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Research Gaps in Protecting Healthcare Workers From SARS and Other Respiratory Pathogens: An Interdisciplinary, Multi-Stakeholder, Evidence-Based Approach

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Abstract

Objective—To identify priorities for further research in protecting healthcare workers (HCWs) from severe acute respiratory syndrome (SARS) and other respiratory pathogens by summarizing the basic science of infectious bioaerosols and the efficacy of facial protective equipment; the organizational, environmental, and individual factors that influence the success of infection control and occupational health programs; and factors identified by HCWs as important.

Method—An extensive literature review was conducted and 15 focus groups held, mostly with frontline HCWs in Toronto. Critical gaps in knowledge were identified and prioritized.

Results—Highest priority was given to organizational factors that create a climate of safety. Other priority areas included understanding aerosolization risks and practical measures to control bioaerosols at the source.

Conclusions—Further research is warranted to improve safety climate in health care and, specifically, to provide greater protection against respiratory pathogens.

Difficulties in recruitment and retention; high rates of work injuries, illness, and absences from work; and escalating costs plague the health-care systems.[1] In British Columbia (BC), Canada, healthcare workers (HCWs) lose more time from work as a result of work-related injury and illness than any other occupational group.[2] There are high levels of stress among registered nurses and other nursing personnel[3]; and, according to the last National

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Population Health Survey, 11% of nursing assistants sought healthcare attention for mental health reasons compared with 7% of other Canadians.[4] Healthcare workers are not only at higher risk for injuries, work-related anxieties, and mental health problems,[5] but have an additional increased risk of acquiring infectious diseases such as tuberculosis and influenza.[6,7] This potential was highlighted with the advent of severe acute respiratory syndrome (SARS) and evidence of its occupational transmission.[8]

During the SARS outbreak, widely divergent opinions on the adequacy of facial protection emerged within the healthcare community, ranging from the view that N-95 respirators were unnecessary for agents mainly spread through droplets to the belief that higher levels of protection (eg, powered air-purifying respirators) were required to adequately protect HCWs under all circumstances. (An N-95 respirator is one of nine types of disposable particulate respirators and are approved by the National Institute for Occupational Safety and Health. The N indicates that the respirator provides no protection against oils and the 95 indicates that it removes at least 95% of airborne particles during “worst case” testing using a “most-penetrating”-sized particle.) The science behind respirator selection and use was also a contentious issue as was the need for fit testing. Similarly, there were conflicting views regarding protective eyewear and expert opinion varied as to the need for safety glasses versus splash goggles or face shields.

Vancouver was one of the cities in which SARS appeared in Canada. During the course of the outbreak, three individuals arrived in Vancouver from Hong Kong with SARS and one nurse developed SARS as a result of occupational exposure. In light of the intense local interest in the disease and because of the close working relationships that developed through the work of the BC Provincial SARS Committee,[9] a unique interdisciplinary team of researchers based in Vancouver undertook a review of the relevant literature on facial protection. The team included experts in occupational medicine, occupational hygiene, infection control, public health, epidemiology, and respiratory therapy, as well as a clinical staff and other frontline care providers. Efforts were coordinated by the Occupational Health and Safety Agency for Healthcare (OHSAH), a unique agency jointly governed by the healthcare unions and health employers in BC.[1] The objective was to synthesize the existing knowledge and identify knowledge gaps needed to prevent occupational respiratory disease transmission in HCWs.

Materials and Methods

A literature review was conducted by developing a list of key words and using them to search citations from 1988 onward in Medline, EMBASE, CINAHL, Web of Science, and OSHROM databases using different combinations. Citations were divided into two general areas: 1) the basic science of aerosols and respiratory protective equipment; and 2) factors that influence effectiveness of occupational health and infection control programs. From these lists of citations, titles and available abstracts were reviewed for relevancy to compile a final list of over 700 citations, including secondary references, which were used as source material for writing the two sections of the review. A more detailed description of the methodology is found in Gamage et al.[10]

After focus group discussions were conducted with seven different classifications of healthcare workers: 1) occupational health staff, 2) infection control practitioners, 3) physicians, 4) clinical nursing staff, 5) allied health professionals (including respiratory therapists, laboratory technicians, radiology technicians, physiotherapists, and others), 6) support staff, and 7) hospital managers to determine the factors they felt were most important in protecting them from SARS and other hospital-acquired infections in Toronto, Ontario, and Vancouver, BC. An additional focus group of occupational health and infection control professionals was held in Ottawa, Ontario, a city not directly affected by SARS, but which experienced the same heightened state of alertness because of the outbreak in Toronto.

