# Airborne Precautions and Personal Protective Equipment: The Powered Air-Purifying Respirator-Only Approach

30

Pranavi V. Sreeramoju and Jose Cadena

Standard precautions including hand hygiene and proper use of personal protective equipment, as well as isolation precautions, are foundational strategies to prevent transmission of pathogens in hospitals and other healthcare settings. The common types of isolation precautions, based on known or suspected modes of transmission, are contact, droplet, and airborne isolation. Airborne isolation, in contrast to droplet isolation, is intended to break the chain of transmission of pathogens carried in aerosol particles less than 5 μ in size [1]. The term respiratory isolation is confusing as it may be used to mean droplet or airborne isolation, and we recommend against the use of this term. The pathogens transmitted via airborne route are tuberculosis (TB), varicella, measles, severe acute respiratory syndrome coronavirus (SARS-CoV), Middle East respiratory syndrome coronavirus (MERS-CoV), hemorrhagic fever viruses such as Ebola, and highly pathogenic avian influenza viruses such as H5N1 and H7N9 [2]. Airborne isolation is also employed for novel and emerging pathogens whose transmission is unknown. In contrast, droplet isolation is used for pathogens/diseases such as diphtheria, epiglottitis, or meningitis for the first 24 h of treatment, and pertussis and influenza [1].

P.V. Sreeramoju (✉)
Internal Medicine-Infectious Diseases, UT Southwestern Medical Center, 5323 Harry Hines Blvd, Dallas, TX 75390, USA
e-mail: Pranavi.Sreeramoju@UTSouthwestern.edu

J. Cadena
Medicine/Infectious Diseases, University of Texas Health Science at San Antonio and South Texas Veterans Healthcare System, San Antonio, TX, USA
e-mail: CADENAZULUAG@uthscsa.edu

## Airborne Isolation Precautions and Personal Protective Equipment

Airborne transmission can be classified into obligate (under natural conditions, transmission occurs only through the airborne route, e.g., *Mycobacterium tuberculosis*), preferential (multiple transmission routes are possible, but small particle inhalation is the most common route, e.g., influenza, MERS-CoV, SARS-CoV), and opportunistic (infection usually occurs through other routes but may occur through small particles under special circumstances, e.g., *Legionella*) [1].

The three major components of airborne isolation precautions as a strategy for reducing transmission of aerosol transmissible diseases are (1) physical space and engineering controls, (2) healthcare personnel respiratory protection and personal protective equipment, and (3) clinical protocols, policies, procedures, and regulatory considerations.

## Physical Space and Engineering Controls

Because aerosol particles remain suspended in air, pathogens transmitted via airborne route can spread across hospital floors and across long distances. Therefore, physical space and engineering controls such as proper ventilation; air handling including air exchanges and air flow management, i.e., negative pressure air flow; and high-efficiency particulate filtration are the cornerstone for preventing airborne transmission. Measures such as ultraviolet lights are also effective when used as an adjunct. Portable HEPA filters can also be used in certain situations. When combined with appropriate use of respiratory protection, airborne transmission can be prevented effectively. Physical space controls gained particular importance in recent years as research into transmission of emerging pathogens such as coronaviruses (MERS and SARS) and influenza viruses (e.g., highly pathogenic


G. Bearman et al. (eds.), *Infection Prevention*, DOI 10.1007/978-3-319-60980-5_30

avian influenza) identified potential for airborne transmission. A complete discussion of physical space and engineering controls is beyond the scope of this chapter.

## Personal Protective Equipment and Healthcare Personnel Respiratory Protection

Respiratory protection against infectious airborne and droplet particles is an important part of the occupational safety of workers in healthcare settings. Some infections can be transmitted through the airborne route, where an infectious patient produces small particles, <5 µm, which are neutrally buoyant and can remain suspended in the air for prolonged periods of time, traveling relatively long distances, and are inhaled by a susceptible individual, reaching the alveolar tissue, and potentially leading to the transmission. This has been observed in Canada during the SARS epidemic (42% of cases were in HCW and resulted from transmission from patients), in New York during the surge of HIV-related TB transmission, and MERS-CoV in the Arabian Peninsula, all of which led to a significant infection rate of healthcare workers [2, 3].

