

Basics of Face Masks and Respirators

Jeffrey Yin Lam Yam^{1†}, Andy Chi Keung Ng²

¹Anaesthesiology Resident, Queen Mary Hospital, Hong Kong

²Anaesthesiology Associate Consultant, Queen Mary Hospital, Hong Kong

Edited by: Dr. Clara Poon, Anaesthesiology Consultant, Queen Mary Hospital, Hong Kong

[†]Corresponding author e-mail: yyl254@ha.org.hk

Published 13 October 2020



KEY POINTS

- SARS-CoV2 is mainly transmitted via droplets and contact routes, but evidence of airborne transmission is emerging.
- Surgical face masks and respirators are recommended for prevention of droplet spread and contraction of COVID-19.
- Spunbond and meltblown polypropylene make up the nonwoven fabric of masks. Filtration efficiency depends on the ability of the meltblown filtering layer to filter out particulates and bacteria (a key factor that determines their level of classification).
- Extended use, limited reuse and decontamination of respirators have been suggested as methods to conserve supplies during the current COVID-19 pandemic.

INTRODUCTION

The recent COVID-19 pandemic, caused by the novel coronavirus SARS-CoV2, has led to a worldwide shortage of personal protective equipment (PPE) for health care workers, especially face masks. There has been much confusion over the differences between various types of face masks and recommendations for their usage in different types of health care settings. In this tutorial, we review the various modes of respiratory pathogen transmission with a specific emphasis on COVID-19. In addition, we describe the basic structure of several types of face masks, recommendations for their use and suggestions for conservation. In the face of the ongoing pandemic and resulting PPE shortages, conservation while ensuring safety is paramount.

PATHOGEN TRANSMISSION

Transmission of pathogens requires 3 components: a source, a susceptible host and a mode of transmission.¹ Depending on the pathogen, the mode of transmission varies.

Contact Transmission: Direct Versus Indirect

Direct transmission occurs when microorganisms are transferred from an infected individual to a susceptible individual by physical contact. Indirect contact transmission occurs when there is no direct human-to-human contact. There is an intermediate object that transmits the microorganism.

Respiratory Transmission: Droplet Versus Aerosol Versus 'Airborne'

Droplets containing infectious pathogens can be generated via coughing, sneezing, or talking. Most droplets are too large to remain suspended in air for long periods of time and will quickly settle. Droplet particles >5-10 µm in diameter are transmitted this way.

An online test is available for self-directed continuous medical education (CME). It is estimated to take 1 hour to complete. Please record time spent and report this to your accrediting body if you wish to claim CME points. A certificate will be awarded upon passing the test. Please refer to the accreditation policy [here](#).

[TAKE ONLINE TEST](#)

Specialities	Examples of Aerosol Generating medical procedures
Surgery	<ul style="list-style-type: none"> - Rigid bronchoscopy - Tracheostomy - High-speed drilling
Anaesthesia	<ul style="list-style-type: none"> - Awake fibre-optic intubation - Mask ventilation - Intubation and extubation - High flow nasal cannula - Non-invasive ventilation - Sputum suctioning - Cardiopulmonary resuscitation

Table 1. Examples of Aerosol-Generating Medical Procedures

An aerosol is a finer droplet (<5-10 µm) that can remain suspended in air when the velocities of the air current exceed the terminal velocities of the particles. Alternatively, the droplets may evaporate before they hit the floor, leaving an even smaller droplet nuclei, free to float over longer distances. In such situations, pathogens are considered 'airborne'. Airborne transmission is defined as dried infectious material smaller than 5 µm that can travel on air currents over considerable distances.

The distance a droplet can reach and result in disease transmission depends on the following:

- the velocity and mechanism by which they are propelled;
- the density of respiratory secretions and infective load of the secretion;
- environmental factors such as concurrent airflow, temperature and humidity; and
- the ability of the pathogen to maintain infectivity over that distance.

Respiratory aerosols are created naturally or during aerosol-generating procedures (see below). They can carry the pathogen directly from the respiratory tract of the carrier to the mucosal surfaces of the recipient. Supporting evidence of such transmission came from epidemiological studies of disease outbreaks such as with the SARS-CoV outbreak as well as experimental studies on aerosol dynamics.