Participants were recruited in three ways for the 11 focus groups conducted in Ontario. First, letters were written to the Chief Executive Officers of 13 hospitals, 11 in Toronto, which had admitted patients with SARS, and two in Ottawa, explaining the study's objective and asking them to identify appropriate participants from their facilities. Second, letters were also sent to the Canadian College of Health Services Executives (Greater Toronto Area Chapter), the Ontario Society of Medical Technologists, the College of Respiratory Therapists of Ontario, Ontario Medical Association, the Ontario Nurses Association, the Registered Nurses Association of Ontario, and the Occupational Health and Safety workers identified by the Ontario Hospital Association human resources database and the Canadian Union for Public Employees (for support staff). Finally, e-mails were also sent to infection control physicians on the Change Foundation's project steering committee requesting their assistance in forwarding the message to other physicians. All invitation letters requested participants to have direct experiences with SARS. In all, 87 individuals came from 22 different healthcare institutions, organizations, and professional associations to participate in the 11 Ontario focus groups. Two focus groups were conducted in Toronto for each of occupational health staff and hospital administrators, because the response was larger than expected. Two groups of mixed workers from two different facilities were also conducted.

Several different strategies were used to recruit participants in the four focus groups in Vancouver. Nurses, allied health professionals and support staff from the five acute-care hospitals in greater Vancouver that had confirmed SARS cases during the outbreak were recruited through their affiliated unions. Infection control practitioners, occupational health staff, and clinical managers were recruited through letters sent to staff from the five hospitals identified by one of the project's steering committees.

The discussion questions were based on a theoretical framework, which is discussed subsequently, and were pilot-tested with a group of diverse HCW professionals in Vancouver. The sessions were led by facilitators who read out one question at a time and allowed the group to exhaust its discussion of the subject before moving on to the next question. Facilitators tried not to interfere in the discussion except where clarification was required or if some members of the group were having difficulty entering the conversation. There was also an opportunity for participants to discuss other issues at the end of the session which were not brought up earlier. The sessions were then recorded and transcribed with transcripts reviewed by one of three researchers and coded according to an agreed-on set of variables. New variables were also recorded and tracked. Summaries of each transcript were written and a narrative synthesis based on these summaries and the significant quotations written as described further in Moore et al.[11]

The results of the literature review were compared with those from the focus groups. Important gaps in the scientific literature were identified, and recommendations for key areas requiring further study were developed by consensus.

Results

Key Findings

Basic Science and Efficacy of Facial Protective Equipment—Bioaerosols are formed as combinations of exhaled respiratory gases, respiratory droplets, and microorganisms. Respiratory droplets can be produced by coughing, shouting, sneezing, and talking, as well as through certain clinical procedures such as suctioning and nebulizer therapy. The size and number of droplets produced is dependent on the method by which droplets are generated.[12] The higher the exhalation velocity, the finer in size and the greater in number the droplets.[13] Particle size also determines the location in the respiratory tract where airborne particles will be deposited. Large respiratory droplets (greater than 5 μm in diameter) that transmit respiratory viruses such as influenza, respiratory syncytial virus (RSV), and coronaviruses (likely including SARS) rapidly fall to the ground once they are produced by coughing or sneezing. Very small droplets, however, such as those less than 5 μm in diameter are called "droplet nuclei"; these may remain suspended in air for several hours, depending on the ambient conditions.[14] Tuberculosis is the classic example of a disease spread by droplet nuclei.