The most important piece of personal protective equipment to prevent infection from airborne pathogens is a respirator. In addition to prevention of airborne transmission of pathogens, these respirators are also used for protection against chemical, radiological, and nuclear materials [4]. The discussion in this chapter will be limited to respiratory protection against infectious pathogens.

It is important to understand the different levels of protection offered by different types of equipment. Face masks are not considered respiratory protection as they are usually designed to protect from large particles and not smaller aerosol particles [4].

Respirators are classified based on specific factors as follows [5, 6]:

1. By air supply: Air-purifying respirators which remove contaminants and pathogens from the air one breathes and air-supplying respirators which provide clean air from an uncontaminated surface.
2. By whether they require a tight seal between respirator and the wearer's face and/or neck: Tight fitting and loose fitting. The tight-fitting respirators need a tight seal between the face and the respirator. Employers who require tight-fitting respirators to be worn in the workplace are required to have respirator fit testing programs in place.
3. By power requirement: Non-powered or powered. All air-supplying respirators are powered, while air-purifying respirators may be powered or non-powered.
4. By type of facepiece: Half mask facepiece respirator that covers the nose and mouth or a full facepiece respirator that covers the nose, mouth, and eyes.
5. By reusability: Disposable or reusable (elastomeric – they have replaceable filters or cartridges, and the surface can be cleaned).
6. By splash protection: Surgical respirators which have surgical mask material on the outside to protect the wearer from splashes (e.g., surgical N95 respirators) vs. medical respirators.
7. By pressure type: Negative pressure (commonest type) which is tight fitting and generates negative pressure inside the facepiece relative to ambient air or positive pressure respirator which is used in an airplane to supply oxygen.

The commonly used N95 respirator (Figs. 30.1 and 30.2.) is a negative pressure, non-powered, air-purifying, particulate, tight-fitting, disposable respirator which may be a medical or surgical (have surgical mask material on the outside to protect the wearer from splashes) respirator. It is also called the N95 mask or dust mask. It is useful to know that particulate respirators are classified as not resistant to oil, N; resistant to oil, R; or oil proof, P. Depending on percent filter efficiency of the air particles they filter, they are designated as 95, 99, or 100, thus resulting in nine classes of non-powered air-purifying particulate filters. An air-purifying respirator can have an air-purifying filter, cartridge, or canister, and it can have a quarter mask facepiece, half mask facepiece, or a full mask facepiece. Powered air-purifying respirators (PAPRs) use a blower to force ambient air through air-purifying elements and then


**Fig. 30.1** Picture of N95 respirator masks or respirators. This image depicts a still life composed of two N95-type face masks, or respirators, at left, one turquoise (foreground), the other white. The N95 respirator works as an air-purifying respirator (APR), also known as a filtering facepiece respirator, and is certified by the National Institute for Occupational Safety and Health (NIOSH). Content providers(s): CDC/ Debora Cartagena; this image is in the public domain and thus free of any copyright restrictions (Image accessed on 3/17/2017 at URL https://phil.cdc.gov/phil/home.asp)

**Fig. 30.2** Powered air-purifying respirator. This image depicts a right lateral view of a laboratory technician wearing garments usually worn by field techs, including a disposable white coverall, a disposable plastic apron, head covering, latex gloves, and foot coverings, and is equipped with what is known as a 3 M™ Breathe Easy™ Powered Air Purifying Respirator, PAPR. Content providers(s): CDC/Dr. Todd Parker; this image is in the public domain and thus free of any copyright restrictions (Image accessed on 3/17/2017 at URL https://phil.cdc.gov/phil/home.asp)

through tubing into a hood or helmet. Parts of a PAPR are a half or full facepiece, hood, or helmet, a breathing tube, a canister or cartridge with filter, and a blower. They may be able to provide additional protection compared to the usual N95 respirators if P100 filters are used, because they filter 99.7% of particles 0.3 μm in diameter and provide full face and neck protection including eyes and ears. Others such as supplied air respirators (as in airlines) or the self-contained breathing apparatus (SCBA) such as those used by divers are rarely necessary for a hospital respiratory protection program or pandemic preparedness. The reader is encouraged to look up resources from CDC, NIOSH, and OSHA [4–6] for a more detailed description of the different types of respirators. The respirator classes are given an assigned protection factor value which is applicable when the respirators are properly selected and used in compliance with the OSHA Respiratory Protection standard (29 CFR 1910.134), with properly selected filters or canisters, as needed. A higher APF value is expected to provide greater respiratory protection to employees. For example, a common N95 respirator has an APF of 5, a full facepiece PAPR has an APF of 1,000, and a full facepiece SCBA has an APF of 10,000 [6].