Aerosol-generating procedures (AGPs) are medical procedures that create aerosols in addition to those that the patient creates during regular breathing, coughing, sneezing and talking. They can produce both large and small droplets, and if done so in high enough concentration, may cause opportunistic airborne transmission of microbes that otherwise are not commonly spread by the airborne route (eg, SARS-CoV2, influenza). Examples of AGPs are shown in Table 1.³ It is important to note that aerosols are often generated as a mixture of small to large droplets. The distinction between droplet and airborne transmission should thus be viewed as a spectrum instead of 2 dichotomising entities. In summary, SARS-CoV2 virus can be spread by direct and indirect contact, droplet and aerosol route, with rising evidence supporting possible airborne transmission.⁴

SURGICAL FACE MASKS

Purpose of Surgical Face Masks

A face mask is a mask that covers the user's nose and mouth and may or may not meet fluid barrier or filtration efficiency levels. In contrast, a surgical mask is a loose-fitting, disposable mask that covers the wearer's mouth and nose and creates a physical barrier to fluids and particulate materials. Contrary to common beliefs, it is designed to limit the expiratory spread of droplets from the wearer to the surroundings. However, an emerging systematic review suggests that the use of surgical face masks may prevent infected individuals from spreading respiratory pathogens to uninfected individuals.⁵ Whether widespread usage of surgical face masks should be implemented remains controversial, and further studies are needed.

Composition of Surgical Face Masks

Surgical masks are made up of multiple fabric layers, typically referred to as an *SMS configuration* or a 3-ply design. SMS stands for *spunbond-meltblown-spunbond* and describes the manufacturing technique of the 3 layers (Figure 1)⁶:

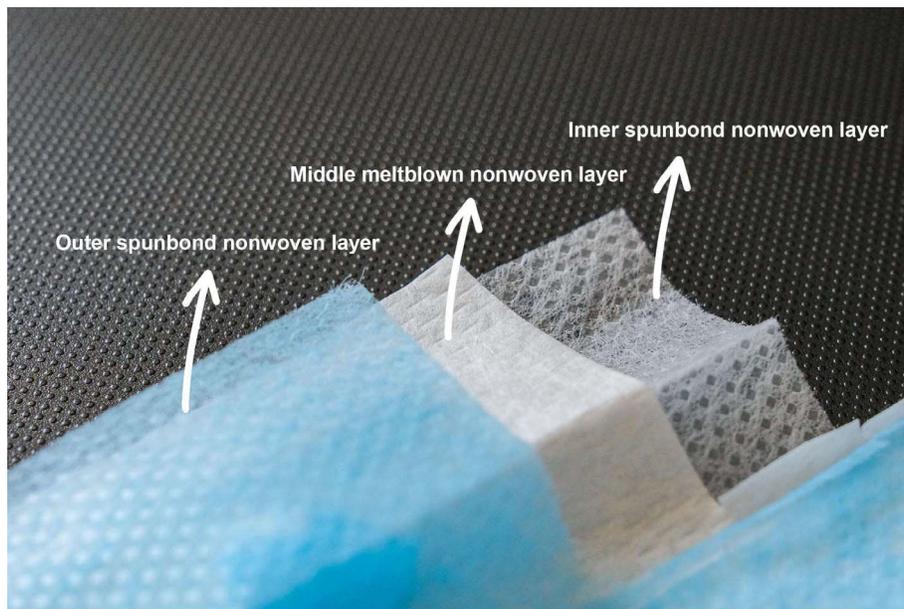


Figure 1. Close-up photo of the 3 different layers of nonwoven fabrics.

- Outer layer: nonwoven layer of spunbond polypropylene with hydrophobic repellent treatment
- Middle layer: filtering nonwoven layer of meltblown polypropylene
- Inner layer: nonwoven layer of spunbond polypropylene with hydrophilic surfactant treatment

Characteristics of these materials are as follows:

- Spunbond polypropylene: Polymers are extruded through a spinneret, forming a web from fine strands of polypropylene filament. The sheet of fabric then goes through calender bonding, in which it is compressed and heat-treated (Figure 2).
- Meltblown polypropylene: High-velocity hot air streams are used to extrude polypropylene polymers into even finer strands of filaments. As the filaments overlay, the fabric thickens to form the filtering layer (Figure 3).
- Spunbond fabric has good strength and durability as well as excellent moisture and temperature resistance. On the other hand, meltblown fabric has relatively weak tensile properties but excellent filtrating, wicking and barrier properties because of the smaller fibre and larger accumulated surface area. The technique of layering these 2 materials together is easy to do, inexpensive and results in a mask with good bacteria filtration efficiency and air permeability. With the addition of repellent and surfactant treatment, droplet transmission prevention is maximised.
- Besides polypropylene, alternative materials can be used to make nonwoven fabric such as polystyrene, polyethylene, polyesters and cellulose-based matter.