Fit-tested, NIOSH-certified N-95 respirators have been the standard for respiratory protection from tuberculosis for HCWs in the United States since 1996.[15] In Canada, N-95-equivalent respirators have also been recommended for tuberculosis and other potentially infectious aerosols,[16] but until the SARS outbreaks, fit-testing of the N-95 respirators was not widely applied in healthcare settings.[17]

The primary purpose of fit-testing is to ensure that the wearer has selected a respirator brand, model, and size that properly seals with his or her face.[18] Fit tests are also useful for training wearers in proper donning and doffing procedures, including how to conduct a fit-check each time the respirator is used.[19] The scientific literature provides clear evidence that fit-testing is important in ensuring that N-95 respirators are able to achieve acceptable reductions in particle exposures. A study conducted by NIOSH in 1996 using 25 subjects wearing N-95 respirators found that geometric mean exposures to airborne particles were 25% of ambient levels before quantitative fit-testing, which does not meet the required 10% level set by NIOSH. However, after fit-testing, geometric mean exposures were reduced to 4% of ambient levels.[20] A similar study published this year found that without fit-testing, only three of 18 N-95 respirator models provided a protection factor of 10, but with fit-testing, 13 of 18 models met this expected standard.[21] Another study, however, did not find a significant benefit in fit-testing individual workers for N-95 respirators compared with classroom teaching and demonstration of proper respirator use.[22]

These studies relied on measuring airborne particles of a standard size range (typically 0.02 to slightly greater than 1 μm), which could easily be measured for their ability to penetrate respirator filters. Another study examined fittesting for its ability to prevent HCW exposures to radiolabeled aerosols generated by nebulizers used by patients undergoing pulmonary function testing. The nebulizer solution contained Tc99m, which could then be measured in the nasal passages of the staff performing the procedure. Without respiratory protection, HCWs were found to have high levels of exposure to Tc99m, with levels of up to 11,000 disintegrations/min being recorded. The use of surgical masks did not appear to significantly reduce these exposures. However, when HCWs were taught simple body substance isolation techniques and provided with fit-tested respirators with high-efficiency filters, overall exposures to Tc99m were reduced by 78%.[23]

Several authors have tried to estimate the added level of protection that fit-tested N-95 respirators provide with respect to tuberculosis (TB).[24,25] One of these estimated that disposable HEPA respirators, similar to an N-95, could provide up to 17 times the level of protection compared with no respirator.[24] Surgical masks were estimated to provide only 2.5 times the protection as shown in Figure 1. These results were based on theoretical models only, because no study has attempted to measure the level of effectiveness in workplace conditions.

No studies were found that measured actual facial, ocular, or nasal area exposure to respiratory tract pathogens. Most studies relating to eye protection were concerned with reducing the risk of splashes from blood[26,27] or from physical or chemical trauma.[28,29] One study that tried to evaluate the effectiveness of using facial protective equipment among dentists found no difference in prevalence of antibodies against influenza A and B and RSV among those who wore masks or eye protection compared with those who did not.[30]

The literature clearly shows that the effectiveness of the protection offered by N-95 respirators is lost if a proper seal between the mask and face is not maintained. Fit-testing should improve the ability to maintain the appropriate seal; however, whether this added level of protection is necessary and whether fittesting is more important than fit-checking (to ensure proper seal) has not been adequately assessed.

Effectiveness of Occupational Health and Infection Control Policies—The theoretical model for this section of the review (Fig. 2), as discussed at length in Moore et al.,[31] was an adaptation of DeJoy’s Behavioral Diagnostic Model,[32] which itself is based on the PRECEDE (Predisposing, Reinforcing and Enabling factors in Educational Diagnosis and Evaluation) framework.[33] This model is particularly suitable for our research because it integrates worker-related as well as organizational factors that affect behavioral intentions toward safe work practices. Worker-centered variables include employees’ beliefs, knowledge, attitudes, perceptions, demographics, type of work setting, and job status, all of which are potentially affected by outside influences, including coworker attitudes, supervisor support, and institutional culture.

Organizational factors such as safety culture, infection control resources and occupational health, and the working environment (eg, accessibility to safety equipment, isolation or single rooms, and barrier supplies) that support and reinforce safe work behaviors are also crucial and are included in our model. Details of the findings of this part of the literature review are provided elsewhere.[10,31] This section synthesizes some of the key findings.