The minimum respiratory protection required is an N95 respirator for routine patient care and aerosol-generating procedures in patients with diseases requiring airborne precautions, viral hemorrhagic fever, and possibly for emerging novel pathogens and pandemic influenza. This minimum respiratory protection is also required for aerosol-generating procedures in patients with seasonal influenza and droplet precautions. PAPRs used by first receivers need to be the most protective type of PAPR equipped with a filter and chemical cartridge. Surgical respirators (without exhalation valves) should be selected for use in environments where a sterile field is needed. The CDC isolation guidelines recommend the use of N95 masks (able to filter 95% or more of the particles <5 μm in size, as well as larger particles) or powered air-purifying respirator (PAPR) [1]. The World Health Organization has similar guidelines for protection of healthcare workers facing acute respiratory illnesses of concern such as SARS [7].

PAPRs are used not only in healthcare but in many other industries.

## Pros and Cons of PAPRs

PAPRs do not require fit testing and are not affected by facial hair. They have a higher assigned protection factor and therefore useful in high-hazard situations. Patients can see the wearer's face, and they are easier for communication than an N95 respirator. Reusable respiratory protection equipment has advantages when dealing with pandemic events of potential airborne transmission (such as pandemic influenza or spread of coronavirus such as MERS). In the setting of a pandemic, it is likely that a very large volume of disposable N95 masks would be required to provide protection to every healthcare worker (including not only physicians and nurses but also any other individual, paid or not, who may share air space with individuals with potentially infections transmitted through the airborne route). In these situations, reusable equipment may be more advantageous. They have the disadvantages of being heavy to wear, interfering with stethoscope use, being noisy and sometimes making communication difficult, needing batteries or electricity, and potential for contamination with infectious material, thereby requiring decontamination and reprocessing between uses [8]. There are also theoretical concerns about how PAPRs may affect the wearer's performance. Some of this data comes from nonmedical use of respirators. Visual acuity may decrease, up to 75% in some reports, and visual range may be diminished. More concerning is the potential impact on steadiness and even cognitive impairment (although most studies have failed to prove this) during use due to thermal burden (when temperature rises over 85 °F, there is decreased reaction time, and this correlates with unsafe work behaviors) especially in hot environments [9–12]. A study performed by AlGhamri et al. [13] found no cognitive impairment in individuals using N95 or PAPRs while performing predetermined tasks but found a negative effect in cognitive function when using negative pressure, full-face respirators. This study was limited by a small sample size and the lack of experience with respirator use by many of the studied subjects. A previous study showed that the use of a PAPR was associated with a potential decline in speech intelligibility, but this did not reach statistical significance when compared to other respiratory protection equipment or no respiratory protection at all. Even though full-face PAPRs do not require fit testing, they need to be properly size fitted. PAPRs are not exempt from limitations in their capacity to protect individuals when they are not properly size fitted. Gao et al. evaluated the level of protection provided by a PAPR in manikins, using different sizes of full-face masks. They found decreased protection when the manikins were not fitted with a properly sized full-face mask [12].

Baracco et al. developed a model to evaluate the cost of three options for respiratory protection requiring airborne isolation in the setting of a severe airborne pandemic event [14]. They compared the cost of stockpiling N95 masks, PAPRs, and reusable elastomeric half-face respirator. They took into account the storage space required, the half-life of the equipment, and the maintenance required, in the setting of a massive event requiring about six million contacts per one million population during the pandemic event. They based their model on assumptions derived from the 1918 influenza pandemic event. They found that the cost of stockpiling PAPRs is likely to be higher than the stockpiling of N95 masks, given the need not only of storage but also maintenance and battery care. Most batteries lose charging capacity over time and need to be replaced. Disposable batteries usually have a longer half-life, but only 10 h of battery life, and are more expensive. These batteries are usually made for the equipment, and regular batteries are not usually utilized. PAPRs need a larger storing area, need to be cleaned between uses, and the batteries expire, requiring battery recharging stations within reasonable access from the patient care areas. They are also more expensive, with each PAPR causing upwards of $1000.