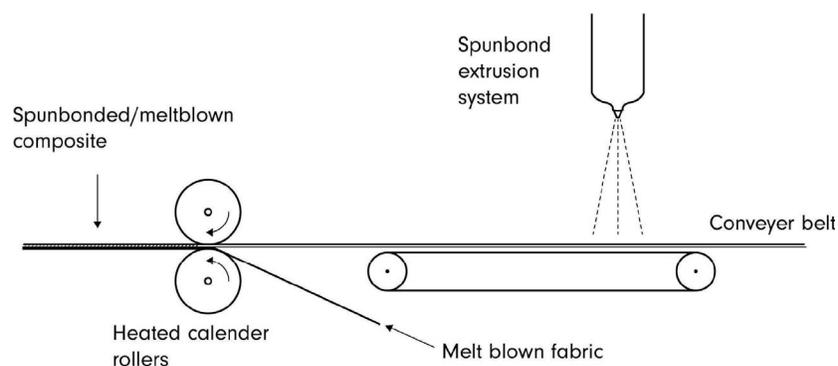


Figure 2. Spunbond: Polypropylene is extruded through the rotatory spinneret. Multiple fibres are layered down and then given compressive heated treatment through a process called *calendering*.

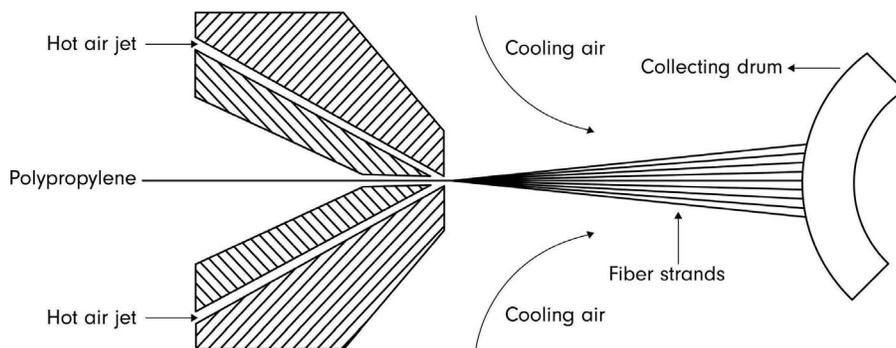


Figure 3. Meltblown: Hot jets of air are used to extrude polypropylene into fine strands of fibre. The fibres are then laid on a rotating drum, forming a thin sheet of nonwoven fabric.

Evaluation and Classification of Face Masks

Once these nonwoven fabrics are made, trimmed and fashioned into a surgical face mask form factor, they are tested for the following criteria⁷:

- **Bacterial filtration efficiency:** Aerosols containing *Staphylococcus aureus* bacteria are propelled at the masks at a controlled volume and rate. A minimum 95% filtration efficiency rate is required.
- **Particle filtration efficiency:** Aerosols of polystyrene microspheres size from 0.1 to 5 μm are sprayed at the masks to ensure the mask can filter particles of various sizes. The percentage indicates the mask filtration efficiency rate for particles.
- **Breathing resistance:** This is tested by blowing air at the mask and measuring the difference in air pressure on both sides of the mask. The unit of measure is $\text{mmH}_2\text{O}/\text{cm}^2$.
- **Splash resistance:** Synthetic blood is forced onto the mask to ensure the liquid cannot penetrate and contaminate the wearer. Test pressure similar to human blood pressure is used.
- **Flammability:** All masks should be flame resistant to prevent fire hazard.
- **Allergenicity:** Face masks should be tested to an international standard (ISO 10993-5,10) for skin sensitivity.⁸
- **Microbial cleanliness:** Face masks are made in a clean, controlled environment to keep the total viable microbial count (cfu/g) on the surface as low as possible.

Based on the results from the above tests, the masks are classified into different levels. Tables 2 and 3 describe the classifications according to American and European standards, respectively.

FILTERING FACEPIECE RESPIRATORS

A filtering facepiece respirator (FFR) is a respiratory protective device intended to cover the nose and mouth of the wearer to help reduce wearer exposure to pathogenic biological airborne particulates. In contrast to a surgical mask, it is designed to achieve a close facial fit and efficient filtration of airborne particles.