Organizational Factors

Organizational factors refer to determinants of workplace safety, which range from very broad issues such as workplace culture and safety climate to specific policies and procedures such as the availability of training programs. Safety climate refers to the perceptions that workers share about safety in their organization and derives from a multidimensional, systems approach to worker health and safety.[34] It is usually measured by asking workers how they rate their organization's commitment to safety. Safety climate has specifically been correlated with better compliance with universal precautions.[35]

Gershon and colleagues identified six key factors to define the specific elements that contribute to a positive safety climate: 1) senior management support for safety programs, 2) absence of barriers to safe work practices, 3) cleanliness and orderliness of the worksite, 4) minimal conflict and good communications among staff, 5) frequent safety-related feedback and training by supervisors, and 6) the availability of personal protective equipment (PPE) and engineering controls.[36] Although some of these factors have been associated with better safety practices, no studies have evaluated interventions to improve poor safety climates.

Training is an important component of any occupational health program, but the type of training that is most effective at promoting compliance and the best methods to conduct follow up to verify that the objectives of the training have been met have not been well-studied. Moongui examined a group of Thai HCWs and found much higher compliance with glove use and handwashing during a peer feedback intervention (83% vs. 49% during baseline), but noted that the effect lessened with the passing of time.[37] During the SARS outbreak in Hong Kong, Lau and colleagues showed that an increased risk of developing SARS was associated with having had less than 2 hours of infection control training, as shown in Table 1.[38]

The Study on the Efficacy of Nosocomial Infection Control (SENIC), conducted in 338 hospitals in the United States in the 1970s, was able to clearly define four specific organizational factors that were associated with hospitals having lower rates of nosocomial infections. These were: 1) having one infection control practitioner per 250 acute-care beds, 2) having at least one full-time physician interested in infection control, 3) having intensive surveillance programs in place to detect nosocomial infections, and 4) having intensive infection control policies and procedures in place.[39] By applying all four of these factors, the authors estimated that up to one third of hospital-acquired infections could be prevented. Despite these well-known findings, many of these recommendations have not been widely applied. A recent survey of 172 Canadian hospitals examining these four critical components of an infection control program noted considerable deficits. There were fewer than 1 full-time equivalent per 250 beds in 42% of hospitals; 40% of the programs had no physician support; the median surveillance index was 65.6 per 100, and the median control index was 60.5 per 100.[40] These studies focused on protecting patients; no similar studies have been published with respect to the occupational health resources needed to protect workers.

Even when appropriate policies are in place, they are often not applied. In a U.S. study of 66 HCWs exposed to coughing patients who were later diagnosed as having had SARS, 40% had not been using a respirator at the time of exposure.[41] Of the 17 HCWs who later developed symptoms, only seven were quarantined, despite there being clear policies that mandated that all 17 should have been placed off work.[41]

Environmental Factors

Environmental factors such as the use of negative pressure rooms and making available specific PPE such as N-95 respirators have been seen as the key to preventing the spread of tuberculosis in healthcare institutions. Although there is good rationale for the use of these interventions, based on our knowledge of how TB is transmitted, very few of them have been definitively shown to reduce infections in HCWs. Infection control guidelines developed by the Centers for Disease Control and Prevention in 1994 to prevent nosocomial transmission of TB have been largely credited with the subsequent reduction of TB cases in HCWs, but the specific factors that most account for the reduction are difficult to determine.[42] Benefit that accrues from nursing patients in negative-pressure rooms, above that of having adequate ventilation throughout the hospital, is not clear. In a study conducted in 17 hospitals in Canada, inadequate ventilation systems (those providing less than two air-exchanges per hour) in general patient areas were associated with an increased risk of TB infection in HCWs.[6] Another study in the United States found that 11% of negative-pressure ventilation systems were not actually generating negative pressure when assessed.[43] Furthermore, a wide range of HCWs (44–97%) were observed in two U.S. hospitals over a 3-year period to be using their N-95 respirators properly while working with patients with TB.[44]

During SARS outbreaks, a number of environmental controls were applied (eg, physical space separation) for which there was good rationale, but these interventions were not tested for effectiveness.[8] Wong et al. examined one of the “superspreading” events in a Hong Kong hospital where a single patient transmitted SARS to 47 HCWs and found that the patient’s cubicle was under positive pressure relative to the rest of the ward and hallway. The authors concluded that the poor general ventilation in the hospital ward played a more significant role in transmitting the illness than did aerosolization procedures.[45]