### Pros and Cons of N95 Respirators

N95 masks work for most people and have the advantage of being disposable. The disadvantages are that they need respiratory fit testing annually in addition to the costs of storing. They are also not suitable for those with beards and those who have undergone facial surgery. The cost of mask fit testing is $18–20 per person using qualitative method. The cost of each mask is $0.73. For an organization that needs to fit test 5000 persons per year, the direct costs would be close to $100,000 per year. According to Susan Johnson, “The sheer number of staff who must be fitted (>8000 annually) is a challenge” [15].

Advantages of the N95 mask include that they allow the use of stethoscopes, are easily available, are inexpensive, and allow for better communication. Disadvantages of N95 include the need for periodic fitting, risk of decreased protection with inappropriate fitting or facial hair, accumulation of moisture, exposure of the face and neck, need to purchase masks on different sizes, need for frequent replacement, and decreased tolerance due to resistance when breathing.

The cost of N95 masks was composed in 25–40% of long-term warehouse storage costs. In addition, many studies omit the costs of N95 issuing and training on their use. Table 30.1 highlights the key differences between N95 respirators and PAPRs.

## Clinical Protocols, Policies, and Procedures

Robust clinical protocols, policies, and procedures are necessary to manage airborne infectious diseases in any healthcare facility. Clinical protocols need to be based on best available scientific evidence. While policies offer guiding principles, procedures offer step by step direction on what needs to be done. In addition to best available scientific evidence, regulatory considerations need to be factored in during the development of policies and procedures. The facility plan for managing highly communicable emerging infectious diseases needs to include an incident command structure, policies, screening and signage, triage and plan for inpatient care, staff training, availability supplies, storage, and maintenance. The plan must detail methods for controlling exposure to aerosol transmissible pathogens are airborne isolation to minimize the number of employees exposed, minimize the amount of infectious aerosol in the air through placement of mask on a patient and use of closed suctioning systems to minimize dispersion of aerosol, and protecting employees who must be exposed through vaccination if available, and use of personal protective equipment.

## Regulatory Standards

Regulatory standards for respiratory protection are mostly set by the Occupational Safety and Health Administration (OSHA) [6, 16]. The OSHA standard 29 CFR 1910.134 requires that employers establish and maintain a respiratory protection program for workplaces in which workers may be exposed to respiratory hazards, and respiratory protection is used as an exposure control method. The OSHA recommends a hierarchy of controls – prevention or substitution, engineering controls, administrative controls and work practices, and, lastly, respiratory protection/personal protective equipment. One of the OSHA requirements is that the employer makes available respiratory protection gear in any

**Table 30.1** Considerations and controversies regarding the use of N95 respirators vs. PAPRS for respiratory protection in healthcare settings

| | N95 respirator | PAPR |
|---|---|---|
| Cost and preparedness | *Advantages*: | *Advantages*: |
| | • Disposable | • Does not need fit testing program |
| | • Lower cost of stockpiling | |
| | *Disadvantages*: | *Disadvantages*: |
| | • Needs fit testing program | • Needs power supply/battery chargers |
| | • Need to purchase different sizes – cost of fitting | • Units can be expensive (>$1000 per piece) |
| | • Large volumes of disposable N95 masks may be required during pandemic | • Needs maintenance, which can be expensive |
| | • Cost of storage given volume | • Need to be properly size fitted, although no formal fitting program is required |
| | | • Need disinfection and cleaning between uses |
| Training | Requires training | Needs special training |
| | | *Disadvantage*: |
| | | • May increase body temperature |
| Contraindications for use | *Disadvantages*: | *Advantage*: |
| | • Decreased protection with facial hair | • Can be used with facial hair |
| | • Decreased protection with increased moisture | |
| | • Not suitable for people with some facial surgeries | |
| Issues during use | *Advantages*: | *Advantages*: |
| | • Does not interfere with stethoscope use | • Faces are visible |
| | • Not heavy | • Reusable |
| | *Disadvantages*: | *Disadvantages*: |
| | • Face may not be visible | • Interferes with stethoscope use |
| | • Can impair communication | • Heavy to wear |
| | • Appropriateness of fitting may change with weight changes and facial hair | • Can impair communications |
| | • Exposure of the face and neck, with limited protection of mucous membranes | • Can affect performance of the wearer, decreasing visual acuity |
| | • Need for frequent replacement | • Additional protection, including coverage of mucous membranes available |
| | • Decrease endurance of the wearer due to resistance when breathing | • Can be noisy |

