Protecting health care workers from SARS and other respiratory pathogens: A review of the infection control literature

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Background: Severe Acute Respiratory Syndrome (SARS) was responsible for outbreaks in Canada, China, Hong Kong, Vietnam, and Singapore. SARS focused attention on the adequacy of and compliance with infection control practices in preventing airborne and droplet-spread transmission of infectious agents.

Methods: This paper presents a review of the current scientific knowledge with respect to the efficacy of personal protective equipment in preventing the transmission of respiratory infections. The effectiveness of infection control polices and procedures used in clinical practice is examined.

Results: Literature searches were conducted in several databases for articles published in the last 15 years that related to infection control practices, occupational health and safety issues, environmental factors, and other issues of importance in protecting workers against respiratory infections in health care settings.

Conclusion: Failure to implement appropriate barrier precautions is responsible for most nosocomial transmissions. However, the possibility of a gradation of infectious particles generated by aerosolizing procedures suggests that traditional droplet transmission prevention measures may be inadequate in some settings. Further research is needed in this area. (Am J Infect Control 2005;33:114-21.)

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BACKGROUND

Severe Acute Respiratory Syndrome (SARS) was responsible for several well-documented nosocomial outbreaks in Canada, China, Hong Kong, Vietnam and Singapore. The infection control practices applied in these varied settings met with mixed success.[1-4] The associated morbidity and mortality in health care workers (HCWs) affected by SARS focused attention on the recommended infection control practices and personal protective equipment (PPE) in preventing airborne and droplet-spread transmission of infectious agents. During the SARS outbreak, widely divergent opinions were voiced on the adequacy of these measures.[5] Expert opinions varied on respirator selection and use, the need for fit-testing N95 respirators, and the need for protective eyewear. Clearly, there was a need to evaluate the adequacy of the infection control measures to ensure that HCWs are protected in future outbreaks, not only for SARS but also against a variety of new and emerging respiratory pathogens. The purpose of this paper is to review the findings of a literature search on the effectiveness of infection control practices aimed at preventing occupational-associated transmission of infectious respiratory agents in the health care setting.

METHODS

A 16-member research team in Vancouver, BC, Canada, composed of experts in occupational medicine, occupational hygiene, infection control, public health, epidemiology, clinicians, and frontline care providers reviewed the current scientific knowledge on the efficacy of personal protective equipment (PPE) in preventing the transmission of respiratory infections and the effectiveness of these protective measures when used in clinical practice under working conditions. Literature searches were conducted in several databases for English-language articles published in the last 15 years that related to infection control practices, occupational health and safety issues, environmental factors, and other issues of importance in protecting workers against infections in health care settings. Databases used were as follows: Medline, EMBASE, CINAHL (Cumulated Index of Nursing and Allied Health Literature), Web of Science, and OSHROM. This produced an initial list of 841 publications, using 80 keywords. From the initial literature search results, a series of research topics were developed under 3 broad categories: (1) basic science and efficacy of facial protective equipment, (2) the effectiveness of specific infection control procedures, and (3) organizational and individual factors that influence infection control and occupational health in health care settings.

The research topics were divided among the research committee members (subgroups) to summarize, using articles from the second iteration of the original citation list. Secondary reference materials, derived from these initial references, were added. Articles were critically evaluated based on the study design (descriptive, analytic, or intervention), the population under study, and the outcomes of interest. This resulted in 168 publications being used in the final report. Drafts from each subgroup were merged, and the compiled version was reviewed by the team as a whole. The existing knowledge was then summarized, and recommendations for further research were developed through consensus by the research team.

RESULTS AND DISCUSSION OF LITERATURE REVIEW

For the purposes of this paper, the discussion is limited to discussing those references that dealt directly with the effectiveness of infection control practices and specific procedures used to protect workers from exposure to respiratory pathogens. It is divided into those articles that dealt with specific references to personal protective equipment and those that were concerned with environmental factors influencing the effectiveness of these procedures. The studies reviewed and the relevant findings are summarized in Table 1.

