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# Efficacy of face masks and respirators in preventing upper respiratory tract bacterial colonization and co-infection in hospital healthcare workers

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ABSTRACT

*Objective.* We compared the efficacy of medical masks (MM) and N95 respirators (N95) in preventing bacterial colonization/infection in healthcare workers (HCWs).

*Methods.* A cluster randomized clinical trial (RCT) of 1441 hospital HCWs randomized to medical masks or N95 respirators, and compared to 481 control HCWs, was performed in Beijing, China, during the winter season of 2008–2009. Participants were followed for development of clinical respiratory illness (CRI). Symptomatic subjects were tested for *Streptococcus pneumoniae*, *Bordetella pertussis*, *Chlamydia pneumoniae*, *Mycoplasma pneumoniae* or *Haemophilus influenza* type B by multiplex polymerase chain reaction (PCR).

*Results.* The rate of bacterial colonization was 2.8% in the N95 group ($p = 0.02$), 5.3% among medical mask users ($p < 0.01$) and 7.5% among the controls ($p = 0.16$). N95 respirators were significantly protective (adjusted RR 0.34, 95% CI: 0.21–0.56) against bacterial colonization. Co-infections of two bacteria or a virus and bacteria occurred in up to 3.7% of HCWs, and were significantly lower in the N95 arm.

*Conclusions.* N95 respirators were significantly protective against bacterial colonization, co-colonization and viral-bacterial co-infection. We showed that dual respiratory virus or bacterial-viral co-infections can be reduced by the use of N95 respirators. This study has occupational health and safety implications for health workers.



## Introduction

Healthcare workers (HCWs) are at a significantly increased occupational risk for a range of infections. These include infections that cause substantial illness and occasional deaths in HCWs (Decker and Schaffner, 1996; Eriksen et al., 2005; Klevens et al., 2007), or are associated with healthcare associated infections (the majority of which are caused by bacteria). Various infectious agents can be transmitted from patients to HCWs and vice versa (Weber et al., 2010). As droplet transmission is a major mode of transmission of some pathogens, standard infection control measures like hand washing alone may not be enough to prevent HCW transmission or outbreaks. HCWs can transmit infections such as tuberculosis, varicella, and influenza by the airborne route (Weber et al., 2010); it is less well appreciated that airborne and other routes of transmission of certain bacterial pathogens may occur.

There is a low awareness of bacterial infections as an occupational health risk for HCWs. In addition, antibiotic resistant bacteria are a very significant problem facing hospitals, and HCWs play a role in their transmission. Bacterial respiratory tract infections are generally not considered a major occupational problem for HCWs. A growing body of evidence suggests that the risk of bacterial respiratory infections is increased by co-infection with viruses and vice-versa, and this has been studied mostly around the relationship between influenza and pneumococcus (Klugman et al., 2009; Madhi and Klugman, 2004; MMWR, 2009; Zhou et al., 2012). Bacterial load in the nasopharynx is also thought to be related to risk of invasive disease or bacterial–viral co-infection (Klugman et al., 2009). A meta-analysis showed frequent bacterial co-infections during influenza outbreaks (Wang et al., 2011). *Streptococcus pneumoniae*, *Haemophilus influenzae*, *Staphylococcus* spp. and other *Streptococcus* spp. are the commoner causes of bacterial secondary infection following an influenza-like illness (ILI) (Wang et al., 2011).

