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Mechanical Ventilation in an Airborne Epidemic

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The severe acute respiratory syndrome (SARS) outbreak of 2003 infected more than 8,000 people in 30 countries and killed more than 700 [1]. About 20% to 30% of SARS patients required admission to an intensive care unit (ICU), and most of them required mechanical ventilation [2]. SARS showed how swiftly infectious diseases can wreak havoc across the globe in the era of air travel. Most alarmingly, the initial pandemonium the SARS epidemic caused exposed how unprepared the medical community was for an airborne epidemic of this nature.

Currently, the threat of pandemic influenza is increasing, with the emergence of a highly virulent avian influenza virus, influenza A/H5N1 (AI H5N1). As of December 14, 2007, the World Health Organization (WHO) had reported 340 human cases of AI H5N1 in 13 countries, of which 208 (61%) have died [3]. There is concern that the acquisition of greater transmissibility by the virus may result in a replay of the Spanish flu, which killed 20 to 50 million people in 1918 [4]. In addition to the menace posed by emerging infectious diseases, a deliberate epidemic caused by a catastrophic bioterrorist attack remains a real and present danger [5].

SARS was an important wake-up call for the medical community and highlighted the need for increased preparedness to meet the looming threats of large-scale airborne epidemics. In these scenarios, intensive care providers will play a crucial role, as it is anticipated that a high proportion of victims will progress rapidly to respiratory failure and require mechanical ventilatory support.

This article explores many issues relating to mechanical ventilation in an airborne epidemic. The authors examine the lessons from SARS and consider the strategies for mechanical ventilation in future airborne epidemics, with special consideration given to the crucial issue of protection of the health care worker. Unfortunately, there is a paucity of evidence-based literature on the subject of mechanical ventilation in this setting, and it must be emphasized that most of the recommendations made are based largely on expert opinion pieces and retrospective reviews of the SARS experience.

Lessons from SARS

The SARS outbreak of 2003 was caused by a novel coronavirus [6]. It is believed that SARS originated in the exotic wildlife markets in southern China, where it crossed the species barrier from animal to man [7]. It first surfaced surreptitiously as an unusual cluster of 305 cases of atypical pneumonia, with at least five deaths in Guangdong province in November of 2002 [8]. Interestingly, this was initially thought to be because of chlamydia, and did not capture much attention.

The global SARS outbreak started on February 21, 2003, when a 65-year-old physician from Guangdong province arrived in Hong Kong to attend his daughter's wedding. He inadvertently infected at least 12 guests from six different countries at the hotel where he stayed. In the ensuing few months, SARS spread rapidly across 30 countries and infected more than 8,000 patients.

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The worst hit regions were China, Hong Kong, Taiwan, Toronto (Canada), and Singapore. The morbidity, mortality, speed, and ease of transmission of SARS caught the medical community by surprise and exposed the lack of preparedness for dealing with an epidemic of this nature.

Approximately 20% to 30% of SARS patients required intensive care and mechanical ventilation for acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) [9]. Among the critically ill SARS patients, approximately 50% died [10,11]. This placed a heavy burden on the staff and facilities of the ICU.

One of the alarming features of the SARS outbreak was nosocomial spread to health care workers caring for the critically ill. Around the world, at least 1,706 health care workers were stricken with SARS and a number died in the line of duty. In Singapore and Toronto, health care workers accounted for half of all SARS cases, and about 20% of critically ill SARS cases [12]. Tragically, one of the victims was Dr. Carlo Urbani of the WHO. Dr. Urbani was the physician who first alerted the world to SARS after being called to assist in the Hanoi outbreak [13]. He died of SARS on March 29, 2003. His foresight in swiftly recognizing the threat of SARS, and in issuing the global warning, saved many lives in Vietnam and around the world.