Effectiveness of personal protective equipment

The issue of surgical masks versus respirators was a subject of much controversy during the SARS crisis, and several articles describing outcomes with these protective items were published. Both Seto et al,[6] in a study on Hong Kong health care workers, and Loeb et al,[7] in a study conducted in Toronto, found that not consistently wearing either a surgical mask or an N95 respirator was associated with developing SARS when compared with their consistent use. The Seto et al study found that only mask usage was significant in the multivariate analysis; however, there was no difference in risk of infection whether HCWs were using surgical masks or N95 respirators.[2] It should be noted that, in this study, the one hospital in which the source of the outbreak was determined to be a patient who was receiving nebulizer therapy was excluded from this study because "droplet precautions have never been recognized as an effective infection control measure for such aerosol-generating procedures." The authors concluded that precautions against droplets (ie, use of a surgical mask) and contact precautions are adequate for prevention of nosocomial SARS when no aerosol-generating procedures are used. The situation is less clear when aerosols may be generated.

Loeb et al, in their retrospective cohort study of 43 nurses in 2 critical care units with SARS patients, did find a trend toward increased protection from N95 respirators compared with surgical masks, but this was not statistically significant.[7] Eight of 32 nurses working with patients became infected. Specifically, 3 of 23 nurses (13%) who consistently wore a surgical mask or an N95 respirator acquired SARS compared with 5 of 9 nurses (56%) who did not consistently wear either ($P = .02$). The relative risk for infection was 0.22 ($P = .06$) for nurses who always wore an N95 respirator when compared with nurses who did not wear any item consistently. The relative risk for infection was 0.45 ($P = .56$) for nurses who always wore a surgical mask when compared with nurses who did not wear any item consistently, implying no statistically significant difference between wearing a surgical mask and not wearing a mask at all. However, the difference in relative risk for SARS infection for nurses who

Table 1. Summary of studies and relevant findings

Investigator	Study design/intervention	Results
SARS exposure and PPE use		
Seto et al	Case/control study Cases 13/controls 241 Evaluated effectiveness of personal protective equipment (PPE) to protect HCW from SARS.	Mask usage was significant in the multivariate analysis (P = .0001); however, there was no difference in risk of infection whether health care workers (HCW) were using surgical masks or N95 respirators.
Loeb et al	Retrospective cohort study N = 43 nurses Evaluated mask type for effectiveness as protection against SARS.	Nurses (13%) who consistently wore a surgical mask or an N95 respirator acquired SARS compared with nurses (56%) who did not consistently wear either (P = .02).
Lau et al	Case/control study Cases 72/controls 144 Evaluated use of PPE for risk of acquiring SARS.	Inconsistent use of PPE was associated with a higher risk of SARS (OR, 6.78) ($P \leq .0001$).
Park et al	Retrospective cohort study Evaluated PPE use by US workers exposed to SARS patients. N = 66	40% of HCW did not use a respirator, but none developed SARS, and no local disease transmission occurred.
Effectiveness of fit-testing respirators		
Huff et al	Clinical trial Evaluated contamination of airways by radioactive technetium during pulmonary function testing.	Demonstrated a significant drop in disintegrations/min in individuals wearing fit-tested respirators compared with those wearing respirators without fit testing or surgical masks ($P \leq .001$).
Hannum et al	Clinical trial Examined the effect of 3 different methods of respirator training on the ability of health care workers to pass a qualitative fit test.	Fit testing as part of training marginally enhanced the ability of HCW to pass a fit test (P = .043).
Environmental factors		
Varia et al	Case series Risk of developing SARS was graded by distance of exposure to SARS patients.	Exposures less than 1 meter from a case were highest risk. Risk decreased sequentially with exposures less than 3 meters from a case or greater than 3 meters and whether they took place with or without cough-inducing or aerosol-generating procedures.
Scales et al	Case series Examined staff that provided care for a patient with unrecognized SARS.	Sustained close contact or participated in high-risk procedures (eg, endotracheal intubation) had a higher risk of developing SARS than those who did not (P = .003).
Ha et al	Case series Described differences in transmission patterns and control measures for SARS in 2 Vietnamese hospitals.	Found larger rooms and the fact that symptomatic patients were physically separated from other patients may have played a role in decreasing transmission.
Decreasing infectious aerosols and particles at the source		
Christian et al	Case series Interviews of 9 staff members involved in a cardiopulmonary resuscitation when SARS transmission was thought to have occurred.	All staff wore complete PPE during exposure. Three of 9 staff developed symptoms (1 confirmed by serology). Participated in aerosol generating procedures (used big valve mask without a filter).
Dwosh et al	Case series Examined exposure risk of 10 staff members who developed SARS.	Nine of the infected staff members had unprotected direct contact with SARS patients; one did not. Noninvasive positive pressure ventilation and nebulized medications were used during exposures.
Environmental decontamination		
Ho et al	Retrospective cohort study of 1312 staff members at a Tai Pai Hospital.	Forty staff members developed SARS; 37 had direct contact with SARS patients or infected coworkers; 3 were cleaners who had no direct contact with patients.