There also appeared to be good rationale for enhanced environmental decontamination to prevent SARS. The SARS coronavirus was shown to survive on plastic surfaces for up to 48 hours; up to 2 days in stool, and up to 4 days with diarrhea.[46] Handwashing was shown to be protective against SARS in one study in the univariate model but not in the final model.[47] The possibility that SARS could be transmitted through indirect contact with inanimate surfaces is further suggested by another report from Hong Kong, which showed that three hospital cleaning staff developed SARS without direct patient contact; their only exposure had been to empty patient rooms that had previously been occupied by SARS patients.[48]

Two studies looked at the effectiveness of specific PPE against SARS. Seto and colleagues showed that wearing any mask was protective against SARS in a case–control study of 13 HCWs who developed SARS and 241 controls who did not.[47] Regularly wearing gowns was protective in univariate analyses, but only mask (surgical or N-95) use was significant in the multivariate analysis. The conclusions from this study must be viewed with caution because of the small number of cases and because the study excluded HCWs from one hospital with a large outbreak where exposure to aerosolizing procedures was likely.

In another study, Loeb et al. constructed a retrospective cohort of 43 intensive-care unit nurses from Toronto.[49] Eight of the 32 nurses who had direct contact with a patient with SARS subsequently developed SARS themselves. Regular use of N-95 respirators and surgical masks was associated with protection from SARS when compared with irregular or no mask or respirator use (Table 2). There was a trend toward increased protection from the N-95 respirators in comparison with surgical masks, but this was not statistically significant. Again, the number of cases limited the power of this study.

Although a great deal of attention was focused on the need for N-95 respirators or even respiratory protection with higher protection factors, it is also worth noting that in Vietnam, N-95 respirators were not available until the third week of the outbreak. However, this did not prevent Hanoi from becoming the first affected jurisdiction to effectively control SARS; masks and barriers with spatial separation were thought to be the key control factors.[50]

Individual Factors

Individual factors, as shown in Figure 2, include HCWs' knowledge, perception of risk, beliefs, attitudes, past experience, and sociodemographic characteristics. A study by Gershon and colleagues in 1995 found that most HCWs had high levels of personal knowledge about universal precautions (UP), but that, in many circumstances, this knowledge did not lead to high levels of compliance.[35] Apparently personal knowledge is influenced by a number of other factors such as age and safety-related attitudes of colleagues. Another study by Gershon's group found that HCWs who were younger than 40 years of age were more likely to comply with UP. However, the authors noted that this may reflect the fact that younger HCWs had been more recently trained.[51] Afif et al. found that physicians had the lowest compliance with UP (22%), and physiotherapists and occupational therapists had highest compliance (89%) with handwashing.[52] Other factors that have been shown to be associated with a lack of adherence to using PPE properly include: having insufficient time, interference with job duties, discomfort, interference with the practitioner–patient relationship, and decreased dexterity.[53–55] Certainly, organizational factors such as providing easy access to the correct PPE when needed can have important influences on HCW adherence.[56]

Focus Groups

Over 100 HCWs who participated in focus groups spent the greatest amount of time discussing organizational factors, as discussed in depth elsewhere.[11]

Organized Factors and Consistency of Messages—Foremost among the concerns of participants was the lack of consistency with safety instructions and the frequently changing directives, which were commonplace during the SARS outbreaks. This was a source of much anxiety for HCWs both in BC and Ontario. Coupled with this was the diversity of views on the role of regulatory agencies such as the Ontario Ministry of Labor and the Workers' Compensation Board of BC. Many workers saw the measures imposed as being somewhat Draconian, whereas others saw some measures such as the requirement for fit-testing as long overdue.

Workplace attitude toward safety was also seen as important. Paramount to this were the attitudes and actions of management and the perceived importance of occupational health and safety, both of which were important determinants of the safety climate within hospitals.

It was also felt that hospitals need to develop specific policies to address issues for part-time staff, physicians, residents, and students. They also felt that the effect of "casualization" and outsourcing of the work-force needed to be evaluated in terms of the effect of these practices on worker health and safety. It was acknowledged that knowledge of infection control procedures and the rationale behind them was important but not sufficient to ensure proper infection control procedures. Professionalism and beliefs in effectiveness of infection control guidelines, as modified by past experiences, were identified as having important influence on worker adherence to procedures.

