center (Dr. Talmor), Boston, MA; University of Arizona (Dr. Erstad), Tucson, AZ; American Association of Critical Care Nurses (Ms. Medina), Aliso Viejo, CA; White River Junction VA Medical Center and Dartmouth Medical School (Dr. Geiling), Hanover, NH.
†A list of Task Force members is given in the Appendix.
The views expressed in this article do not represent official positions of the Department of Veterans Affairs.
During the period of the project, Dr. Rubinson initially received partial salary support from a contract with the Strategic National Stockpile program at the CDC Coordinating Office for Terrorism and Preparedness and Emergency Response. He then received full salary support through an Interagency Position Agreement at the CDC Division of Healthcare Quality Promotion. The findings and conclusions in this manuscript are those of the author and do not necessarily represent the views of the CDC. The other authors have no conflicts of interest to disclose.
Manuscript received November 4, 2007; revision accepted March 3, 2008.

Correspondence to: Lewis Rubinson, MD, PhD, University of Washington, Harborview Medical Center, Campus Box 359762, 325 Ninth Ave, Seattle, WA 98104; e-mail: rubinson@u.washington.edu
DOI: 10.1378/chest.07-2691

Table 1—*Task Force Suggestions for Essential Medical Resources for EMCC*

PPV
3.1: EMCC requires one mechanical ventilator per concurrent patient receiving sustained ventilatory support.
3.2: PPV equipment purchased for surge capacity should at a minimum do the following: (1) be able to oxygenate and ventilate most pediatric and adult patients with either significant airflow obstruction or ARDS; (2) be able to function with low-flow oxygen and without high-pressure medical gas; (3) accurately deliver a prescribed minute ventilation in nonspontaneously breathing patients, and (4) have sufficient alarms to alert the operator to apnea, disconnect, low gas source, low battery, and high peak airway pressures.
Pharmaceuticals
3.3: To optimize medication availability and safe administration, the Task Force suggests that modified processes of care should be considered prior to an event, such as the following: (1) rules for medication substitutions, (2) rules for safe dose or drug frequency reduction, (3) rules for conversion from parenteral administration to oral/enteral when possible, (4) rules for medication restriction (*eg*, oseltamavir if in short supply during an influenza pandemic), and (5) guidelines for medication shelf life extension.
Treatment space
3.4: EMCC should occur in hospitals or similarly designed and equipped structures (*eg*, mobile medical facility designed for critical care delivery, veterinary hospital, or outpatient surgical procedure center). After ICUs, postanesthesia care units, and emergency departments reach capacity, hospital locations for EMCC should be prioritized in the following order: (1) IMCUs, step-down units, and large procedure suites; (2) telemetry units; and (3) hospital wards.
3.5: Nonmedical facilities should be repurposed for EMCC only if disasters damage regional hospital infrastructure by making hospitals unusable and if immediate evacuation to alternate hospitals is unavailable.
Staff
3.6: Principles for staffing models should include the following: (1) patient care assignments for caregivers should be managed by the most experienced clinician available; (2) assignments should be based on staff abilities and experience; (3) delegation of duties that usually lie within the scope of some workers' practice to different health-care workers may be necessary and appropriate under surge conditions; and (4) systematic efforts to reduce care variability, procedure complications, and errors of omission must be used when possible.

the opportunity to construct a more restricted list of medical resources for critical care surge capacity (Tables 2–4). This abridged set of resources is intended to make sufficient critical care surge capability achievable by most communities.

The Task Force sought to define the types and quantities of medical equipment, as well as the treatment space characteristics and staff competencies for EMCC. The primary objective guiding the derivation of the suggested resource lists and concepts was to maximize the ratio of clinical benefit to preparedness cost. In a separate document, the Task Force suggests that hospitals with ICUs plan to provide modified but sufficient critical care for a total daily census of critically ill patients equal to triple baseline ICU capacity for up to 10 days without adequate external assistance (see "Definitive Care for the Critically Ill During a Disaster: A Framework for Optimizing Critical Care Surge Capacity"). In this document, when quantities of equipment are presented, the suggestions reflect the requirements for 10 patient treatment spaces over a duration of 10 days. Communities are encouraged to determine their total equipment needs to meet their EMCC capacity goals.

The Task Force assumes durable medical equipment requirements to be one device for each treatment space for the entire 10-day period. To determine the suggested quantities of consumable medical equipment, the Task Force used (when available) published clinical practice guidelines and medical resource consumption data regarding everyday ICU management of common critical care syndromes that are anticipated to be predominant medical conditions during mass critical care events (*eg*, ARDS and severe sepsis). As a result of the paucity of published medical resource data for these conditions, most of the Task Force suggestions had to be derived empirically from the extensive, multiprofessional expertise of Task Force members in the fields of critical care, the military, and disaster medicine. To account for the impact of patient turnover on required consumable medical equipment, a supply buffer was developed. The premise for this additional quantity of equipment is that not all critically ill disaster victims will require 10 days of critical care; some will improve and no longer require critical care, and others will die. The next patient who is admitted to the same critical care treatment space will then require new consumable medical equipment, and thus the actual consumable equipment requirement will be greater than that calculated for one patient for 10 days. Given the lack of definitive data to estimate the additional equipment necessary to account for patient turnover across the range of plausible mass critical care events, the Task Force suggests that the supply buffer should be an additional 30% of consumables above what one individual patient would require for 10 days (130% of the resource; *ie*, plan on 1.3 endotracheal tubes per patient). The Task Force considers an additional 30% supply to be within the range of plausible need and still would not add a major financial barrier, which impedes most communities from adhering to the suggestions; 20% or 40% could just as easily be justified by individual communities. The Task Force also recog-

Table 2—*Suggested Characteristics for Stockpiled Surge Mechanical Ventilators

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[16] 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_2O compliance; 20 cm H_2O/L/s resistance; 10 cm H_2O PEEP; low-flow oxygen source at 4 L/min and 10 L/min; not 50 to 55 pounds per square inch 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; F_{IO_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[17]	PEEP upper limit ≥ 20 cm H_2O
Oxygen titration	Room air to F_{IO_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
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 both 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_2O compliance; 20 cm H_2O/L/s resistance; 10 cm H_2O PEEP; F_{IO_2} of 1.0 and 0.5; 1:2 I:E ratio; > 38 min F_{IO_2} = 1.0; > 104 min F_{IO_2} = 0.5 Time to empty 680-L E tank: assist-volume control; 6 L minute ventilation; 12 breaths/min; 30 mL/cm H_2O compliance; 20 cm H_2O/L/s resistance; 5 cm H_2O PEEP; F_{IO_2} 1.0 and 0.5; 1:2 I:E ratio; > 100 min F102 = 1.0; 280 min F_{IO_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_2O; resistance 20 cm H_2O/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_2O; resistance 200 cm H_2O/L/ (may be a separate machine for both 2,000-h evaluations); reference contacts for three or more clinical institutions where equipment used ≥ 2 wk continuously	

Table 2—*Continued*

Ventilator Criteria	Mandatory Characteristics	Beneficial, Optional Characteristics
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 one 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
Stockpiling issues		
General durability	Fluid spill resistance; mechanical shock (similar to 4-foot drop, military standard); mechanical vibration; electromagnetic compatibility and electrical safety testing; m; storage temperature and humidity (– 20° to 60°C, 0 to 95% relative humidity); operating temperature and humidity (5° 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 one 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 one patient ≤ 30 pounds; wheels provided on case	Weight of kit with ventilator and all ancillary equipment needed to ventilate one 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

*AC = alternating current; DC = direct current; PEEP = positive end-expiratory pressure; psi = pounds per square inch; F_{IO_2} = fraction of inspired oxygen; I:E = inspiratory/expiratory; ASTM = American Society for Testing and Materials; ISO = International Standards Organization.