consistently wore N95 respirators compared with those who consistently wore surgical masks was also not statistically significant ($P = .5$). The study is one of the most informative coming from the SARS outbreak itself but suffers from many limitations. Unfortunately, the small sample size of the cohort and other confounding factors made interpretation of the results difficult. The role of fit testing was not addressed, and the potential for accidental autoinoculation when removing gear was not examined. The suggestion by the authors that consistent use of even a surgical mask was sufficient protection is supported from descriptions of SARS control measures in Vietnam. Ha et al[4] reported that, in one hospital in which workers were exposed to confirmed SARS patients, none of the workers subsequently developed SARS, despite the fact that N95 respirators were not available until the third week of the outbreak. Despite this lack of respirators, initial control measures were successful in limiting spread.[4]

Lau et al conducted a case-control study of 72 hospital workers who developed SARS in Hong Kong, along with 144 matched controls.[2] They found that inconsistent use of PPE was associated with a higher risk of SARS. One hundred percent of HCW used an N95 respirator or surgical mask, and no difference was noted in the use of N95s between cases and controls. Again, small sample sizes may have limited the power of these studies to show the effects of these interventions. No published studies have evaluated the effectiveness of face shields and/or goggles in their ability to protect HCWs against SARS.

One of the more interesting aspects of the Lau et al study[2] was the information provided regarding perception of risk and education on infection control procedures. The authors found that having an inadequate amount of infection control training was associated with a higher risk of SARS infection. In addition, HCWs who perceived that the amount of personal protective equipment available was inadequate were at higher risk for developing SARS, and this effect remained significant in the multivariate model.[2] Because the study was conducted in 5 hospitals in Hong Kong, the researchers were unable to confirm what specific items (if any) were inadequately supplied. They noted, however, that, given the large differences in risk for SARS infection (odds ratio >5; $P < .001$), it was likely that *actual* rather than *perceived* PPE shortages were at least partially responsible.

N95 respirators have been required for HCWs in the United States since 1994. Studies of their use in clinical practice have shown that a range of between 44% and 97% of HCWs use the respirators properly.[8] Thus, it is feasible that the improved efficacy of an N95 respirator over a surgical mask may be easily lost if compliance is poor or inadequate training is provided. The Centers for Disease Control and Prevention (CDC) emphasizes the importance of formal respiratory protection programs as well as ensuring that workers understand the correct order in which to remove PPE.[9] Park et al retrospectively reviewed HCWs who had been exposed to those American patients with laboratory evidence of SARS-CoV infection and supports the observations of others with regard to compliance with infection control guidelines.[10] Sixty-six HCWs reported exposure to patients who were coughing and later found to be SARS positive, yet 40% did not use a respirator. Despite being exposed and developing symptoms, 10 of 17 HCWs were not furloughed. However, none of the HCWs developed SARS, and no local disease transmission occurred.

An elegant study by Huff et al[11] emphasizes the importance of a proper facial seal with respirator use. The authors tracked the dispersal of aerosolized droplets during pulmonary function testing, which used a nebulizer solution containing radioactive technetium. Personnel were evaluated for potential contamination of airways by quantitatively analyzing nose swabs. A clear demonstration of a drop in disintegrations/minute in individuals wearing fit-tested respirators compared with those wearing respirators without fit testing or surgical masks was demonstrated.[11] It must be emphasized that studies have demonstrated that fit testing reduces the risk of *exposure* to infectious agents by the airborne route; however, it is unclear as to whether or not the risk of *infection* in health care workers is reduced for tuberculosis or for other respiratory pathogens.[12]

Fundamental to the fit-testing process is the educational component, ie, teaching the worker to select the correct mask for best facial fit and to perform a fit check each time a respirator is worn. The relative importance of fit testing versus education on how to perform a proper fit check is unclear, and, in fact, fit checking may be the most valuable skill of the 2 in reducing exposures to infectious aerosols. Hannum et al examined the effect of 3 different methods of respirator training on the ability of health care workers to pass a qualitative fit test.[12] Group A, which received one-on-one training and fit testing, did not significantly differ from the group that received a classroom demonstration by infection control nurses in the proper use of respirators without fit testing. The authors concluded that fit testing as a part of training marginally enhanced the ability of HCWs to pass a fit test. The limited studies, demonstrating the importance of fit checking each and every time to ensure a good seal, suggests that regular fit testing is less important than on-going assessment of the ability of health care workers to achieve an effective seal through fit checking.