Healthcare workers also expressed support for the development of evidence-based and practical infection control policies, which would include representatives of frontline workers. Ensuring adequate resources for infection control was also seen as a priority. To improve worker adherence to infection control guidelines, focus group participants felt that better enforcement of infection control guidelines was needed but did not want such enforcement to rely on nurses "policing" other professionals. Participants also saw the need for more accommodation of worker concerns and infection control guidelines for patients and visitors.

Training and Communication—Training in infection control was also discussed at length. Focus group members expressed their views that repeated training was needed and that better tracking methods to monitor who has been trained and who requires training should be developed. Workers felt that the appropriateness of the "train-the-trainer" model needs to be evaluated with respect to time commitments on frontline workers.

Communication about safety within healthcare organizations was seen as having a key role in protecting HCWs, especially during the SARS outbreaks. Face-to-face "town hall" meetings were seen as necessary to build worker confidence in hospital infection control policies during SARS. A variety of communication media were seen to be more effective than any single strategy, and workers identified a need for communication strategies to be adapted for multicentered organizations. Similarly, recent organizational changes have resulted in there being fewer frontline managers today, formerly responsible for much of the communication with frontline HCWs. Communication among employees, units, and especially between occupational health and infection control was seen as being important in creating safe work-places. The peer environment, especially the compliance of other occupational groups (including physicians), and the feedback from peers were also identified as factors that could exert positive or negative influence on individual worker actions. Attitudes of family members, in particular the fear that family members expressed toward contracting SARS, also influenced HCW behavior.

Environmental factors were the least-discussed issues in the focus groups. The topics discussed included the role of isolation rooms for patients with suspected communicable diseases, the availability of anterooms for HCWs to change into PPE, and the use and availability of negative-pressure rooms. Participants also discussed the importance of environmental decontamination, primarily handwashing, and the well-documented problems with the availability of specific PPE during SARS, especially with respect to N-95 masks and face shields or goggles.

Environmental Factors and Personal Protective Equipment—Focus group participants discussed fittesting at length, but the value of it was not universally accepted, because different institutions used different methods and workers often saw these inconsistencies as sources of concern for the whole process.

The participants also identified the need to address the increased amount of worker fatigue that existed when HCWs work with full PPE. The increased time constraints, increased workload, and discomfort associated with wearing PPE were also felt to be important barriers to worker adherence to recommendations.

Discussion

Despite the fact that research group members were drawn from a wide variety of disciplinary backgrounds and professional duties, we were able to easily come to an agreement on what the literature had to say, the key themes from the focus groups, and the areas that needed attention and further research. The literature was clear that failure to implement appropriate barrier precautions and hand hygiene was responsible for most nosocomial transmission. It was also striking that the concerns identified as highest priority in the focus groups of frontline workers matched well with what the interdisciplinary multistakeholder group has concluded were scientific gaps. As such, there was a strong consensus that attention to understanding why there was a failure to implement appropriate precautions, and how best to promote compliance in future, is an important topic for study. Taking into account the evidence from the literature review and the priorities identified through the focus group analysis, the following areas for further research were identified.

Priority 1: Improving Workplace Health and Safety Through Organizational Factors

Although many studies have shown that workplace safety climate is an important determinant of worker safety, no studies have evaluated interventions on how to improve the safety climate in healthcare institutions. If effective interventions could be designed, this would likely result in improvements in worker health and safety well beyond reducing infectious disease transmission, because workplace culture appears to be an important determinant of many occupational injuries and illnesses.

The SENIC studies from the 1970s and 1980s provided a good understanding of the human resources needed in healthcare institutions to reduce the incidence of nosocomial infections. However, similar studies have not been conducted in health-care institutions to assess occupational health and safety needs. This has, in part, led to wide variations in the staffing levels of occupational physicians, occupational health nurses, ergonomists, hygienists, and other occupational health staff in healthcare facilities, which in turn has led to variations in the scope of occupational health programming. Research is urgently needed to provide policymakers with evidence as to what programs and staff are needed to provide effective occupational health programs to protect workers from preventable illness and injury. Such research would provide evidence for the development of provincial and national standards for occupational health in healthcare.