Table 3—*Suggested Ancillary Equipment for Surge PPV

Devices	Reusable/ Consumable	Duration of Use	Minimum Number Per 10 Treatment Spaces for 10 d†	Comments
PPV equipment				
Manual resuscitator with face mask	Consumable or reusable	Duration of ventilation	13	Intubation/reintubation and some situations for patient transport, airway care, and emergency loss of medical gas or ventilator power source
Ancillary respiratory equipment‡				
Airway care				
Closed-circuit suction catheter	Consumable	Duration of ventilation	13	Crucial for respiratory-transmitted epidemics
Endotracheal tube	Consumable	Duration of ventilation	16	7.5 mm and 8.0 mm adequate for most adults; assumption: 3 extra per 10 treatment spaces to accommodate extubation failures and equipment malfunctions
Endotracheal tube securing device	Consumable	Duration of ventilation	16	Tape acceptable
Single-use suction catheter	Consumable	One time	10	If suctioning is required after extubation; assumption: approximately 50% survive, and 50% of them are extubated within 10 d; several catheters per patient and for tracheostomy patients not requiring continuous ventilation
Yankauer suction catheter	Consumable	Multiple use	13	For suctioning oropharyngeal secretions peri-intubation, while intubated, and when needed after extubation; kept with patient's equipment during entire mechanical ventilation requirement
Suction trap and hoses (regulator to trap and trap to suction device)	Consumable	Duration of ventilation	13	
Vacuum source and suction regulator	Reusable	Duration of ventilation	10 (if possible; multiple patient management processes require vacuum source)	
Circuits				
Circuit for use with HME	Consumable	Duration of ventilation	9	Assumption: HME acceptable for ~70% of patients.
Circuit for use with heated humidifier without wire	Reusable	Duration of ventilation	4§	Requires additional consumable items (see humidifier section)
Circuit for use with heated humidifier with wire	Reusable	Duration of ventilation	4§	
Expiratory limb filter in ventilator circuit				
HEPA style filter	Consumable	12 to 48 h depending on type of humidifier	100 (does not include 35 HME with filter; see humidification below)	If suspicious for contagious respiratory secretions; benefit is uncertain; possibility for occlusion with water and secretions; alternatively, may promote disease transmission owing to need to open circuit to replace when occluded

Table 3—*Continued*

Devices	Reusable/ Consumable	Duration of Use	Minimum Number Per 10 Treatment Spaces for 10 d†	Comments
Humidifiers				
HME (with or without filter)	Consumable	3 to 5 d per patient (without filter); 2 d per patient (with filter)	25 (without filter), or 50 (with filter capability if suspicious for contagious respiratory secretions)	Suggestions: absolute humidity ≥ 30 mg/L, dead space < 75 mL; assumption: acceptable for approximately 70% of patients
Heated humidifier, no heated wire circuit	Reusable	Duration of ventilation	4§	Meets needs of all patients but adds expense of a durable item and additional consumables
Water traps	Consumable or reusable	Duration of ventilation	4§	Not needed for HME; only needed for heated system without wire; consumables could be cleaned and reused
Heated humidifier, with heated wire circuit	Consumable	Duration of mechanical ventilation	4§	
Chamber	Consumable	Duration of ventilation	4	Not needed for HME but needed for either heated system; some companies still supply a reusable chamber
Sterile water	Consumable	2 L every 24 h	80 L	Not needed for HME but needed for either heated system; water is heavy, expensive, and requires large storage area
Medical gas				
Compressed air	Permanent	Duration of ventilation		Air compressors make air on site as long as electrical power is available; present at most hospitals
Compressed oxygen	Finite quantity that requires resupply	Duration of ventilation if 50to 55 psi oxygen not available		Number of cylinders limited by space and cost
50 to 55 psi line with quick connections from source to ventilator	Reusable	Duration of ventilation	10 air; 10 oxygen	
Liquid oxygen	Finite quantity that requires resupply			If distribution from supplier to hospital remains functional, provides significant oxygen capacity; existing piping of hospital may limit high flow if most or all oxygen stations are utilized
Oxygen reservoir for low-flow oxygen use by mechanical ventilator (if applicable)	Consumable	Duration of ventilation if 50 to 55 psi oxygen not available	13	
Oxygen regulators	Reusable	Duration of ventilation	1 per ventilator	50 to 55 psi regulator for gas cylinders if ventilator is pneumatically driven; otherwise, flow meter acceptable for supplementing oxygen to mechanical ventilator
Monitoring devices				
Pulse oximeter	Reusable	Intermittent patient checks	10	Task Force believes each patient must have continuous pulse oximetry because of the potential infection control challenges for staff performing oximetry rounds

Table 3—*Continued*

Devices	Reusable/ Consumable	Duration of Use	Minimum Number Per 10 Treatment Spaces for 10 d†	Comments
Disposable pulse oximetry probe	Consumable	Duration of stay	26	Disposable probes preferable in face of contact-transmissible diseases; number of disposable probes assumes that some will fall off patient after a period of time
Respiratory medication delivery				
MDI adapters	Consumable	Duration of ventilation	13	For patients needing bronchodilators
Up-Draft nebulizer (Hudson RCI; Durham, NC)	Consumable	Duration of ventilation	4	For patients needing nebulized medications not available in MDI form

*Pediatric-specific equipment, while not presented in order to limit the complexity of the suggestions, should be considered. Some devices may be used interchangeably for adults and most pediatric patients (*eg*, mechanical ventilators approved for adult and pediatric use). Amounts of pediatric-specific equipment should be determined by regional analysis of need in consultation with pediatric experts. HEPA = high-efficiency particulate air; HME = heat and moisture exchanger; MDI = metered dose inhaler; see Figure 2 legend for expansion of abbreviation.
†Consumable equipment for 10 patient-care spaces for 10 d assumes 30% patient turnover assumption (clinical improvement and deaths).
‡Does not include endotracheal intubation/tracheostomy equipment. Pharmaceuticals and intubation equipment should be available.
§Numbers will depend on decision to use a circuit with or without a heated wire. If heat and moisture exchangers are stockpiled exclusively, existing heated humidifiers can still be assigned for patients with copious secretions and/or high minute ventilation.

nizes that in catastrophic situations, care processes may by necessity degrade even beyond EMCC standards. For instance, if disposable ventilator circuits become in short supply, clinicians may consider reusing them for subsequent patients after sterilization attempts.

Owing to the broad scope of equipment necessary for EMCC, this article cannot provide comprehensive rationales for every suggested piece of equipment. The Task Force deliberately concentrated on surge positive pressure ventilation (PPV) because of its underrepresentation in the published medical literature, the importance of the topic, and recent calls for this guidance.[18]

Mechanical Ventilation: Surge PPV

Suggestion 3.1: EMCC requires one mechanical ventilator per patient concurrently receiving sustained ventilatory support.

Several groups[19,20] have described use of a single ventilator with a multiple-limb ventilator circuit. While at first glance this strategy is appealing, the research to date has demonstrated only that similar test lungs and pharmacologically paralyzed sheep with normal lungs can be ventilated by this approach. Perhaps this strategy would have utility for ventilating patients with normal lungs (*eg*, isolated traumatic brain injury) and thereby free additional ventilators for patients with high resistance or low compliance. Extrapolation to EMCC would require pharmacologically paralyzed patients who remain matched for minute ventilation requirements, dynamic airflow resistance, and compliance throughout the duration of ventilation; however, these parameters are likely to vary during the duration of mechanical ventilation, and may even change over a period of minutes (*eg*, secretions causing increased airflow obstruction). Because the Task Force anticipates that most additional patients requiring mechanical ventilation during a mass critical care event will have severe airflow obstruction or lung injury[21] and will require days of ventilatory support, the Task Force suggests that each patient should have his or her own mechanical ventilator.

Suggestion 3.2: PPV equipment purchased for surge capacity should at a minimum accomplish the following: (1) be able to oxygenate and ventilate most pediatric and adult patients with either significant airflow obstruction or ARDS; (2) be able to function with low-flow oxygen and without high-pressure medical gas; (3) accurately deliver a prescribed minute ventilation when patients are not breathing spontaneously; and (4) have sufficient alarms to alert the operator to apnea, circuit disconnect, low gas source, low battery, and high peak airway pressures.