Case studies documenting the role of HCWs in transmission of *S. pneumoniae* are absent, possibly because this is usually not an outbreak-associated disease, and because the pathogenesis of invasive

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disease is complex (including the relationship with prior colonization). Further, HCWs with invasive pneumococcal disease may go unreported in the occupational context (Sherertz et al., 2001). On the other hand, *Bordetella pertussis* outbreaks among HCWs have been widely reported (Addiss et al., 1991; Gehanno et al., 1999; Pascual et al., 2006), with such outbreaks attributed to airborne transmission through droplets (Nouvellon et al., 1999). In another study, evidence of acute infection with *Chlamydia pneumoniae* was detected in 2% of HCWs (Hyman et al., 1995). Outbreaks of *Mycoplasma pneumoniae* among HCWs have been observed in Finland, where 44% (n = 97) of HCWs tested positive for the pathogen without detectable *M. pneumoniae*-specific antibody, suggesting acute infection (Kleemola and Jokinen, 1992). *Legionella* has also been described as an occupational risk factor for HCWs (Borella et al., 2008; Rudbeck et al., 2009). In contrast to these outbreaks, there are few prospective studies of bacterial respiratory infections or colonization and the clinical implications for HCWs.

There has been recent interest in the role of medical masks and respirators in preventing respiratory infections in HCWs and the general community (MacIntyre et al., 2009, 2011, 2013). Medical masks (MMs) are unfitted devices worn by an infected person, HCW, or member of the public to reduce transfer of potentially infectious body fluids between individuals. They were originally designed for surgeons in order to attenuate wound contamination, but have not been demonstrated to have their intended efficacy (Mitchell and Hunt, 1991; Orr, 1981; Tunevall, 1991). Of note, MMs have not been shown to clearly provide respiratory protection in the community or HCW setting (Aiello et al., 2012; Cowling et al., 2009; MacIntyre et al., 2009, 2011). This may be attributed to lower filtration efficiency and poorer fit than respirators which, in contrast, are specifically designed to provide respiratory protection (Balazy et al., 2006; Lawrence et al., 2006; Weber et al., 1993). We have previously shown that a N95 respirator provides significantly better protection against clinical respiratory infection than medical masks in HCWs (MacIntyre et al., 2011, 2013). Although our previous work tested clinical efficacy in preventing infection, the relative importance of different routes of transmission (airborne, aerosol, and direct hand-to-mouth contact) in the clinical efficacy of respiratory protection is unknown. That is, a mask may provide protection against more than one mode of transmission. The only bacterial infection for which respirators are considered and recommended for HCWs is tuberculosis (Chen et al., 1994; Nicas, 1995). In this study, our aim was to determine the efficacy of respiratory protection in preventing bacterial colonization and co-infections or co-colonization in HCWs.

## Methods

A prospective, cluster randomized trial of N95 respirators (fit tested and non-fit tested) and medical masks compared to each other and to controls who did not routinely wear masks was conducted in frontline HCWs during the winter of 2008–2009 (December to January) in Beijing, China. The methodology and consort diagram used in the study and the primary clinical and viral infection outcomes have been previously described (MacIntyre et al., 2011). We also measured bacterial colonization/infection and co-infections in symptomatic trial subjects, which has not been previously reported. This study describes the efficacy of the interventions (N95 respirators and medical masks) in preventing bacterial colonization and co-infection in HCWs.

Recruitment commenced on December 1, 2008 and final follow-up completed on January 15, 2009. 1441 HCWs in 15 hospitals were randomized to one of three intervention arms: (1) Medical masks (3M™ medical mask, catalog number 1820); (2) N95 fit tested mask (3M™ flat-fold N95 respirator, catalog number 9132); (3) N95 non-fit tested mask (3M™ flat-fold N95 respirator, catalog number 9132) (MacIntyre et al., 2011). A secure computerized randomization program was used to randomize the hospitals to each intervention. A convenience control group of 481 HCW who did not routinely wear masks were recruited and prospectively followed up in the same way as the trial participants for the development of symptoms. The study protocol was approved by the Institutional Review Board (IRB), Human Research Ethics Committee of the Beijing Ministry for Health. Staff who agreed to participate provided informed consent.