Both occupational health and infection control rely on training programs to transfer knowledge to frontline HCWs. However, some studies have shown that training achieves short-term changes in behavior, at best, and requires ongoing feedback to sustain these changes. For example, a study of Thai HCWs[37] demonstrated higher compliance with glove use and handwashing during a peer feedback intervention (83% compliance vs. 49% compliance at baseline). However, compliance fell to 73% in the post-intervention phase. The authors noted that other techniques, including inservice education sessions, computer-assisted learning, as well as provision of education and group feedback by researchers also failed to show long-term effectiveness. More research needs to be conducted to determine the best training techniques to ensure that workers learn what they need to know to protect themselves and apply this knowledge on a daily basis. Fit-testing appears to have an important educational benefit in ensuring that workers properly use N-95 respirators; however, the relative role of the fit-test versus the fit-check and the frequency of monitoring compliance with either requires further evaluation.

Healthcare institutions communicate with their staff to transfer important safety-related information to workers on a daily basis. However, the best mechanisms to provide communication to frontline workers to ensure that new information is incorporated into their daily work practice have not been clearly identified.

Finally, the organization of the workplace in healthcare in Canada has undergone dramatic changes in recent years resulting in reduced staffing levels, increased acuity of patients in the hospital, increased casualization, and increased out-sourcing of basic services. Research is needed to understand whether and how these changes have affected of worker health and safety.

Priority 2: Understanding Transmission of SARS and Other Respiratory Pathogens

Before SARS, aerosol-generating procedures such as nebulizer therapy and suctioning of respiratory secretions were not thought to pose health risks to HCWs except when caring for patients with tuberculosis. However, it is clear that these procedures very much facilitated the spread of the virus in healthcare settings. Although it was well understood that patients could produce infectious respiratory droplets by coughing or sneezing, they appeared to travel only short distances and remain aloft for very short periods of time. More basic research is needed to determine how infectious droplets produced by aerosolizing procedures differ from those produced by more "natural" methods such as coughing or sneezing in terms of their size, their spread, and their infectivity. This question is key because it addresses the issue of the hierarchy of exposure controls. Classic occupational hygiene teaching stresses that control "at the source," then "along the path," are preferred to control "at the person" relying on PPE. Although it is quite possible that HCWs may not be threatened by SARS ever again, it is likely that a pandemic strain of influenza could produce similar or worse effects if these issues are not addressed.

Much attention during SARS outbreaks was also focused on the potential for transmission through fomites to HCWs, in particular the potential for contaminated PPE and environmental surfaces to transmit disease. However, there are few studies that have examined whether respiratory tract pathogens can survive on barrier equipment and clothing and transmit disease. This has implications for environmental decontamination, reuse of barriers versus the use of disposals, and the potential importance of autoinoculation through contaminated PPE.

As well, there have been few studies that have assessed the relative importance of the transocular route as a means of transmission of disease by respiratory tract pathogens. Eye protection is now being recommended for droplet-spread organisms, but the effectiveness of this protection in decreasing the risk of acquiring disease remains to be tested.

Priority 3: Risk Reduction Through Engineering Controls and Personal Protective Equipment

The SARS epidemics highlighted the risks associated with airborne infectious particles. Research is required to determine the changes to the physical environments in hospitals that can most effectively reduce these risks. Potential engineering controls include changes to temperature, air exchange, and relative humidity to maximize particle fall out or decrease viability of organisms contained in respiratory droplets. Equipment design needs to be reexamined with a critical eye to minimizing the generation and dispersal of infectious aerosols during respiratory therapy (eg, continuous positive airway pressure devices, nebulizer therapy, ventilator aerosols). Following directly from the basic science research noted here, research is also needed on the effectiveness of decreasing aerosols at the source.

Recommendations have been made to nurse patients with SARS in negative-pressure rooms. However, the added benefit of a negative pressure atmosphere over physical isolation and adequate ventilation throughout hospitals has not been established and should be researched thoroughly. More research is also needed regarding the effectiveness of facial protection against bioaerosols. In conjunction with more research on the importance of transocular transmission of respiratory tract pathogens, answers to this question will clarify the relative importance of full facial protection, versus eye protection, versus nose and mouth protection.