Table 4—*Suggested Nonrespiratory Medical Equipment for EMCC**

Devices	Reusable/ Consumable	Duration of Use	Minimum Number Per 10 Treatment Spaces for 10 d†	Comments
Hemodynamic support				
CVC	Consumable	Duration of need	13	Multilumen percutaneously inserted, nontunneled CVCs or PICCs (with skilled operators) are acceptable; assumption: average of 1 CVC per patient; some patients many not require CVCs and some may require multiple CVCs during a 10-d period
CVC ancillary supplies (*eg*, administration sets, insertion site dressings, flush)	Consumable	Per institutional preference	Sustained-use equipment: 13 × units of equipment per patient × 10/duration of use (d); daily consumable equipment: 13 × units of equipment per patient per day × 10 d	
Peripheral IV equipment	Consumable	4 d	65	
IV crystalloid solution	N/A	4 to 5 L on day 1, 2 to 3 L on days 2 and 3; 1 to 2 L/d thereafter	200 L	Crystalloid choice is dependent on institutional practice; volume may be reduced if institution prefers hypertonic saline solution
IV pump (multilumen)	Reusable	Duration of need	10	Patients requiring additional pumps may be too ill to support during extreme shortages
Miscellaneous equipment				
Disposable bath package	Consumable	2 to 3 d	35	
Nasogastric/orogastric tubes	Consumable	Duration of need	13	Route for enteral nutrition and medications in ventilated patients; if there are insufficient enteral feeding pumps, bolus feeding by gravity is an acceptable alternative
Nasogastric/orogastric tube ancillary supplies (*eg*, securing tape, syringe, ophthalmic lubricating ointment)	Consumable	Per institutional preference	Sustained-use equipment: 13 × units of equipment per patient × 10/duration of use (d); daily consumable equipment: 13 × units of equipment per patient per day × 10 d	
Optional equipment				
Continuous heart rate and rhythm monitor	Reusable	Duration of need	10	May consider at least one device capable of cardioversion (for nonpulseless but unstable arrhythmias)
ECG cable/leads	Reusable (consumable)	Duration of need	10 or 13	
ECG patches	Consumable	Duration of need	100	
Sequential compression device	Reusable	Duration of need	10	Dependent on institutional practice and patient VTE risk and risk of adverse event from chemical VTE prophylaxis

Table 4—*Continued*

Devices	Reusable/ Consumable	Duration of Use	Minimum Number Per 10 Treatment Spaces for 10 d†	Comments
Sequential compression boots	Consumable	Duration of need	13	
Patient monitoring				
Noninvasive BP cuff	Consumable	Duration of patient stay	1 small; 10 standard; 3 large adult; 1 thigh	Consumable cuff or cuff cover is acceptable; proportions of sizes may vary based on anticipated patient sizes
Thermometer	Reusable or consumable	Duration of patient stay	13 disposable probes	Temperature measurement site based on institutional preference
Urinary catheter with collection bag	Consumable	Duration of need	13	

*Pediatric-specific equipment, while not presented to limit the complexity of the suggestions, should be considered. Some devices may be used interchangeably for adults and most pediatrics (*eg*, mechanical ventilators approved for adult and pediatric use). Amounts of pediatric-specific equipment should be determined by regional analysis of need in consultation with pediatric experts. N/A = not applicable; CVC = central venous catheter; PICC = percutaneous inserted central catheter; VTE = venous thromboembolism.
†Equipment for 10 patient care spaces for 10 d assumes 30% patient turnover (clinical improvement and deaths).

Manual ventilators (*eg*, Ambu bags; Ambu; Linthicum, MD) are inexpensive and relatively plentiful and may have short-term applications in disasters.[22] Manual ventilators, though, are difficult to use for extended periods of time, especially for patients with significant air flow obstruction or low compliance. Sophisticated mechanical ventilators offer significant advantages over manual ventilators, especially when PPV augmentation will be required for more than several hours. Major benefits include the ability to deliver consistent and appropriate minute ventilation, to conserve oxygen and staff stamina, and (because of alarms that alert staff to unsafe patient-ventilator interactions) to allow health professionals to perform other medical functions, thus reducing the required time at bedside.

Hospitals should plan to provide acceptable surge PPV equipment sufficient to meet their EMCC capacity goal. However, the initial purchase and ongoing maintenance costs will likely prohibit most hospitals from having their own stockpile to meet their entire EMCC capacity goal. Therefore, short-term strategies to augment PPV capacity until equipment from outside agencies arrives are encouraged. Anesthesia machines may be repurposed as ventilators (although some surgeries may have to be deferred), as may noninvasive PPV (NIPPV) equipment capable of providing volume ventilation through an endotracheal tube. These temporary options should not be considered definitive solutions for prolonged, large-scale events, such as an influenza pandemic. At least some anesthesia machines will need to be reassigned for surgeries if the response is longer than several days and there are insufficient quantities of appropriate noninvasive devices at hospitals to handle the quantities of additional patients anticipated for such events.[23] When existing hospital PPV equipment—including repurposed anesthesia machines, noninvasive devices, and sophisticated transport ventilators—is not available in sufficient quantities to meet patient needs, then devices from unaffected hospitals or stockpiled PPV equipment should be requested from local, state, and federal stockpiles via the usual resource request channels.[24] For most disasters, outside assistance can be expected. For events involving multiple regions or entire nations, outside assistance may be insufficient to meet the mechanical ventilation needs of a local community.

The Task Force does not suggest that each hospital individually purchase all of the PPV equipment necessary to surge to their EMCC capacity goals. Rather, hospitals should work with their local, regional, and state partners to perform a PPV needs analysis for all plausible mass critical care events, such as a severe influenza pandemic. Hospital PPV equipment together with existing caches, such as the US Centers for Diseases Control and Prevention

(CDC) Strategic National Stockpile ventilator inventory,[25] should be evaluated to make sure they are sufficient to meet EMCC capacity goals within reasonable time expectations and assuming multiple hospitals concurrently requesting equipment. For these analyses, hospitals are cautioned against relying solely on rental PPV equipment because multiple hospitals within a region are usually dependent on the same several vendors and the overall rental supply is often limited. Additional nonfederal stockpiles of PPV equipment are appealing because the devices would be expected to more reliably arrive in a timely manner. Also these stockpiles will allow for distribution of one or two ventilator models to affected hospitals, as opposed to piecing together a supply of many makes and models, and will increase likelihood that staff will be able to operate the devices and that necessary device-specific ancillary equipment (*eg*, ventilator circuits) will be available. If regional analyses demonstrate significant PPV gaps and additional metropolitan, intrastate regional, or state caches are considered, Table 2 provides guidance for surge PPV equipment. Equipment characteristics were based on the following: (1) perceived requirement for adequate, sustained mechanical ventilation; (2) demonstrated effectiveness; (3) ease of use; and (4) minimization of purchase, maintenance, and training costs.

Several groups[21,26,27] have cautioned against purchasing additional noninvasive ventilation equipment designed primarily for mask ventilation as surge PPV equipment. The Task Force concurs with these cautions and does not propose NIPPV as a principal strategy for managing mass casualty respiratory failure, for the following reasons: the need for experienced users[28]; requirement of significant initial staff time[29]; limited benefit and infrequent use in practice for ARDS[30–32]; and the uncertainty as to whether NIPPV may generate significant respiratory aerosols that would be difficult to scavenge during an epidemic of a respiratory-transmitted pathogen.[33–36]

Mechanical ventilators require ancillary equipment to function properly. The Task Force suggests a list of ancillary respiratory equipment (Table 3). Ancillary equipment selection is also based on the same four criteria as for surge PPV. Quantities of consumable equipment were determined from standard practice and expert opinion and adjusted for the consumable equipment supply buffer (refer to prior section). This equipment list was developed as a guide for hospitals and government agencies preparing for EMCC, but it is not intended as a rigid mandate. Individual institutions and regions should modify the list to match their local practices. At the same time, the Task Force cautions that trying to manage patients with less than the recommended equipment may render some elements of EMCC care unsafe or ineffective.