The primary study endpoint was the presence of laboratory-confirmed bacterial colonization of the respiratory tract in subjects who were symptomatic. We tested for *S. pneumoniae*, *Legionella* spp., *B. pertussis*, *Chlamydia*, *M. pneumoniae* or *H. influenzae* type B by multiplex PCR. These organisms have been reported in the HCW setting (Kurt et al., 1972; Rudbeck et al., 2009; Wang et al., 2011). We also looked at co-colonization with more than one bacteria, and co-infection with a laboratory-confirmed viral infection and bacterial colonization. Laboratory-confirmed viral respiratory infection was defined as detection of adenoviruses, human metapneumovirus, coronaviruses 229E/NL63 and OC43/HKU1, parainfluenza viruses 1, 2 and 3, influenza viruses A and B, respiratory syncytial viruses A and B, or rhinovirus A/B by nucleic acid testing (NAT) (MacIntyre et al., 2011).

### *Eligibility*

Nurses or doctors who worked full time in the emergency or respiratory wards at the participating hospitals were eligible. HCWs were excluded if they: (1) were unable or refused to consent; (2) had beards, long mustaches or long facial hair stubble; (3) had a current respiratory illness, rhinitis and/or allergy; and (4) worked part-time or did not work in the selected wards/departments (MacIntyre et al., 2011).

### *Intervention*

Subjects were randomized to masks or respirators, and wore the mask or respirator on every shift (8–12 h) for four consecutive weeks and were shown how to wear it and fit it correctly. Participants were supplied daily with three masks for the medical mask group or two N95 respirators. They were asked to store the mask in a paper bag every time they removed it (for toilet breaks, tea /lunch breaks and at the end of every shift) and place the bagged mask or respirator in their locker. All participants were instructed on the importance of hand hygiene prior to/ after the removal of medical masks and respirators, as described (MacIntyre et al., 2011). Participants in the fitted N95 arm underwent a fit testing procedure using a 3M™ FT-30 Bitrex Fit Test Kit according to the manufacturers' instructions (3M™, St Paul, MN, USA) (MacIntyre et al., 2011).

### *Follow-up*

All participants were followed up for four weeks for development of respiratory symptoms, and for an additional week after mask wearing had ceased (to account for incubation of infections acquired in week 4). Validated diary cards were provided for the four-week period to record daily the (1) number of hours worked; (2) mask/respirator usage; and (3) recognized CRI (MacIntyre et al., 2011).

Participants were contacted daily by the study team either by phone or face-to-face contact to actively identify incident cases of viral respiratory infection. CRI was defined as at least two respiratory symptoms (cough, sneezing, runny nose, shortness of breath, sore throat) or one respiratory symptom and one systemic symptom (including fever, headache, and lethargy). If any respiratory symptom was present, subjects were tested, following collection of a nose and throat swab, for bacterial and viral pathogens.

### *Sample collection and laboratory testing*

Subjects with respiratory symptoms had two pharyngeal swabs collected by a trained nurse or doctor. Double rayon-tipped, plastic-shafted swabs were used to scratch both tonsil areas and the posterior pharyngeal wall. These were transported immediately after collection to the laboratory, or at 4 °C if transport was delayed within 48 h. Pharyngeal swabs were tested at the Laboratories of the Beijing Centers for Disease Control and Prevention. A multiplex PCR (Seegen Inc., Seoul, Korea) was used to detect *S. pneumoniae*, *M. pneumoniae*, *B. pertussis*, *Legionella* spp., *Chlamydia* and *H. influenza* type B. After preheating at 95 °C for 15 min, 40 amplification cycles were carried out under the following conditions in a thermal cycler (GeneAmp PCR system 9700, Foster City, CA, USA): 94 °C for 30 s, 60 °C for 1.5 min, and 72 °C for 1.5 min. Amplification was completed at the final extension step at 72 °C for 10 min. The multiplex PCR products were visualized by electrophoresis on an ethidium bromide-stained 2% agarose gel. Laboratory-confirmed viral respiratory infection, defined as detection of adenoviruses, human metapneumovirus, coronaviruses 229E/NL63 and OC43/HKU1, parainfluenza viruses 1, 2 and 3, influenza viruses A and B, respiratory syncytial viruses A and B, or rhinovirus A/B by nucleic acid testing (NAT)