SARS taught the medical community several important lessons. It showed us how rapidly emerging infectious diseases in distant parts of the globe can reach our doorsteps in days, and highlighted the importance of global cooperation to contain infectious diseases. It demonstrated the vulnerability of health care facilities in an airborne epidemic, and the necessity of establishing stringent infection control measures and crisis management protocols. The high proportion of patients requiring mechanical ventilation alerted us to the ease at which an outbreak could overwhelm our critical care resources if we do not develop adequate surge capacity. Finally, SARS renewed our faith in the dedication of the medical professionals who care for patients, even at the risk of their own lives, while underlining the critical duty of health care administrators and senior physicians in instituting procedures to maximize the safety of frontline staff.

Strategies for mechanical ventilation

Approximately 20% of patients with SARS and most hospitalized patients with AI H5N1 progress rapidly to ALI or ARDS and require ventilatory support [14]. In an airborne epidemic caused by emerging infections or a bioterrorism event, it is envisaged that there will be a high incidence of hypoxemic respiratory failure because of ALI or ARDS, necessitating mechanical ventilation.

Lung protective ventilatory strategy

A low tidal volume lung protective strategy has been shown to improve survival in patients with ALI or ARDS [15]. Because most patients with ALI or ARDS do not die of refractory hypoxemia, this low tidal volume strategy likely improves outcome by reducing the systemic inflammatory response produced by ventilator-induced lung injury [16]. As the clinical and pathologic manifestations of SARS and AI H5N1 are indistinguishable from other causes of ALI or ARDS, and the cause of death is similarly refractory systemic inflammation, shock, and multiorgan failure, it seems reasonable that the ventilatory management principles learned in ALI and ARDS should be adopted in an airborne epidemic [9]. Thus, the authors recommend using volume or pressure control ventilation targeting tidal volumes of 6-mL/kg predicted body weight and plateau pressures of less than 30-cm of water. In addition, positive end expiratory pressure and fraction of inspired oxygen are adjusted to maintain a partial pressure of oxygen of 55 mm Hg to 80 mm Hg. Of particular note is the significant incidence of pneumothorax reported in patients with AI H5N1, which may necessitate a cautious approach to lung recruitment maneuvers [17].

Adjuvant strategies

Adjuvant strategies shown to decrease morbidity and mortality in critically ill patients on mechanical ventilation include deep venous thrombosis prophylaxis, stress ulcer prophylaxis, sedation protocols, and avoidance of neuromuscular blockage, if possible; semirecumbent position should also be employed during airborne epidemics causing hypoxemic respiratory failure [18]. While there were several reports on the use of corticosteroids in SARS and AI H5N1, there is insufficient evidence at this time to recommend their routine use [9,19].

High frequency oscillatory ventilation

There remains controversy regarding appropriate modes of ventilation for patients with refractory respiratory failure from highly infectious diseases. In particular, there are infection control concerns regarding aerosol generation with high-frequency oscillatory ventilation (HFOV) and the inability to filter exhaled air to the environment. There is currently little data available on the risk of disease transmission to health care workers from HFOV, and a retrospective study did not show a clear association between HFOV and SARS infection among health care workers, but the sample size was small and the verdict is still uncertain [20].

Noninvasive positive pressure ventilation

Similarly, there is debate about the use of noninvasive positive pressure ventilation (NIPPV). There have been reports of NIPPV being effective in treating patients with SARS and reducing the need for intubation [21]. This is an attractive option, especially in a pandemic scenario when the demand for mechanical ventilatory support is overwhelming. However, there are conflicting reports regarding its safety for health care workers [22]. There is worry about dispersion of infectious particles, and an experimental model confirmed substantial exposure to exhaled air occurring within 0.5 meters of patients receiving NIPPV [23]. Nevertheless, there were no reports of nosocomial transmission with adequate respiratory protection during SARS [19]. Patient selection is important for NIPPV, as it has not been shown to improve mortality in ARDS [24], and may not be suitable for patients where near-term improvement is not expected.