The Task Force wants to focus special attention to the requirement for surge PPV to be able to operate without high-pressure medical gas. High-pressure medical gas, which is required by PPV devices without internal compressors, is provided in hospitals as medical air and oxygen. Many patient locations outside of critical care units do not have all of the equipment necessary to deliver either of the high-pressure medical gases to ventilators. Even if medical air is available, PPV devices whose internal oxygen blenders require consistent high-pressure oxygen will be unable to provide supplemental oxygen to patients in treatment spaces that have only low-flow oxygen regulators. Alternatively, the high-pressure equipment may be present, but provision of sufficient oxygen pressure and flow may be compromised as a result of insufficient oxygen on site (limited liquid oxygen volume or failure of oxygen concentrators), interruption of the main supply line to the hospital, or flow limitation of the oxygen piping system of the entire hospital.

All but the smallest hospitals rely on bulk cryogenic storage or concentrators as the source of oxygen, which is distributed through piping to oxygen stations (also referred to as *terminal units*) in clinical locations.[37,38] Bulk liquid oxygen is an efficient way to store the large volume of oxygen used by hospitals. The major vulnerability specific to liquid oxygen is that it is not made at hospitals and therefore requires distribution from manufacturers. Most hospitals have enough liquid oxygen on site to respond to a short-term event without resupply; Charity Hospital in the wake of Hurricane Katrina still had enough liquid oxygen for several additional days at the time of evacuation (Ben Deboisblanc, MD; personal communication; May 2006). Maintaining a medical response, either by hospitals with small oxygen reserves or by most hospitals during a prolonged response, will require resupply of liquid oxygen. Resupply may be unreliable owing to damaged transportation routes or insufficient numbers of available, trained drivers (because of illness or fear) to make oxygen deliveries. Fewer hospitals rely on on-site oxygen concentrators rather than liquid oxygen as their primary gas source. These systems are not dependent on oxygen distribution from off-site manufacturers, but still require a continuous supply of electricity to operate. At most facilities, regardless of their source of oxygen and even with reserve oxygen systems for primary source failure, oxygen intended for the entire facility enters using the same length of pipe.[37] If the primary system fails as a result of disruption of this piping connection (*eg*, earth-

quake), then the reserve system, if it relies on the same piping external to the hospital, will be ineffectual.

Because of costs and size limitations, piping systems to distribute oxygen throughout the hospital are not designed to provide high-flow oxygen to every oxygen station in the hospital at the same time.[39,40] Instead, "diversity factors" are employed that assume only a certain number of oxygen stations will be operating concurrently at high flow. This has important implications for events when hospitals need to deliver high-flow oxygen from most of their oxygen stations. There may be sufficient bulk oxygen source on site, but the flow of oxygen may become limited in some treatment spaces. For these situations, additional means to deliver oxygen to treatment spaces will be necessary.[41] Compressed oxygen, such as the commonly used E cylinder (644 L) or H cylinder (6,900 L) can meet short-term oxygen needs. However, it is logistically difficult to have enough oxygen for many patients provided by compressed gas cylinders. Each patient who uses 4 L/min of oxygen requires 5,760 L of gaseous oxygen per day, nearly an H cylinder per day. Given cost and storage constraints, most hospitals maintain only enough cylinders to cover short-term disruptions of the bulk liquid systems.

Using small oxygen concentrators is another option. These devices, which provide up to 10 L/min, can bypass the hospital oxygen piping distribution system, and their capability to trans-fill compressed gas cylinders is appealing. Concentrators require a continuous supply of energy and do not directly provide high-pressure oxygen to drive pneumatically driven mechanical ventilators. A third surge oxygen option is use of several hundred liter liquid oxygen containers with a portable liquid oxygen vaporizer.[42] Mass critical care events may require a patchwork of oxygen alternatives that can be connected to isolated zones of the hospital piping system[41] or can distribute oxygen directly to patient areas in order to augment or back up primary bulk oxygen systems; hospital planners are encouraged to work with personnel who have medical gas expertise, including extensive knowledge of relevant regulations.[43,44] PPV equipment that minimizes oxygen use and that can use different oxygen sources (*eg*, does not require a constant high-pressure source of oxygen or air) is highly desirable for EMCC.

Non-Respiratory Critical Care Therapeutics and Interventions

Select non-respiratory medical equipment for EMCC is presented in Table 4. This list provides equipment for the essential nonrespiratory critical care interventions, including hemodynamic support, that are suggested for EMCC (see "Definitive Care for the Critically Ill During a Disaster: A Framework for Optimizing Critical Care Surge Capacity"). For article length considerations and to facilitate information dissemination, this list was not intended to be exhaustive. Instead, it highlights types and quantities of key medical equipment (*eg*, nasogastric tubes) and expects hospitals to consider and plan for associated equipment (*eg*, tape for securing nasogastric tubes). Equipment not specific to EMCC (*eg*, linens and bedpans) are not included but must be considered by hospitals for any surge event, not just those requiring EMCC. Regions and individual hospitals are encouraged to identify any additional resources they believe necessary to provide EMCC. This planning would be done best within a regional health-care collaborative group.[45]

Implicit in this list is that EMCC is being performed in adequate medical treatment locations (see "Emergency Mass Critical Care Treatment Space" below). Equipment found in most treatment spaces (*eg*, hospital beds and staff call systems) is not included in the Table. This document was developed with a specific focus on critical care surge equipment for a severe influenza pandemic. For infection control equipment excluding ventilator circuit filters, readers are encouraged to refer to World Health Organization and US Department of Health and Human Services guidance for H5N1 and pandemic influenza.[46,47] Lastly, because the equipment for renal replacement therapy and enteral nutrition are widely variable and these interventions are optional for EMCC, they are not included in Table 4. Institutions and regions should involve health-care professionals with expertise in these two interventions to determine whether these interventions are deemed essential for local EMCC and, if so, to develop equipment and staffing guidance.

EMCC requires a myriad of pharmaceutical agents and related equipment for administering medications. The 2004 Working Group on Emergency Mass Critical Care provided a list of basic medications organized by organ system. Disaster planners and pharmacists should review this information.[3] The Task Force did not feel a need to further develop the EMCC pharmaceutical list. The Task Force believes that the most important aspect of pharmaceutical preparedness for EMCC is the active involvement of pharmacists, especially critical care pharmacists, in institutional and regional EMCC and general surge capacity planning.

Suggestion 3.3: To optimize medication availability and safe administration, the Task Force suggests that modified processes of care should be considered prior to an event, such as the following: (1) rules for

*medication substitutions, (2) rules for safe dose or drug frequency reduction, (3) rules for conversion from parenteral administration to oral/enteral when possible, (4) rules for medication restriction (*eg*, oseltamavir if in short supply during an influenza pandemic), and (5) guidelines for medication shelf-life extension.*

EMCC Treatment Space

Suggestion 3.4: EMCC should occur in hospitals or similarly designed and equipped structures (eg, mobile medical facility designed for critical care delivery, veterinary hospital, or outpatient surgical procedure center). After ICUs, postanesthesia care units, and emergency departments reach capacity, hospital locations for EMCC should be prioritized in the following order: (1) intermediate care units, step-down units, and large procedure suites; (2) telemetry units; and (3) hospital wards.

Suggestion 3.5: Nonmedical facilities should be repurposed for EMCC only if disasters damage regional hospital infrastructure by making hospitals unusable and if immediate evacuation to alternate hospitals is unavailable.

ICUs are deliberately designed to optimize critical care.[48–50] Critically ill patients have demanding environmental and medical equipment requirements owing to their physiologic fragility, susceptibility to nosocomial infections and pressure ulcers, complex medication regimens, and need for organ-supportive care (*eg*, mechanical ventilation). In most hospitals, non-ICU patient treatment spaces have patient care layouts and medical equipment that are less optimal for caring for critically ill patients. Studies[51–53] suggest that critically ill patients have better outcomes in ICUs than on other hospital wards. Mass casualty critical care will nevertheless require EMCC to be delivered outside of ICUs, postanesthesia care units, and emergency departments. To provide EMCC as safely as possible in alternate locations, sites should be prioritized by degree of similarity to the environmental and equipment characteristics of ICUs (Fig 1).