workplace where respiratory protection may be required. This includes the presence of a program to select the type of respirators, ensure its proper maintenance, employee fitting if tight-fitting respirators are used, use during potential emergencies, cleaning/storage/maintenance of the respiratory protection equipment, training of employees on respirator use, risks of exposures, and evaluation of effectiveness of the program. It is required that respirators are fitted. The standard requires employees to be fit tested prior to the initial use of a respirator, annually, and whenever a different respirator facepiece (size, style, model, or make) is used. Furthermore, personal protective equipment must be provided at no cost to the employee.

Professionals in infection control and occupational health, as well as hospital administrators, need to be knowledgeable about and comply with regulations governing respiratory protection programs in their respective hospitals. While OSHA stipulates federal standards that are followed by the Centers for Medicare and Medicaid Services and most organizations, the Joint Commission requires that each healthcare facility clearly outlines elements of their respiratory protection program in their policies and procedures and demonstrates compliance [15]. Furthermore, there is considerable variation among states and organizations, especially those which are public, county-owned, or state-owned teaching institutions. The Centers for Disease Control and Prevention recommends that healthcare facilities follow their respective federal, state, or local regulations as it is not a regulatory agency [17]. It is important to know these nuances. Studies show that hospitals are experiencing challenges with the implementation of their respiratory protection programs. Twenty-four states have state-approved OSHA plans. These state-level plans incorporate regulations that are at least as strict as those set forth by OSHA at the federal level.

In August 2009, during the peak of H1N1 pandemic, California enacted the nation's first occupational standard for aerosol transmissible diseases [18]. The standard requires, among other things, that hospitals care for patients with pandemic influenza using respiratory protection that includes an N95 respirator at a minimum. In addition to variation in state-level plans, recent studies in Minnesota, Illinois, and New York have demonstrated a wide variation in interpretation and implementation at the hospital level [19, 20].

## PAPR-Only Approach?

The most common approach in healthcare settings for respiratory protection is the use of N95 respirator masks along with employee fit-testing program which could be expensive. An alternative approach used in some settings is the use of PAPRs only, which eliminate the need for employee fit testing, if the PAPRs selected do not have a tight-fitting face piece.

Use of respirator masks vs. PAPRs depends on the following variables in any given facility:

1. Ease of use
2. Training and competencies, e.g., respirator fit testing annually
3. Cleaning between uses for PAPRs
4. Volume of patients and anticipated frequency of use
5. Storage/maintenance/repair and disposal
6. Annual costs
7. Regulatory standards
8. Level of protection needed
9. Intensity of contact and nature of healthcare personnel-patient interaction, including performance of any surgical procedures or aerosol-generating procedures (e.g., intubation, resuscitation, bronchoscopy, autopsy, aspiration of the respiratory tract)
10. Availability of engineering controls