Protection of the health care worker

The heavy toll paid by health care workers during the SARS outbreak demonstrated the vulnerability of health care workers in a respiratory epidemic. The risk of transmission was particularly high in the ICU because of the high viral load in the critically ill, as well as aerosol-generating procedures, such as intubation, suctioning, and bronchoscopy. A retrospective cohort study reported a staggering 13-fold increase in the risk of becoming infected among health care workers who performed or assisted in endotracheal intubations [19].

The number of infected health care workers dropped dramatically after infection control measures were put in place, such as isolation of infected patients, use of personal protective equipment (PPE) for health care workers, and strict hand-hygiene for all [25]. WHO and the Centers for Disease Control and Prevention (CDC) have issued guidelines that recommend the use of standard, contact, and airborne protection, including respirators of N95 standard or higher in an airborne epidemic [26,27]. Standard PPE includes N95 masks, gloves, gowns, caps, and face shields or goggles. All staff should be mask fit-tested to ensure an adequate seal. When performing high-risk procedures, such as intubation, bag-mask ventilation, or bronchoscopy, protection should be enhanced with powered air-purifying respirators.

In view of the high risk of disease transmission during endotracheal intubation, airway management protocols have been proposed [28]. Early intubation should be done, preferably in the ICU, rather than performing crash-intubation on the floor. Adequate sedation and neuromuscular blockade is recommended during intubation to minimize cough and dispersion of respiratory secretions. Finally, the procedure should be performed by the most experienced person available, both to minimize the dispersal of infectious particles and to reduce the number of individuals exposed during the intubation.

Other general recommendations include ensuring that the infectious disease ward is close to the ICU and that the ICU is equipped with negative pressure rooms. Aerosol-generating procedures should be avoided whenever possible. Measures to minimize respiratory droplet transmission include using in-line suctioning to maintain the ventilator circuit as a closed system. Humidification should be done via heat-moisture exchangers with viral-bacterial filter properties rather than heated humidifiers. Each ventilator should have two filters: one between the inspiratory port and ventilator circuit and the other between the expiratory port and ventilator circuit, to provide additional protection from exhaust gases and minimize ventilator contamination.

An essential component of infection-control strategy is staff training and the implementation of clear management protocols, including the use of PPE, monitoring staff health, quarantining staff, transport of patients, transfer to ICU, airway management, aerosol-generating procedures, environment and equipment disinfection, and visitation policies.

Pandemic scenario and preparations

For many years, public health officials have worried about a repeat of the Spanish influenza pandemic of 1918 to 1919, which infected approximately 500 million persons and killed 20 to 50 million [29]. In the United States, over a quarter of the population was infected, and some 675,000 died, or 10 times the number of Americans who died fighting in World War I [30].

There is little modern health care experience with respiratory mass casualties of this scale. However, it is apparent that the mortality, morbidity, and public confidence in the time of an airborne pandemic are likely to be highly dependent on the critical care response. It is therefore imperative for critical care providers to take the lead in planning and preparing for large-scale airborne epidemics and pandemics. Issues to be considered include developing triage protocols, augmenting ICU surge staffing, implementing rational infection control measures, stockpiling medical equipment and supplies, and information sharing among many units.

Surge capacity

Several recent publications have addressed the issue of expansion of intensive care in an epidemic [31–33]. Rubinson and colleagues [32] have recommended modifying usual standards of care, termed "emergency mass critical care practices," to maximize the number of patients treated. Others feel that over-stretching resources and deploying unfamiliar staff may backfire and result in staff infection, as well as a standard of care too poor to be of value. However, most investigators agree that there is a need to develop some surge capacity in response to an epidemic. Preparations include stockpiling positive pressure ventilators and medical supplies, adapting general hospital beds for critical care delivery, augmenting and training staff, enhancing infection control measures, and conducting preparedness exercises. To this end, many local, state, and national bodies have developed such stockpiles and disaster management plans. It is incumbent that all critical care practitioners be aware of these resources and plans . The Appendix lists resources for pandemic influenza planning and preparedness.