During events when inpatient surge capacity is needed, some communities are considering repurposing nonmedical buildings of convenience.[54] This strategy has been successfully used in the past, including in the aftermath of Hurricane Katrina,[55,56] and in well-prepared communities it is a good option to augment care for noncritically ill patients. Caring for critically ill patients in these alternate care sites, even while recognizing that many processes of care for critically ill patients will be omitted or minimized during disasters, is highly discouraged owing to the logistic hurdles to creating environments remotely similar to ICUs.

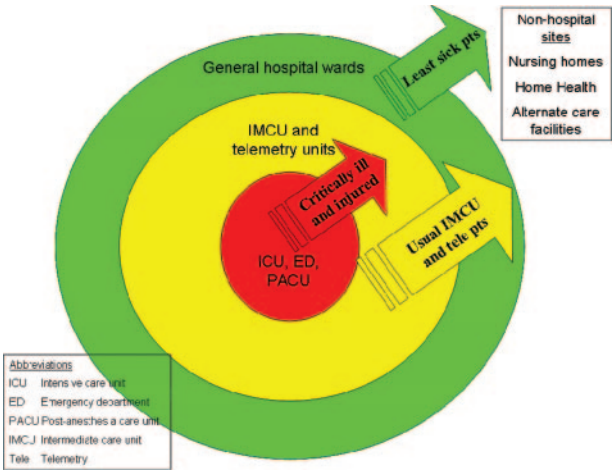

FIGURE 1. Initial expansion of critical care treatment space during disasters. Hospital facilities are the preferred location for the provision of critical care during a disaster. Expanding available critical space therefore becomes a priority that requires the repurposing of current bed utilization. The least sick patients (pts) should be discharged or transferred to community care facilities. This has the downstream effect of permitting the movement of intermediate care/telemetry patients to general practice wards and critical care capabilities expanding into IMCU/telemetry space.

For the initial surge, intermediate care units (IMCUs), also called *step-down units*, should be repurposed first if present (Fig 1). Once the IMCU reaches capacity, patients normally requiring IMCU-level care should be admitted or transferred to hospital wards, which usually provide the next lower level of care. Discharge of general ward patients to home, assisted-living facilities, non-acute nursing facilities, or other community medical surge facilities can allow for enhanced movement of patients from the higher-acuity-level wards to general hospital wards.[57] To triple the usual ICU capacity of a US hospital, approximately 40% of total hospital rooms are needed for provision of EMCC (ICU beds constitute approximately 13% of US hospital beds).[58] Half as many hospital beds have been made available within a day of previous disasters.[59] For events that evolve over several days or weeks, if hospital admissions are prioritized for critically ill people and temporary medical treatment sites are set up to care for less complex patients (*eg*, those who would normally be awaiting skilled nursing facility placement or home health evaluation or those who are several days from discharge without expectation of clinical worsening), then tripling ICU capacity in terms of treatment space is possible (Fig 2). If the mass critical care event is related to an epidemic of a potentially airborne-transmitted pathogen and critically ill patients are feared to be the most likely to transmit the disease, then infection control consid-

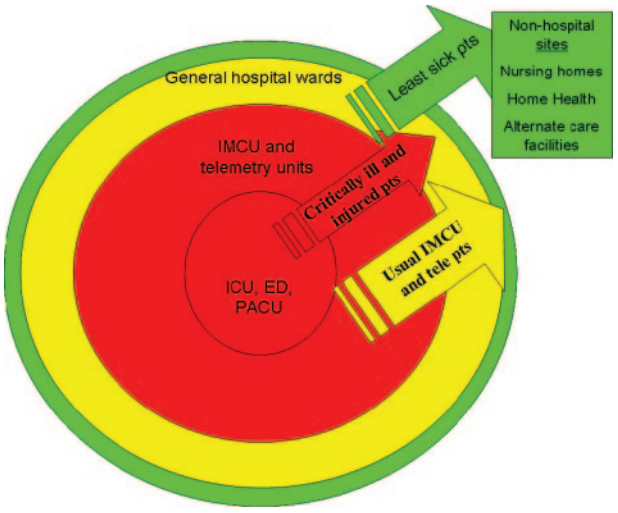

FIGURE 2. Critical care expansion during sustained catastrophies will require further expansion of critical care capabilities. All remaining IMCU/telemetry patients (from Fig 1) still in the medical ICU will be transferred to general hospital wards. Most, if not all, lower-acuity patients on the wards will also now need to move out of the hospital. Critical care patients will now occupy most of the hospital, including some of the general hospital wards. See Figure 1 legend for expansion of abbreviations.

erations may warrant prioritizing another hospital ward over those best equipped for critical care. While critical care may need to be delivered on a number of hospital wards, patients with the most complex monitoring or treatment requirements can still be preferentially assigned to traditional ICU locations. A multiprofessional team of critical care health professionals should establish stratified patient selection criteria for placement in the various EMCC sites.

Current deployable, specialized medical facilities (*eg*, field hospitals with deliberately designed critical care units) may be an acceptable alternative site for small-scale EMCC.[60,61] This equipment must be able to arrive expeditiously with adequate staff who are adept at making the facility rapidly functional. The purchase, maintenance, and ongoing training costs of such equipment generally restrict such resources to state or federal agencies. Even for these agencies, despite the significant expense, most products offer limited additional critical care capability, and the time from request to functionality may be several days; thus, this approach is helpful only for select situations. For a severe influenza pandemic, staff for these facilities are unlikely to be available and there are not sufficient mobile assets to help every community in need.

Some long-term care facilities also may be acceptable sites for EMCC, especially those equipped with hospital beds, bulk oxygen, and piping systems for widespread distribution of medical air, oxygen, and vacuum to patient care sites. As with the deployable facilities, a significant amount of treatment space would be required to justify the effort to provide care outside of traditional hospitals, as additional medical equipment and staff would need to be transferred from hospitals to these facilities. Specialty care and a broader range of laboratory and diagnostic services are more likely to be widely available in hospitals, so traditional hospital inpatient sites should remain the first priority for EMCC until acceptable alternatives are available.

STAFFING

Original staffing suggestions for EMCC recommended that non-critical care health-care professionals work in collaborative critical care teams to augment staffing.[3] The recommendations were based on the following premise: (1) that critical care requires health professionals with critical care experience or comparable experience with unstable patients (*eg*, anesthesia and emergency department staff); (2) during disasters with delayed external assistance, such specialized staff are likely to be in short supply[62–64]; and (3) other health professionals may be able to assist with augmenting critical care capability. Given the complexity of critical care management, it was suggested that critical care professionals work collaboratively with non-critical care health professionals to optimize capability and outcomes by overseeing critical care components on a broader set of patients than usual, allowing providers with less experience to provide basic nursing and medical care. The 2004 recommendations stressed the need to cross-train non-critical care health professionals for delivery of basic, core critical care medicine. The Task Force endorses this previously suggested collaborative team model of critical care surge staffing.

Staff Prioritization and Augmentation

In staffing for critical care surge, a deliberate model of delegation is desirable. During a disaster, all work usually preformed may not be "essential" but all health-care workers are essential. The goal of the model is to match the caregiver competencies with patient needs. To that end a common-sense version, a plan that acknowledges the scope of practice and experience of various caregivers, should be used to assign caregivers to the patients.

Suggestion 3.6: Principles for staffing models should include the following: (1) patient care assignments for caregivers should be managed by the most

experienced clinician available; (2) assignments should be based on staff abilities and experience; (3) delegation of duties that usually lie within the scope of some workers' practice to different health-care workers may be necessary and appropriate under surge conditions; and (4) systematic efforts to reduce care variability, procedure complications, and errors of omission must be used when possible.

Physicians

The use of specially trained physicians to care for critically ill patients is becoming the norm for ICUs and has been recommended as a model to improve critical care for the future.[65] Intensivists come from a variety of backgrounds, including internal medicine, subspecialty-trained internists (most commonly pulmonologists, but also cardiologists, nephrologists, and infectious disease specialists), anesthesiologists, emergency medicine physicians, and general or specialty-trained surgeons. During EMCC implementation, all will be called on to provide care for an overwhelming number of critically ill patients.

Intensivist resources are already limited in most facilities,[66] so an EMCC model relying solely on intensivists for primary physician management would be impractical at most hospitals. Other physicians can assist with the care of critically ill patients. Most physicians' training includes time in ICUs, and many have even spent several months on critical care services. This previous experience may prove invaluable in a mass care setting.