Infection control procedures directed at environmental factors

Physical space separation. During the SARS outbreaks in Singapore, Taiwan, Hong Kong, Hanoi, and Toronto, a number of different physical space interventions were applied, including separating triage patients in waiting rooms for emergency wards and other hospital departments; isolating suspected SARS patients in single rooms in emergency departments, general medical wards, and intensive care units; and using anterooms to separate donning and doffing of PPE from patient care activities.[3,4,13] In examining the evidence for the transmission route of SARS, Varia et al found that the risk of developing SARS in Toronto health care workers and family members was graded by distance, with exposures less than 1 meter from a case being highest risk. Risk decreased sequentially with exposures less than 3 meters from a case or greater than 3 meters and whether they took place with or without cough-inducing or aerosol-generating procedures.[14] This implies that physical separation of SARS patients from other patients and staff members should have some effect on preventing transmission of SARS. However, this intervention has not been evaluated formally.

Scales et al looked at staff members who provided care for a patient with unrecognized SARS. They found that, of HCWs exposed to the patient, those who had sustained close contact or participated in high-risk procedures (eg, endotracheal intubation) had a higher risk of developing SARS than those who did not.[15]

Ha et al found marked differences in transmission rates of SARS in 2 Vietnamese hospitals. Neither hospital had negative-pressure rooms. Hospital A was a more modern facility; however, hospital B had designated SARS isolation wards and large spacious rooms with high ceilings and ceiling fans and large windows that were kept open for cross-ventilation. In contrast, hospital A's rooms were smaller, and individual air-conditioning units were in use early during the outbreak. Nosocomial clusters occurred in hospital A but not in hospital B. The fact that hospital B had larger rooms and that symptomatic patients were physically separated from other patients may have played a role in decreasing transmission.[4]

Decreasing infectious aerosols and particles at the source. The practice of infection control differs from the approach of industrial worker protection in that, historically, infection control approached the protection of HCWs primarily by applying barriers to those individuals who might potentially be exposed. This is in contrast to industry, whose occupational health approach is first to apply environmental and engineering controls to control hazardous materials from the source. This difference in approach was reflected in the review of the literature of which there was relatively little information concerning control of infectious exposures at the source. The recently published studies on the hospital-associated outbreaks of SARS have all concluded that direct contact or close exposure to a SARS patient is generally required to transmit the virus, although important exceptions exist.[5,13-16] In some circumstances, aerosol-generating procedures have resulted in spread beyond that which is expected by droplet transmission of less than 3 feet. These episodes suggest that traditional concepts of droplet versus airborne transmission require reexamination. For example, some procedures, such as intubation, the use of continuous positive-pressure (CPAP) ventilation, or nebulizer therapy seemed to result in the generation of finer infectious droplets from SARS patients that could travel farther than those generated spontaneously through coughing. An analysis of a large outbreak in the Amoy Gardens apartment complex in Hong Kong concluded that the aerosolization of SARS from fecal material by flushing toilets allowed spread of disease through the building's ventilation system because of improper seals around floor drains.[17] This again resulted in transmission that ranged farther than could be explained by respiratory droplets. Such aerosol generation seems to be responsible for some episodes of spread at distances greater than those commonly found with large droplets and some instances of failure of infection control practices to prevent transmission.[5,9]

These ''super-spreading'' events, during which smaller infectious droplets are aerosolized, may well occur with other infectious agents but, because of innate immunity in the general population, are unrecognized. The possibility of a gradation of particles generated by aerosolizing procedures led to recommendations to avoid aerosol-generating procedures, such as nebulizer therapy, and procedures to limit the generation of infectious aerosols during intubation were also developed.[7,18] Limiting the generation or dissemination of infectious particles from patients can be seen as a means of controlling the source of a hazardous occupational exposure. Early infection control guidelines for SARS suggested placing surgical masks on suspected patients in triage or while being transported in the hospital to reduce infectious exposures.[19-21] Understanding the mode or modes of transmission is key to designing effective environmental control practices (particularly at the ''source'') for hospital-acquired infections.