Conclusion and Next Steps

Compiling this report (available at www.ohsah.bc.ca or www.change-foundation.com) provided an opportunity for the different disciplines and stakeholders across the province, from the health authorities, unions, the BC Centre for Disease Control, OHSAH, and the Workers' Compensation Board, to come to an agreement as to what we know and identify gaps in knowledge. This has already served as a tool to direct future research and to develop evidence-based practice in the interim. Specifically, the team, with the assistance of a grant from the Canadian Institutes of Health Research (CIHR), is now conducting further research into measures to improve safety climate and specifically provide greater protection from respiratory pathogens. The team is also designing a study to better characterize aerosolization and characteristics of droplet spreads. Meanwhile, by September 2004, we completed 23 train-the-trainer sessions across the province, and, through our CIHR grant, we will have an opportunity to study the effectiveness of this training.

This experience illustrates the value of an interdisciplinary multi-stakeholder approach to developing evidence-based policy in important areas in occupational health.

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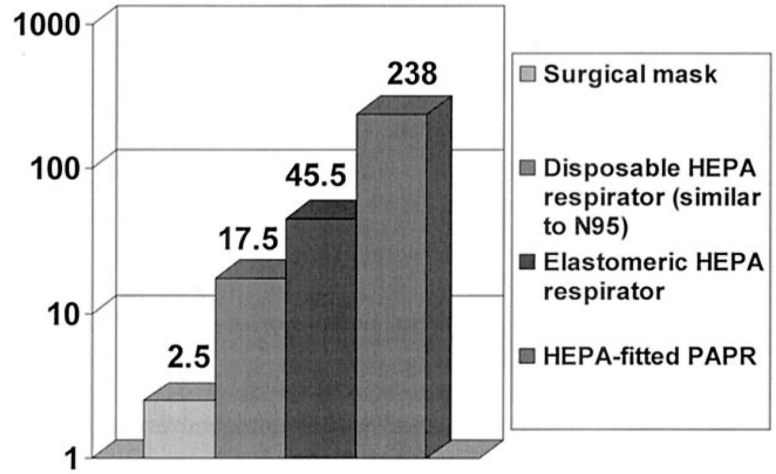

Fig. 1.

Estimated effectiveness of various forms of respiratory protective equipment against tuberculosis infection. Adapted from reference 24.

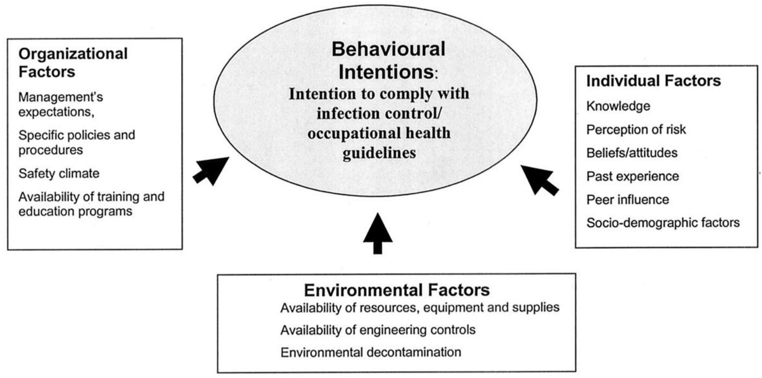

Fig. 2.

Theoretical model for factors associated with self-protective behavior at work. Adapted from reference 32.

TABLE 1

Factors Associated With Acquiring SARS in 72 Healthcare Workers From Hong Kong

Factor	Adjusted Odds Ratio	95% Confidence Interval
Perceived inadequacy of PPE supply	4.27	1.66–12.5
Inconsistent PPE use with direct pt contact	5.06	1.91–598
SARS infection control training < 2 hrs	13.6	1.24–27.5

Adapted from reference 38.

PPE, personal protective equipment.

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TABLE 2

Factors Associated With SARS Infection in 43 Intensive-Care Unit Nurses From Toronto

Factor	Crude Odds Ratio	95% Confidence Interval
Intubation	4.2	1.58–11.1
Manipulation of 0_2 mask	9.0	1.25–65.8
N-95 or surgical mask	0.23	0.07–0.78
N-95 only	0.22	0.05–0.93
Surgical mask only	0.45	0.07–2.71

Adapted from reference 49.