To enhance the availability of critical care physicians to supervise care of many additional critically ill patients and to be immediately present at the bedside of unstable patients, willing nonintensivists should be encouraged to participate in critical care teams. Collaborative teams of nonintensivists and intensivists can be designed similarly to physician ICU teams used by most critical care training programs, thus ensuring a strong clinician presence in all areas providing EMCC. The level of independence of nonintensivists should be commensurate with their recent critical care experience. Availability of specialist physicians to participate will be situation dependent. Willing general and subspecialty internists and pediatricians, hospitalists, anesthesiologists, surgeons, emergency physicians, and obstetricians could be assigned to care for up to six critically ill patients each, with intensivists overseeing four to eight of these nonintensivist clinicians (up to 48 patients, depending on their experience). The expansion of physician services may be submaximal early in the scenario until the less-experienced nonintensivists develop the competence and confidence to care for these patients with increasing independence.

Registered Nurses

Those most experienced in the charge nurse role should be identified because they are likely to be the best prepared to quickly match patient needs and caregiver capabilities. Critical care charge nurses are expert at assigning patient beds based on acuity and anticipating abilities of nurses based on experience level. The charge nurse could assign critical care nurses to oversee a deliberately constructed "pod" of patients and mentor non-critical care caregivers assigned to the pod. The charge nurse would assign patients and caregivers to pods but would then rely on the critical care nurses of the pod to assign specific patients to non-critical care nurses in his/her group. The critical care nurses would care for the most challenging patients and be available to assist the non-critical care nurses as needed. Health-care workers without a nursing background could assist with general activities that fall under the purview of nursing responsibilities (*eg*, patient turning, bathing, vital sign monitoring) but which not only nurses can provide.

Another option would be to assign critical care nurses to all patients while other health-care personnel would be assigned to deliver specific care functions for a group of patients rather than providing a broad range of critical care services for one or several patients. Non-critical care nurses and pharmacists could be responsible for medication delivery; and paramedics, if available, could be assigned to airway maintenance. A hybrid of the "pod" and "functional" options could also be used. Health-care workers with less specific critical care functional expertise but broad health-care knowledge (*eg*, physical therapists, social workers, nutrition specialists, occupational therapists) can assist nurses with general patient care, and those with "functional" expertise can provide such services. No matter what option used, the critical care charge nurse will provide oversight and work closely with the rest of the critical care team overseeing care management.

Caregivers assisting nurses at the bedside must have a core set of competencies in order to not only provide quality care, but also protect themselves and others. The skill set requires at a minimum the following: (1) infection control practices; (2) physical care activities (*eg*, patient turning and cleaning); (3) suctioning and artificial airway maintenance; (4) vital signs and monitoring equipment; (5) Foley catheter care and management of bodily wastes; and (6) delivery of medications and nutrition (when applicable) through enteral tubes and use of IV pumps (if available).

Respiratory Therapists

Staffing of respiratory therapists in the ICU can be accomplished based on a model that combines pa-

tient severity of illness along with required respiratory care procedures.[67] As an example of time and skill needs, the American Association for Respiratory Care Uniform Reporting Manual details the time required for care rendered by respiratory therapists, from monitoring the mechanically ventilated patient (often referred to as the *patient ventilator system check*) to delivery of a metered-dose inhaler.[68] Under normal circumstances, one respiratory therapist routinely cares for four to six ICU patients receiving mechanical ventilation. This care includes evaluation of patient/ventilator interaction, assessment for weaning, airway care, delivery of inhaled medications, blood sampling for blood gas analysis, and therapy for secretion mobilization.

In a scenario where nearly all of the additional patients have severe respiratory failure, several staffing models are possible. The first reduces the intensity of care and at the same time increases the number of patients receiving mechanical ventilation per respiratory therapist to eight or nine. Under these circumstances, therapy would be triaged and the less crucial care processes omitted by necessity. If this strategy is still insufficient to meet need, a critical care respiratory therapist could supervise one to three non-critical care respiratory therapists (RTs). The critical care RT should perform the more complex tasks and be available to supervise the non-critical care RT staff. This supervision will be most needed when the staff is first undertaking simpler tasks, including suctioning of the airway, delivery of aerosolized bronchodilators, and circuit maintenance; after they are observed to competently perform the tasks, the intensity of supervision can be decreased. This model would allow one critical care RT and one non-critical care RT to care for perhaps 12 to 14 patients.

If need is still unmet, non-respiratory care allied health professionals (*eg*, occupational therapists, physical therapists) could perform such tasks as airway suctioning, oxygen saturation checks, or metered-dose inhaler administration. This approach has been suggested and even underwent initial evaluation by University of Colorado investigators.[69] Their model uses a digital video disk to deliver just-in-time training to the recruited non-respiratory health-care workers. This strategy is attractive because it allows for drawing staff from a larger pool of available candidates, and theoretically it would not require recurrent training, which is difficult to sustain for large numbers of health-care workers. Of course, a better option would be to cross-train allied health-care workers recurrently with the materials, and then use the digital video disk also as a refresher during the disaster response. Whether this just-in-time strategy alone is effective at preparing staff to competently perform basic airway care procedures, especially during outbreaks of respiratory-transmitted pathogens, requires further investigation.

Pharmacists

Critical care-trained pharmacists will be in short supply; in many institutions, pharmacy staffing does not provide for dedicated ICU support during usual operations. Shifting an emphasis to EMCC may therefore require repurposing of general pharmacy staff.

The two-tiered approach may be applied to these professionals as well. Critical care-trained pharmacists would oversee pharmacists inexperienced with the critical care setting in such an approach, which could also include use of pharmacy technicians. This approach would allow concentration of support and expertise in the critical care area. In addition, pharmacy support of critical care requires frequent reassessment of drugs in the main pharmacy to ensure smooth delivery of medications along the supply chain. Therefore, pharmacists from all health-system pharmacies in the same geographic location should work together, ideally in coordination with regional health emergency planners, to efficiently redistribute scarce pharmaceutical resources when possible.

All of these staffing models assume that reassigning non-critical care health professionals to assist with critical care will benefit additional critically ill patients. However, staffing in other areas may suffer as a result of these strategies. Critical care requires fewer patients per staff member. More total staff will therefore be necessary to staff the entire hospital when critical care is expanding to nontraditional critical care treatment areas. Staffing for EMCC could increase the number of patients per available staff member for non-critically ill patients if EMCC staffing goes unchecked. The allocation of staff for non-critical care and EMCC services must be dynamic and be matched to the circumstances of the disaster to ensure that the fewest patients are harmed by staffing shortages.

Immediate Challenges To Implementing EMCC

The Task Force is the second large North American effort to issue suggestions for mass casualty critical care. The concepts for augmenting critical care have become increasingly mature over the past decade, but their impact on local hospital preparedness efforts is unknown and implementation is likely limited. EMCC has been developed by senior, experienced critical care and disaster medicine experts, but the suggestions remain untested for civilian

disasters in countries with modern health-care systems. The lack of evidence for EMCC as a guide for preparedness and response may reduce acceptance by clinicians.[70]

Many reimbursement, regulatory, and liability questions remain unanswered. Clinicians and hospitals generally want to assist with disaster preparedness and response; nevertheless, perceived risk of adverse action for deliberately modifying processes of care may make many shy away from planning for EMCC. A core Western societal expectation of health care is the nearly limitless provision of critical care to those who need and want it; EMCC necessitates significant deviation from this expectation. Emergency powers or legislative efforts must therefore provide indemnity to health professionals following EMCC principles in good faith. Policymakers must ensure that EMCC-relevant issues are prioritized for legislative consideration.

EMCC was developed by professionals committed to improving medical outcomes for our communities during disasters. Despite best intentions, EMCC has essentially been conceived of and modified in forums devoid of nonprofessionals. EMCC and its underlying ethical and resource assumptions must be brought to community discussions for evaluation and modification so that it can be improved by incorporating additional perspectives and ideas. These efforts will be necessary for community support and acceptance, which will be paramount for EMCC implementation during a disaster.