Transmission of SARS appears to only occur from those who are symptomatic with the disease.[22] Furthermore, 3 recently published seroprevalence studies of health care workers in the United States, Hong Kong, and Vietnam have shown that asymptomatic infection does not appear to occur.[4,10,23] Therefore, directing infection control measures against those patients who have symptoms compatible with SARS should be an effective means of controlling the outbreak. This was, in fact, the case in all of the outbreaks in 2003. Once the disease was recognized and appropriate infection control measures were put into place, the numbers of new infections declined rapidly.

This may well be applicable to any number of respiratory pathogens. In many cases, patients admitted to a hospital with respiratory infections are not cared for by HCWs using precautions. The rate of transmission of many common respiratory viruses to health care workers is unknown. In examining the nosocomial transmission of respiratory syncytial virus (RSV), Goldman found that that virus is spread by direct hand contact with the secretions of infected patients or with contaminated objects in the patients' environment.[24] Personnel may infect themselves by rubbing their eyes or nose with contaminated hands, thus becoming vectors in the transmission of RSV to patients under their care. Compliance with contact precautions, which requires the use of gloves and gown, dramatically reduces the incidence of nosocomial RSV infection. The consistent application of infection control precautions for all patients with respiratory symptoms, without waiting for confirmation of diagnosis, is key to preventing transmission to HCWs.

Another method of source control is limiting the movement of patients once admitted to the hospital. In a hospital with a large HIV unit in Lisbon, Portugal, restricting patient movements was identified as one of a number of infection control measures that were introduced to eliminate risks for nosocomial transmission of multidrug-resistant tuberculosis.[25]

Ventilation systems, which generate 6 to 10 air exchanges per hour, and exhaust outside the hospital resulting in the creation of negative-pressure environments in patient care rooms, have been shown to remove 99.9% of airborne contaminants within 69 minutes and are recommended for patients with known or suspected tuberculosis.[26] However, in one study of the effectiveness of these systems revealed that 11% of such ventilation systems in 3 US hospitals were not actually generating negative pressure and that 19% of tuberculosis patients were not isolated on the first day of admission because the etiology of their problem was not recognized.[27] Similarly, Canadian researchers have shown that inadequate ventilation systems in general patient rooms can lead to increased risks to tuberculosis infection for health care workers because of patients with unrecognized infections.[28] These observations emphasize that early identification of high-risk patients combined with physical isolation of patients, limiting aerosolizing procedures, and wearing appropriate protective gear consistently are very important in controlling transmission. If negative-pressure rooms are used, they must be regularly monitored.

Environmental decontamination. Cleaning and disinfecting surfaces were recommended as a means of preventing SARS transmission early in the course of the epidemic. This was supported by the observation that the SARS CoV could survive on plastic surfaces for up to 48 hours.[22] The virus has also been shown to be able to survive up to 2 days in stool and up to 4 days if the patient was experiencing diarrhea.[22] The hypothesis that the virus could be transmitted by contaminated fomites was supported by the observation of Ho et al when 3 hospital cleaning staff members became infected with SARS, despite having only exposures that involved cleaning a room that had been vacated by a SARS patient.[16] Similarly, one of the infected HCWs in Seto et al's cohort did not have direct exposure to a SARS-infected patient, suggesting either community acquisition or fomite transmission.[6] Environmental decontamination has not been formally evaluated as a control measure for SARS, but other common respiratory viruses (influenza, rhinovirus, RSV) are commonly transmitted through contact with the environment surrounding an infected patient, and it is likely that this also applies for the SARS coronavirus.[29]

Handwashing can be viewed as a type of environmental decontamination. Seto et al did show that HCWs who reported handwashing during patient care experienced a lower risk of developing SARS in univariate analyses; however, this was not significant in multivariate analysis.[6] No other evaluation of handwashing has been reported directly related to SARS, but hand hygiene has been shown to be effective in decreasing the transmission of other common respiratory viruses, including human coronaviruses, in a number of studies.[30-33]

CONCLUSION

SARS is a disease largely spread by respiratory droplets. The lack of spread within the community indicates that SARS is less contagious than influenza and other similar respiratory viruses during routine contact and care.[34] The literature is clear that failure to implement appropriate barrier precautions was responsible for most nosocomial transmission.