## Implementation Approaches in Different Hospitals and Health Systems

PAPRs are generally specified for high-hazard procedures because they reduce risk more than the N95 respirators. The APF for loose-fitting PAPRs is 25 and for full facepiece tight-fitting PAPRs is 1000, which is more than the APF for a typical N95 respirator mask which is 10. In a workshop conducted by the Institute of Medicine in 2015 [8], the participating experts noted that PAPR use is increasing in facilities across the nation. In a study (REACH II Public Health Practice Study – Respirator Evaluation in Acute Care Hospitals 2010–2012) that evaluated hospitals' respiratory protection programs and respirator usage in six states across the USA, CA, MI, MN, IL, NY, NC, more than 85% of the participating hospital managers and unit managers said their facilities had PAPRs available for use, while 30% of the healthcare personnel themselves were not aware of how to access a PAPR in their facility [8]. More than 40% of the healthcare personnel did not know what would happen if someone failed a fit test. A major finding of the study was that healthcare personnel were largely unaware of appropriate use of respiratory PPE and that the employer focus was on fit testing rather than training on proper use. PAPRs do not require fit testing, allow the patients to see their full face, and they accommodate facial hair. The disadvantage is they do not allow the use of a stethoscope. That being said, each PAPR costs about $1800, and there are costs associated with cleaning and disinfection between use and annual maintenance. Many experts are not convinced that there is a scientific basis for respirator fit testing annually as OSHA stipulates.

Before we decide on taking a PAPR-only approach in any health system, we need to recognize the unanswered questions in the area of healthcare worker respiratory protection. The key unanswered questions are:

### PPE Choice and Safety

What PPE is required for aerosol-generating procedures?

What donning and doffing procedures are the safest and in what order? What is the clinical evidence on the safety of repeated donning and doffing of respiratory protection? Research is needed to strengthen the evidence of the effectiveness of PAPRs and of specific donning and doffing protocols.

What is the clinical evidence on the safety of different levels of wear compliance for respiratory protection?

How do we verify that improved filtration efficiency translates into enhanced healthcare worker safety?

What's the best way to use PAPRs in a sterile field?

How does an appropriate protection factor translate into adequate protection in actual clinical practice?

How does the respiratory physiology of a healthcare worker change during PAPR use?

### Maintenance of PAPR

What are the appropriate procedures for the disinfection of PAPR components? Which components need to be disposable?

### Indications for Use

What is the relative contribution of potential modes of transmission? Droplet, opportunistic airborne, or airborne transmission?

How strong is the evidence that respiratory worker safety translates to safer and healthier workers and patients?

### Cost-Effectiveness for Routine Clinical Care and Pandemic Preparedness

What is the epidemiologic threshold at which the cost of N95 + annual fit testing outweighs use of PAPRs?

What should be the adequate size and composition of respiratory protective device stockpile?

### PAPR Design

How can PAPRs be better designed so they are more useful to healthcare?

How do we decrease noise, simplify cleaning and storage requirements, and improve battery life?

How do we improve products such as stethoscopes so that they are compatible with PAPRs?

## When Would PAPR-Only Approach Work?

For ongoing respiratory protection to prevent transmission of TB and other airborne infections in the hospital, the expenses associated with annual respirator fit testing program may justify a PAPR-only approach. This is particularly true in healthcare facilities with a very low incidence of TB, and many such facilities are currently moving toward a PAPR-only approach for ongoing respiratory protection. This PAPR-only approach may not work in facilities with a high incidence of TB and a high volume of patients unless a seamless process for availability of PAPRs, cleaning and disinfection between uses, a maintenance plan, operational ownership plan, and training plan are fully established. In these facilities, a combination approach with N95 masks and PAPRs may be appropriate.

Pandemic situations present different challenges compared to ongoing prevention of infections potentially transmissible by the airborne route in facilities. Experts note that "given the high cost per unit, PAPR availability will always be a problem in the event of a major outbreak or act of bioterrorism. Health care facilities need to have dual systems for N95 respirators and PAPRs, and they need to train health care workers to use both" [8]. Studies have found that stockpiling PAPRs was the most expensive strategy for a pandemic scenario. Furthermore, respirators do not eliminate the need for negatively pressured rooms or ultraviolet lights or the costs associated with triage and screening in pandemic situations. Therefore, for pandemic situations, a combination approach is probably better, and the proportion of N95 vs. PAPR needs to be customized per the local needs of the hospital.