EMCC requires training of staff, but training health-care workers in unfamiliar procedures and processes for infrequent events is fraught with difficulty. Health-care professionals have numerous training mandates, and it will be difficult to make EMCC training an ongoing priority. Within the realities of competing training obligations, strategies must be developed to still provide acceptable levels of training for EMCC. These strategies must take into consideration the expected attrition of knowledge and competency resulting from disuse of skills. Strategies must also anticipate the need to incorporate periodically updated EMCC recommendations.

Despite these challenges, mass critical care events could happen tomorrow or even today. We cannot wait to develop perfect surge strategies because the first time the modern North American health-care system faces mass critical care may prove catastrophic. We must be prepared to implement surge strategies based on contemporary knowledge, experience, and expert opinion.

Appendix

Task Force Members in Alphabetical Order

Capt. Dennis Amundson, MD, USN, San Diego, CA; Capt. Michael B. Anderson, RN, MHA, CNAA, Department of Homeland Security, Washington, DC; Robert Balk, MD, Rush University Medical Center, Chicago, IL; Tom Baudendistel, MD, California Pacific Medical Center, San Francisco, CA; Ken Berkowitz, MD, VHA National Center For Ethics in Health Care, New York, NY; Michael Bourisaw, BS (Steering Committee), American College of Chest Physicians, Northbrook, IL; Dana Braner, MD, Doernbecher Children's Hospital, Portland, OR; Suzanne Burns, RN, MSN, RRT, University of Virginia Health System, Charlottesville, VA; Michael D. Christian, MD, FRCPC (Steering Committee), University of Toronto, Toronto, ON, Canada; J. Randall Curtis, MD, MPH, Harborview Medical Center, Seattle, WA; Asha Devereaux, MD (Steering Committee), Sharp Coronado Hospital, San Diego, CA; Jeffery Dichter, MD (Steering Committee), Presbyterian Hospital, Albuquerque, NM; Nancy Dubler, LLB (Steering Committee), Montefiore Medical Center, Bronx, NY; Brian Erstad, PharmD (Steering Committee), University of Arizona Medical Center, Tucson, AZ; J. Christopher Farmer, MD, Mayo School of Graduate Medical Education, Rochester, MN; James Geiling, MD (Steering Committee), VA Medical Center, White River Junction, VT; Dan Hanfling, MD, Inova Fairfax Hospital, Falls Church, VA; John Hick, MD (Steering Committee), Hennepin County Medical Center, Minneapolis, MN; Capt. Ann Knebel, RN, DNSc, Department of Health and Human Services, Washington, DC; John Krohmer, MD, Department of Homeland Security, Washington, DC; Capt. Deborah Levy, PhD, MPH (Steering Committee), Centers for Disease Control and Prevention, Atlanta, GA; Henry Masur, MD, National Institutes of Health, Bethesda, MD; Justine Medina RN, MS (Steering Committee), American Association of Critical Care Nursing, Aliso Viejo, CA; Nicki Pesik, MD (Steering Committee), Centers for Disease Control and Prevention, Atlanta, GA; Jim Pile, MD, The Cleveland Clinic, Cleveland, OH; Tia Powell, MD, New York State Task Force on Life and the Law, New York, NY; Lewis Rubinson, MD, PhD (Steering Committee), Harborview Medical Center, Seattle, WA; Christian Sandrock, MD, MPH, University of California-Davis, Davis, CA; Richard Serino, BS, Boston Emergency Medical Services, Boston, MA; Lewis Soloff, MD, New York City Department of Health and Mental Hygiene, New York, NY; Daniel Talmor, MD, MPH, Beth Israel Deaconess Medical Center, Boston, MA; Alvin Thomas Jr, MD, Howard University Hospital, Washington, DC; Richard Waldhorn, MD, University of Pittsburgh Medical Center, Baltimore, MD; Mark Woodhead, MD, Guidelines Director, European Respiratory Society; Robert Wise, MD, The Joint Commission, Chicago, IL; Randy Wax, MD, Mount Sinai Hospital, Toronto, ON, Canada; Kevin Yeskey, MD (Steering Committee), Department of Health and Human Services, Washington, DC.

References

1 Gomersall CD, Tai DY, Loo S, et al. Expanding ICU facilities in an epidemic: recommendations based on experience from the SARS epidemic in Hong Kong and Singapore. Intensive Care Med 2006; 32:1004–1013

2 Roccaforte JD, Cushman JG. Disaster preparation and management for the intensive care unit. Curr Opin Crit Care 2002; 8:607–615

3 Rubinson L, Nuzzo JB, Talmor DS, et al. Augmentation of hospital critical care capacity after bioterrorist attacks or

epidemics: recommendations of the Working Group on Emergency Mass Critical Care. Crit Care Med 2005; 33: 2393–2403
4 Booth CM, Stewart TE. Severe acute respiratory syndrome and critical care medicine: the Toronto experience. Crit Care Med 2005; 33(1 Suppl):S53–S60
5 Rubinson L, O'Toole T. Critical care during epidemics. Crit Care 2005; 9:311–313
6 Sariego J. CCATT: a military model for civilian disaster management. Disaster Manag Response 2006; 4:114–117
7 Farmer JC, Carlton PK Jr. Providing critical care during a disaster: the interface between disaster response agencies and hospitals. Crit Care Med 2006; 34(3 Suppl):S56–S59
8 Hawryluck L, Lapinsky SE, Stewart TE. Clinical review. Crit Care 2005; 9:384–389
9 Anderson TA, Hart GK, Kainer MA. Pandemic influenza-implications for critical care resources in Australia and New Zealand. J Crit Care 2003; 18:173–180
10 Menon DK, Taylor BL, Ridley SA. Modeling the impact of an influenza pandemic on critical care services in England. Anaesthesia 2005; 60:952–954
11 Hick JL, O'Laughlin DT. Concept of operations for triage of mechanical ventilation in an epidemic. Acad Emerg Med 2006; 13:223–229
12 Kvetan V. Critical care medicine, terrorism and disasters: are we ready? Crit Care Med 1999; 27:873–874
13 National planning scenarios: created for use in national, federal, state, and local homeland security preparedness activities. Available at: media.washingtonpost.com/wp-srv/nation/nationalsecurity/earlywarning/NationalPlanningScenariosApril2005.pdf. Accessed April 4, 2008
14 Cook A. The dangers of stockpiling: planning rules change as hospitals brace for potential disasters. Mater Manag Health Care 2007; 16:32–34
15 Moon S. Taking cost off supply shelf: healthcare turning to supply chain management techniques honed by retail, manufacturing to limit inventory, slash expenses. Mod Healthc 2004; 34:26–28
16 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; 357:327–336
17 Austin PN, Campbell RS, Johannigman JA, et al. Imposed work of breathing during ventilator failure. Respir Care 2002; 47:667–674
18 Osterholm MT. Preparing for the next pandemic. N Engl J Med 2005; 352:1839–1842
19 Neyman G, Irvin CB. A single ventilator for multiple simulated patients to meet disaster surge. Acad Emerg Med 2006; 13:1246–1249
20 Paladino L, Silverberg M, Charchaflieh JG, et al. Increasing ventilator surge capacity in disasters: ventilation of four adult-human-sized sheep on a single ventilator with a modified circuit. Resuscitation 2008; 77:121–126
21 Rubinson L, Branson RD, Pesik N, et al. Positive-pressure ventilation equipment for mass casualty respiratory failure. Biosecur Bioterror 2006; 4:183–194
22 Dacey MJ. Tragedy and response: the Rhode Island nightclub fire. N Engl J Med 2003; 349:1990–1992
23 Maheshwari V, Paioli D, Rothaar R, et al. Utilization of noninvasive ventilation in acute care hospitals: a regional survey. Chest 2006; 129:1226–1233
24 Centers for Disease Control and Prevention. Strategic national stockpile. Available at: http://www.bt.cdc.gov/stockpile/. Accessed November 1, 2007
25 American Association for Respiratory Care guidelines for acquisition of ventilators to meet demands for pandemic flu and mass casualty incidents. Available at: http://www.aarc.org/resources/vent_guidelines.pdf. Accessed July 28, 2006
26 Gruber PC, Gomersall CD, Joynt GM. Avian influenza (H5N1): implications for intensive care. Intensive Care Med 2006; 32:823–829
27 American Association for Respiratory Care guidelines for acquisition of ventilators to meet demands for pandemic flu and mass casualty incidents with addendum. Available at: http://www.aarc.org/resources/vent_guidelines_08.pdf. Accessed February 27, 2008
28 Girou E, Brun-Buisson C, Taille S, et al. Secular trends in nosocomial infections and mortality associated with noninvasive ventilation in patients with exacerbation of COPD and pulmonary edema. JAMA 2003; 290:2985–2991
29 Kramer N, Meyer TJ, Meharg J, et al. Randomized, prospective trial of noninvasive positive pressure ventilation in acute respiratory failure. Am J Respir Crit Care Med 1995; 151: 1799–1806
30 Antonelli M, Conti G, Esquinas A, et al. A multiple-center survey on the use in clinical practice of noninvasive ventilation as a first-line intervention for acute respiratory distress syndrome. Crit Care Med 2007; 35:18–25
31 Girard TD, Bernard GR. Mechanical ventilation in ARDS: a state-of-the-art review. Chest 2007; 131:921–929
32 Maheshwari V, Paioli D, Rothaar R, et al. Utilization of noninvasive ventilation in acute care hospitals: a regional survey. Chest 2006; 129:1226–1233
33 Han F, Jiang YY, Zheng JH, et al. Noninvasive positive pressure ventilation treatment for acute respiratory failure in SARS. Sleep Breath 2004; 8:97–106
34 Cheung TM, Yam LY, So LK, et al. Effectiveness of noninvasive positive pressure ventilation in the treatment of acute respiratory failure in severe acute respiratory syndrome. Chest 2004; 126:845–850
35 Fowler RA, Guest CB, Lapinsky SE, et al. Transmission of severe acute respiratory syndrome during intubation and mechanical ventilation. Am J Respir Crit Care Med 2004; 169:1198–1202
36 Hui DS, Hall SD, Chan MT, et al. Noninvasive positive-pressure ventilation: an experimental model to assess air and particle dispersion. Chest 2006; 130:730–740
37 Stoller JK, Stefanak M, Orens D, et al. The hospital oxygen supply: an "O2K" problem. Respir Care 2000; 45:300–305
38 Friesen RM, Raber MB, Reimer DH. Oxygen concentrators: a primary oxygen supply source. Can J Anaesth 1999; 46: 1185–1190
39 AIA Facility Guidelines Institute guidelines for design and construction of health care facilities. Washington, DC: American Institute of Architects, 2006
40 Medical gas and vacuum systems. Plumb Syst Design 2006; 5:44–50
41 Gjerde GE. Retrograde pressurization of a medical oxygen pipeline system: safety backup or hazard? Crit Care Med 1980; 8:219–221
42 Ritz RH, Previtera JE. Oxygen supplies during a mass casualty situation. Respir Care 2008; 53:215–224
43 National Fire Protection Association. Standard for the storage, use, and handling of compressed gases and cryogenic fluids in portable and stationary containers, cylinders, and tanks. Quincy, MA: National Fire Protection Association, 2005
44 National Fire Protection Association. NFPA 99: standard for health care facilities. Quincy, MA: National Fire Protection Association, 2005
45 Barbera J, Macintyre A, eds. Medical surge capacity and capability: a management system for integrating medical and health resources during large-scale emergencies. Alexandria, VA: CNA Corporation, 2004