Triage

Despite our best preparations, it remains likely that in a pandemic scenario, the number of critically ill patients will overwhelm our critical care capacity. There is a need to develop triage protocols to prioritize access to limited resources, including mechanical ventilation [34]. Triage criteria should be based on clinical indicators of survivability, and resources allocated to those most likely to benefit. These are difficult decisions and cannot be left until times of crisis. Development of triage protocols should be done in advance, with careful consideration of ethical principles [35]. It is crucial to engage the community in this process so that public trust exists when it is most needed.

Summary

With the increasing threat of pandemic influenza and catastrophic bioterrorism, it is important for intensive care providers to be prepared to meet the challenge of large-scale airborne epidemics causing mass casualty respiratory failure. The SARS outbreak exposed the vulnerability of health care workers and highlighted the importance of establishing stringent infection control and crisis management protocols. Patients with ALI or ARDS who require mechanical ventilation should receive a lung protective, low tidal volume strategy. There remains controversy regarding the use of HFOV and NIPPV. Standard, contact and airborne precautions should be instituted in the ICU, with special care taken when aerosol-generating procedures are performed. During an airborne pandemic, the mortality, morbidity, and public confidence are likely to be highly dependent on the critical care response. It is imperative for critical care providers to take the lead in planning and preparing for this eventuality.

Appendix

Web resources for pandemic influenza planning and preparedness

Official United States Government Web site for pandemic influenza: www.pandemicflu.gov

WHO epidemic and pandemic alert and response: www.who.int/csr/disease/influenza/pandemic/en

CDC Influenza Pandemic Operation Plan: www.cdc.gov/flu/pandemic/cdcplan.htm

Strategic National Stockpile: www.bt.cdc.gov/stockpile

United States State Government pandemic influenza resources: www.cidrap.umn.edu/cidrap/files/68/usplans.pdf