## References


1. Siegel JD, Rhinehart E, Jackson M, Chiarello L, The Healthcare InfectionControl Practices Advisory Committee. 2007. Guideline for isolation precautions: preventing transmission of infectious agents in healthcare settings http://www.cdc.gov/ncidod/dhqp/pdf/isolation2007.pdf
2. Weber DJ, Rutala WA, Fischer WA, Kanamori H, Sickbert-Bennett EE. Emerging infectious diseases: focus on infection control issues for novel coronaviruses (severe acute respiratory syndrome-CoV and Middle East respiratory syndrome-CoV), hemorrhagic fever viruses (Lassa and Ebola), and highly pathogenic avian influenza viruses, A(H5N1) and A(H7N9). Am J Infect Control. 2016;44(5Suppl):e91–e100.
3. Wear compliance and donning/doffing of respiratory protection for Bioaerosols or infectious agents: a review of the effectiveness, safety, and guidelines [Internet]. Ottawa (ON): Canadian Agency for Drugs and Technologies in Health; 2014 Aug 19. Available from http://www.ncbi.nlm.nih.gov/books/NBK253733/PubMed
4. CDC and NIOSH hospital respiratory protection program toolkit. Available at: http://www.cdc.gov/niosh/docs/2015-117/pdfs/2015-117.pdf. Accessed 27 Jan 2017.
5. United States Department of Labor, OSHA. Respirator types. Available at: https://www.osha.gov/video/respiratory_protection/resptypes_transcript.html Accessed 27 Jan 2017.
6. OSHA. Assigned protection factors for the revised respiratory protection standard. Available at: https://www.osha.gov/Publications/3352-APF-respirators.html. Accessed 27 Jan 2017.
7. World Health Organization. Infection prevention and control of epidemic- and pandemic-prone acute respiratory infections in healthcare. WHO, Geneva (2014) http://apps.who.int.libproxy.uthscsa.edu/iris/bitstream/10665/112656/1/9789241507134_eng.pdf?ua=1
8. Board on Health Sciences Policy, Institute of Medicine. The use and effectiveness of powered air purifying respirators in health care: workshop summary. Washington, DC: National Academies Press (US); 2015. PubMed
9. Cuta K. Powered air purifying respirators: versatility beyond respiratory protection. Occup Health Saf. 2014;83(11):20. 22
10. Roberts V. To PAPR or not to PAPR? Can J Respir Ther. 2014 Fall;50(3):87–90.
11. Radonovich LJ Jr, Yanke R, Cheng J, Bender B. Diminished speech intelligibility associated with certain types of respirators worn by healthcare workers. J Occup Environ Hyg. 2010 Jan;7(1):63–70.
12. Gao S, McKay RT, Yermakov M, Kim J, Reponen T, He X, Kimura K, Grinshpun SA. Performance of an improperly sized and stretched-out loose-fitting powered air-purifying respirator: manikin-based study. J Occup Environ Hyg. 2016;13(3):169–76.
13. AlGhamri AA, Murray SL, Samaranayake VA. The effects of wearing respirators on human fine motor, visual, and cognitive performance. Ergonomics. 2013;56(5):791–802.
14. Baracco G, Eisert S, Eagan A, Radonovich L. Comparative cost of stockpiling various types of respiratory protective devices to protect the health care workforce during an influenza pandemic. Disaster Med Public Health Prep. 2015 Jun;9(3):313–8.
15. The Joint Commission. Implementing hospital respiratory protection programs: strategies from the field. Oakbrook Terrace: The Joint Commission; 2014. http://www.jointcommission.org. Accessed 17 Mar 2017
16. OSHA. Personal protective equipment, general requirements. Available at: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9777
17. Centers for Disease Control and Prevention. Tuberculosis factsheets. Available at: https://www.cdc.gov/tb/publications/factsheets/prevention/rphcs.htm. Accessed 17 Mar 2017.
18. California Code of Regulations, Title 8, Section 5199. Aerosol Transmissible Diseases. Available at https://www.dir.ca.gov/Title8/5199.html. Accessed 17 Mar 2017.
19. Brosseau LM, Conroy LM, Sietsema M, Cline K, Durski K. Evaluation of Minnesota and Illinois hospital respiratory protection programs and health care worker respirator use. J Occup Environ Hyg. 2015;12(1):1–15.
20. Hines L, Rees E, Pavelchak N. Respiratory protection policies and practices among the health care workforce exposed to influenza in New York State: evaluating emergency preparedness for the next pandemic. Am J Infect Control. 2014;42(3):240–5.