46 US Department of Health and Human Services. Pandemicflu.gov. Available at: http://www.pandemicflu.gov/. Accessed April 4, 2008
47 World Health Organization. Avian influenza, including influenza A (H5N1), in humans: WHO interim infection control guideline for health care facilities. Available at: http://www.int/csr/disease/avian_influenza/guidelines/infectioncontrol1/en/index.html. Accessed April 4, 2008
48 Ferdinande P. Recommendations on minimal requirements for intensive care departments: members of the Task Force of the European Society of Intensive Care Medicine. Intensive Care Med 1997; 23:226–232
49 O'Connell NH, Humphreys H. Intensive care unit design and environmental factors in the acquisition of infection. J Hosp Infect 2000; 45:255–262
50 Haupt MT, Bekes CE, Brilli RJ, et al. Guidelines on critical care services and personnel: recommendations based on a system of categorization of three levels of care. Crit Care Med 2003; 31:2677–2683
51 Simchen E, Sprung CL, Galai N, et al. Survival of critically ill patients hospitalized in and out of intensive care units under paucity of intensive care unit beds. Crit Care Med 2004; 32:1654–1661
52 Hersch M, Sonnenblick M, Karlic A, et al. Mechanical ventilation of patients hospitalized in medical wards vs the intensive care unit: an observational, comparative study. J Crit Care 2007; 22:13–17
53 Simchen E, Sprung CL, Galai N, et al. Survival of critically ill patients hospitalized in and out of intensive care. Crit Care Med 2007; 35:449–457
54 Providing mass medical care with scarce resources: a community planning guide. In: Phillips SJ, Knebel A, eds. Washington DC: Agency for Healthcare Research and Quality, 2006
55 Eastman AL, Rinnert KJ, Nemeth IR, et al. Alternate site surge capacity in times of public health disaster maintains trauma center and emergency department integrity: hurricane Katrina. J Trauma 2007; 63:253–257
56 Connelly M. IMERT deployment to Baton Rouge, Louisiana in response to Hurricane Katrina, September 2005. Disaster Manag Response 2006; 4:4–11
57 Kelen GD, Kraus CK, McCarthy ML, et al. Inpatient disposition classification for the creation of hospital surge capacity: a multiphase study. Lancet 2006; 368:1984–1990
58 Halpern NA, Pastores SM, Greenstein RJ. Critical care medicine in the United States 1985–2000: an analysis of bed numbers, use, and costs. Crit Care Med 2004; 32:1254–1259
59 Hick JL, Hanfling D, Burstein JL, et al. Health care facility and community strategies for patient care surge capacity. Ann Emerg Med 2004; 44:253–261
60 Heller PJ. Mobile hospitals prepped for disaster: California spends $18 million for three 200-bed mobile field hospitals to address disaster concerns. Available at: http://www.disasternews.net/news/article.php?articleid=3433. Accessed October 15, 2007
61 Ottilie W. Lundgren Memorial Mobile Field Hospital. Available at: http://www.epareexpo.com/web-content/MFHNorthCarolina.pdf/. Accessed October 15, 2007
62 Alexander GC, Wynia MK. Ready and willing? Physicians' sense of preparedness for bioterrorism. Health Aff (Millwood) 2003; 22:189–197
63 Qureshi KA, Merrill JA, Gershon RR, et al. Emergency preparedness training for public health nurses: a pilot study. J Urban Health 2002; 79:413–416
64 Qureshi KA, Gershon RR, Merrill JA, et al. Effectiveness of an emergency preparedness training program for public health nurses in New York City. Fam Commun Health 2004; 27:242–249
65 The Leapfrog Group: ICU physician staffing fact sheet. Available at: http://www.leapfroggroup.org/media/file/Leapfrog-ICU_Physician_Staffing_Fact_Sheet.pdf. Accessed April 4, 2008
66 Angus DC, Shorr AF, White A, et al. Critical care delivery in the United States: distribution of services and compliance with Leapfrog recommendations. Crit Care Med 2006; 34:1016–1024
67 Brilli RJ, Spevetz A, Branson RD, et al. Critical care delivery in the intensive care unit: defining clinical roles and the best practice model. Crit Care Med 2001; 29:2007–2019
68 Uniform reporting manual for acute care hospitals fourth edition. Irving, TX: American Association of Respiratory Care, 2004
69 US Department of Health and Human Services, Agency for Healthcare Research and Quality. Project XTREME cross-training respiratory extenders for medical emergencies. Available at: http://www.ahrq.gov/prep/projxtreme. Accessed November 26, 2007
70 Cabana MD, Rand CS, Powe NR, et al. Why don't physicians follow clinical practice guidelines? A framework for improvement. JAMA 1999; 282:1458–1465