Although largely spread by the droplet route, there is indirect evidence that the generation of aerosols and the lack of control of aerosols at the source was another important factor in hospital dissemination. The available evidence on the importance of aerosols for transmission suggests that procedures likely to generate high concentrations of aerosols should be limited as much as clinically possible. However, these topics require further investigation, and more research is needed on the generation and behaviour of respiratory particles during aerosolizing events such as nebulizer therapy and continuous positive airway pressure.

Inadequate hospital ventilation systems in the general patient area may have been an important determinant of "superspreading events" of SARS. More research needs to be done on the adequacy of existing ventilation systems in limiting the spread of infectious aerosols. The added benefit of negative-pressure rooms beyond that of following isolation practices and having adequate ventilation throughout the hospital needs to be determined.

It is still unclear whether N95 respirators offered significantly better protection than surgical masks for all patient care activities. Some HCWs contracted SARS while working with what should have been adequate PPE during aerosol-generating procedures. It will be important to study whether the failures to protect HCWs in these circumstances were due to failure in efficacy of controls or in the effectiveness in their use. Failures in efficacy would imply that better PPE (ie, N95 respirators) may be needed to protect adequately the HCWs from SARS in these circumstances. However, failure in effectiveness in the use of PPE would imply that less complicated infection control guidelines that focus on the key protective factors, combined with enhanced compliance, may ultimately be more successful in reducing infections. Additional studies to assess the relative importance of fit testing versus fit checking are required, particularly because the former has significant resource implications. Finally, the importance of the transocular route in disease transmission and how existing eye protection reduces this risk to HCWs are not understood.

Preventing the transmission of infectious diseases spread by either airborne or droplet routes poses a significant challenge. The practice of infection prevention and control requires ongoing critical review in this age of emerging infectious diseases.

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References

1. Wong TW, Lee C-k, Tam W, Lau JT-F, Yu T-s, Lui S-f, et al. Cluster of SARS among medical students exposed to single patient, Hong Kong. Emerg Infect Dis 2004;10:269-76.
2. Lau J, Fung K, Wong T, Kim J, Wong E, Chung S, et al. SARS transmission among hospital workers in Hong Kong. Emerg Infect Dis 2004;10:280-6.
3. Abdullah ASM, Tomlinson B, Cockram CS, Thomas GN. Lessons from the severe acute respiratory syndrome outbreak in Hong Kong. Emerg Infect Dis 2003;9:1042-5.
4. Ha L, Bloom S, Nguyen Q, Maloney S, Le Q, Leitmeyer K, et al. Lack of SARS transmission among public hospital workers, Vietnam. Emerg Infect Dis 2004;10:265-8.
5. Christian MD, Loutfy M, McDonald LC, Martinez KF, Ofner M, Wong T, et al. Possible SARS coronavirus transmission during cardiopulmonary resuscitation. Emerg Infect Dis 2004;10:287-93.
6. Seto WH, Tsang D, Yung RWH, Ching TY, Ng TK, Ho M, et al. Effectiveness of precautions against droplets and contact in prevention of nosocomial transmission of severe acute respiratory syndrome (SARS). Lancet 2003;361:1519-20.
7. Loeb M, McGeer A, Henry B, Ofner M, Rose D, Hlywka T, et al. SARS among critical care nurses, Toronto. Emerg Infect Dis 2004;10: 251-5.
8. Tokars JI, McKinley GF, Otten J, Woodley C, Sordillo EM, Caldwell J, et al. Use and efficacy of tuberculosis infection control practices at hospitals with previous outbreaks of multidrug-resistant tuberculosis. Infect Control Hosp Epidemiol 2001;22:449-55.
9. Ofner M, Lem M, Sarwal S, Vearncombe M, Simor A. Cluster of severe acute respiratory syndrome cases among protected health-care workers, Toronto, Canada, April 2003. JAMA 2003;289: 2788-9.
10. Park BJ, Peck AJ, Kuchnert MJ, Newbern C, Smelser C, Comer JA, et al. Lack of SARS Transmission among health care workers, United States. Emerg Infect Dis 2004;10:244-8.
11. Huff RD, Horwitz P, Klash SJ. Personnel protection during aerosol ventilation studies using radioactive technetium (Tc99m). Am Indust Hyg Assoc J 1994;55:1144-8.
12. Hannum D, Cycan K, Jones L, Stewart M, Morris S, Markowitz SM, et al. The effect of respirator training on the ability of health care workers to pass a qualitative fit test. Infect Control Hosp Epidemiol 1996;17:636-40.
13. Dwosh HA, Hong HH, Austgarden D, Herman S, Schabas R. Identification and containment of an outbreak of SARS in a community hospital. CMAJ 2003;168:1415-20.
14. Varia M, Wilson S, Sarwal S, McGeer A, Gournis E, Galanis E, et al. Investigation of a nosocomial outbreak of severe acute respiratory syndrome (SARS) in Toronto, Canada. CMAJ 2003;169:285-92.
15. Scales DC, Green K, Chan AK, Poutanen SM, Foster D, Nowak K, et al. Illness in intensive care staff after brief exposure to severe acute respiratory syndrome. Emerg Infect Dis 2003;9:1205-10.
16. Ho AS, Sung JJY, Chan-Yeung M. An outbreak of severe acute respiratory syndrome among hospital workers in a community hospital in Hong Kong. Ann Intern Med 2003;139:564-7.
17. Yu I, Li Y, Wong T, Tam W, Chan AT, Lee JHW, et al. Evidence of airborne transmission of the severe acute respiratory syndrome virus. N Engl J Med 2004;350:1731-9.
18. Cooper A, Joglekar A, Adhikari N. A practical approach to airway management in patients with SARS. CMAJ 2003;169:785-7.
19. Health Canada. Infection control guidance for health care workers in health care facilities and other institutional settings–Severe Acute Respiratory Syndrome (SARS). Ottawa: Health Canada; 2003.
20. World Health Organization. Hospital infection control guidance for Severe Acute Respiratory Syndrome (SARS). WHO; 2003.
21. Riley S, Fraser C, Donnelly CA, Ghani AC, Abu-Raddad LJ, Hedley AJ, et al. Transmission dynamics of the etiological agent of SARS in Hong Kong: impact of public health interventions. Science 2003;300: 1961-6.
22. World Health Organization. Consensus document on the epidemiology of severe acute respiratory syndrome (SARS). WHO; 2003.