Singapore Influenza Pandemic Readiness and Response Plan: www.crisis.gov.sg/FLU

United Kingdom Department of Health: www.dh.gov.uk/en/PandemicFlu/index.htm

References

[1] World Health Organization. Summary of probable SARS cases with onset of illness from November 1, 2002 to July 31, 2003. Available at: http://www.who.int/csr/sars/country/table2004_04_21/en/index.html. Accessed December 18, 2007.
[2] Peiris JSM, Phil D, Yuen KY, et al. The severe acute respiratory syndrome. N Engl J Med 2003;349:2431–41.
[3] World Health Organization. Cumulative number of confirmed human cases of avian influenza A/(H5N1) reported to WHO. Available at: http://www.who.int/csr/disease/avian_influenza/country/cases_table_2007_12_14/en/index.html. Accessed December 18, 2007.
[4] Tumpey TM, Basler CF, Aguilar PV, et al. Characterization of the reconstructed 1918 Spanish influenza pandemic virus. Science 2005;310:77–80.
[5] Karwa M, Bronzert P, Kvetan V. Bioterrorism and critical care. Crit Care Clin 2003;19(2):279–313.
[6] Ksiazek TG, Erdman D, Goldsmith CS, et al. A novel coronavirus associated with severe acute respiratory syndrome. N Engl J Med 2003;348:1953–66.
[7] Guan Y, Zheng BJ, He YQ, et al. Isolation and characterization of viruses related to the SARS coronavirus from animals in southern China. Science 2003;302:276–8.
[8] Zhao Z, Zhang F, Xu M, et al. Description and clinical treatment of an early outbreak of severe acute respiratory syndrome (SARS) in Guangzhou, PR China. J Med Microbiol 2003;52:715–20.
[9] Levy MM, Baylor MS, Bernard GR, et al. Clinical issues and research in respiratory failure from severe acute respiratory syndrome. Am J Respir Crit Care Med 2005;171:518–26.
[10] Fowler RA, Lapinsky SE, Hallet D, et al, for the Toronto SARS Critical Care Group. Critically ill patients with severe acute respiratory syndrome. JAMA 2003;290:367–73.
[11] Lew TW, Kwek TK, Tai D, et al. Acute respiratory distress syndrome in critically ill patients with severe acute respiratory distress syndrome. JAMA 2003;290:374–80.
[12] Booth CM, Matukas LM, Tomlinson GA, et al. Clinical features and short-term outcomes of 144 patients with SARS in the greater Toronto area. JAMA 2003;289:2801–9.
[13] Reilley B, Van Herp M, Sermand D, et al. SARS and Carlo Urbani. N Engl J Med 2003;348:1951–2.
[14] Beigel JH, Farrar J, Han AM, et al. Avian influenza A (H5N1) infection in humans. N Engl J Med 2005;353:1374–85.
[15] The Acute Respiratory Distress Syndrome Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med 2000;342:1301–8.
[16] Parsons PE, Eisner MD, Thompson BT, et al. Lower tidal volume ventilation and plasma cytokine markers of inflammation in patients with acute lung injury. Crit Care Med 2005;33(1):1–6.
[17] Gruber PC, Gomersall CD, Joynt GM. Avian Influenza (H5N1): implications for intensive care. Intensive Care Med 2006;32:823–9.
[18] Dellinger RP, Carlet JM, Masur H, et al. Surviving sepsis campaign for management of severe sepsis and septic shock. Crit Care Med 2004;32:858–73.
[19] Arabi Y, Gomersall CD, Ahmed QA, et al. The critically-ill avian influenza A (H5N1) patient. Crit Care Med 2007;35:1397–403.
[20] 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;169:1198–202.
[21] 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;126:845–50.
[22] Xiao Z, Li Y, Chen RC, et al. A retrospective study of 78 patients with severe acute respiratory syndrome. Chin Med J (Engl) 2003;116:805–10.
[23] Hui DS, Hall SD, Chan MT, et al. Noninvasive positive-pressure ventilation: an experimental model to assess air and particle dispersion. Chest 2006;130:730–40.
[24] Delclaux C, L'Her E, Alberti C, et al. Treatment of acute hypoxemic nonhypercapnic respiratory insufficiency with continuous positive airway pressure delivered by a face mask: a randomized controlled trial. JAMA 2000;284:2352–60.
[25] Low DE, McGeer A. SARS: one year later. N Engl J Med 2003;349:2381–2.
[26] World Health Organization. Avian Influenza, including influenza A (H5N1), in humans: WHO interim infection control guidelines for health care facilities. Available at: http://www.who.int/csr/disease/avian_influenza/guidelines/infectioncontrol1/en/index.html. Accessed December 18, 2007.
[27] Centers for Disease Control and Prevention. Interim recommendations for infection control in health care facilities caring for patients with known or suspected avian influenza. Available at: http://www.cdc.gov/flu/avian/professional/infect-control.htm. Accessed December 18, 2007.
[28] Caputo KM, Byrick R, Chapman MG, et al. Intubation of SARS patients: infection and perspectives of healthcare workers. Can J Anesth 2006;53(2):122–9.
[29] Taubenger JK, Morens DM. 1918 influenza: the mother of all pandemics. Emerg Infect Dis 2006;12:15–22.
[30] Billings M. The influenza pandemic of 1918. Available at: www.stanford.edu/group/virus/uda. Accessed December 18, 2007.
[31] Gommersall 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;32:1004–13.

[32] Rubinson L, Nuzzo JB, Talmor DS, et al. Augmentation of hospital critical care capacity after bioterrorist attack or epidemics: recommendations of the Working Group on Emergency Mass Critical Care. Crit Care Med 2005;33:2393–403.

[33] Daugherty EL, Branson R, Rubinson L. Mass casualty respiratory failure. Curr Opin Crit Care 2007;13:51–6.

[34] Christian MD, Hawryluck L, Wax RS, et al. Development of a triage protocol for critical care during an influenza pandemic. CMAJ 2006; 175(11):1377–81.

[35] Thompson AK, Faith K, Gibson JL, et al. Pandemic influenza preparedness: an ethical framework to guide decision-making. BMC Medical Ethics 2006;7:12.