23. Chow PKH, Ooi E-E, Tan H-K, Ong K-W, Sil BK, Teo M, et al. Healthcare worker seroconversion in SARS outbreak. Emerg Infect Dis 2004;10:249-50.
24. Goldmann DA. Nosocomial viral infections: recent developments and new strategies. Eur J Clin Microbiol Infect Dis 1989;8:75-81.
25. Hannan MM, Peres H, Maltez F, Hayward AC, Machado J, Morgado A, et al. Investigation and control of a large outbreak of multi-drug resistant tuberculosis at a central Lisbon hospital. J Hosp Infect 2001;47:91-7.
26. Segal-Maurer S, Kalkut GE. Environmental control of tuberculosis: continuing controversy. Clin Infect Dis 1994;19:299-308.
27. Sutton PM, Nicas M, Harrison RJ. Tuberculosis isolation: comparison of written procedures and actual practices in three California hospitals. Infect Control Hosp Epidemiol 2000;21:28-32.
28. Menzies D, Fanning A, Yuan L, FitzGerald JM. Hospital ventilation and risk for tuberculosis infection in Canadian health care workers. Ann Intern Med 2000;133:779-89.
29. Goldmann DA. Transmission of viral respiratory infections in the home. Pediatr Infect Dis J 2000;19(Suppl 10):S97-102.
30. Paes BA. Current strategies in the prevention of respiratory syncytial virus disease. Paediatr Respir Rev 2003;4:21-7.
31. Gagneur A, Sizun J, Vallet S, Legr MC, Picard B, Talbot PJ. Coronavirus-related nosocomial viral respiratory infections in a neonatal and paediatric intensive care unit: a prospective study. J Hosp Infect 2002;51:59-64.
32. Hall CB. Nosocomial respiratory syncytial virus infections: the "Cold War" has not ended. Clin Infect Dis 2000;31:590-6.
33. Purssell E. Preventing nosocomial infection in paediatric wards. J Clin Nurs 1996;5:313-8.
34. Isakbaeva ET, Khetsuriani N, Beard RS, Peck A, Erdman D, Monroe SS, et al. SARS-associated coronavirus transmission, United States. Emerg Infect Dis 2004;10:225-31.
35. Yassi A, Bryce E, Moore D, Janssen R, Copes R, Bartlett K, et al. Protecting the faces of health care workers: knowledge gaps and research priorities for effective protection against occupationally acquired respiratory infectious diseases. Toronto: The Change Foundation; 2004.