Test	Level 1 (Low)	Level 2 (Moderate)	Level 3 (High)
BFE (Bacterial Filtration Efficiency) at 3.0 micron	$\geq 95\%$	$\geq 98\%$	$\geq 98\%$
PFE (particulate Filtration Efficiency) at 0.1 micron	$\geq 95\%$	$\geq 98\%$	$\geq 98\%$
Breathing Resistance ($\text{mmH}_2\text{O}/\text{cm}^2$)	<4.0	<5.0	<5.0
Splash Resistance (mmHg)	80	120	160
Flame Spread	Class 1	Class 1	Class 1

Table 2. American Society for Testing and Materials (ASTM) F2100-11 (2011) Defines Face Masks at 3 Levels

Test	Type I	Type II	Type IIR
BFE (Bacterial Filtration Efficiency) at 3.0 micron	≥95%	≥98%	≥98%
PFE (particulate Filtration Efficiency) at 0.1 micron	Not required	Not required	Not required
Breathing Resistance (mmH ₂ O/cm ²)	<3.0	<3.0	<5.0
Splash Resistance (mmHg)	Not required	Not required	120mmHg / 16kPa
Flame Spread	Not required	Not required	Not required
Microbial cleanliness (cfu/g)	≤30	≤30	≤30

Table 3. European Standard EN 14683 Defines Face Masks as 3 Types

Makeup of Respirators

Disposable respirators such as the commonly used N95 or FFP2 are generally made up of 4 layers.⁹

- Outer layer: hydrophobic nonwoven layer of spunbond polypropylene with repellent treatment.
- Prefiltration layer: nonwoven material that is needle punched together and thermally treated. It forms a thicker, stiffer layer, which can then be moulded to desired shapes. Some manufacturers use cellulose-based material for this layer, which has different implications when considering decontamination (see below).
- Filtration layer: polarised nonwoven layer of meltblown polypropylene, which determines the filtration efficiency of the respirator.
- Inner layer: hydrophilic nonwoven layer of spunbond polypropylene with surfactant treatment.

Although the manufacturing process may be similar to that of surgical masks, respirators have higher filtering efficiency with a form factor that allows for a better seal around the face (Table 4). They are designed to protect the wearer from airborne particles and finer respiratory droplets. They are especially recommended when a high concentration of infective aerosols and droplets is anticipated.

Respirator Classification

Respirators are classified according to the following:

- Barrier characteristics and filtration efficiency;
- Degree of oil resistance of the filter;
- How they are designed to be worn.

Barrier Characteristics and Filtration Efficiency

Respirators undergo a series of tests to determine classification and certification. Testing criteria are similar across different standardising bodies but may vary slightly in their cutoffs. The most commonly used FFR standards are the American NIOSH-42CFR84 (Table 5) and the European EN 149-2001 (Table 6).⁹ The 2 most recognised FFRs certified by these 2 standards are the N95 and FFP2. The Chinese manufactured KN95 (GB2626-2006) is gaining in popularity because of rising demands, but further testing may be warranted to establish its reliability.¹⁰

Degree of Oil Resistance of the Filter

Series

The American National Institute for Occupational Safety and Health (NIOSH) classifies respirator filters into 3 series based on oil resistance:

- N series filter solid and water-based particulates;
- R series are resistant to oil;
- P series are oil proof.

	Surgical mask	Respirator
Testing and approval	Cleared by the U.S. Food and Drug Administration (FDA)	Evaluated, tested, and approved by NIOSH
Intended use and purpose	Protects the wearer against large droplets, splashes, or sprays of bodily or other hazardous fluids.	Reduces wearer's exposure to airborne particles, aerosols and large droplets
Fitting	Limits droplet emission from wearer's respiratory tract Loose-fitting Fit test not required	Tight-fitting Fit test required User seal check required each time the respirator is donned
Leakage	Leakage occurs around the edge of the mask when user inhales	When properly fitted and donned, minimal leakage occurs around edges of the respirator when user inhales
Filtration	Does not provide wearer with a reliable level of protection from inhaling smaller airborne particles and is not considered respiratory protection	Filters out at least 95% of airborne particles including large and small particles
Limitations	Disposable. Discard after each patient encounter.	Ideally should be discarded after each patient encounter and after AGPs. It should also be discarded when <ul style="list-style-type: none"> ● damaged or deformed and no longer forms an effective seal to the face ● wet or visibly dirty ● breathing becomes difficult ● contaminated with blood, respiratory, or nasal secretion or other bodily fluid from patients

Table 4. Comparison Between Surgical Mask and Respirator (Reproduced From CDC Infographic)

Water-based particulates are responsible for disease transmission; therefore, the N series is more appropriate in most health care settings.

Evaluating Respirators

Prior to testing, respirators are conditioned at 38°C at 85% relative humidity for 24 hours. After conditioning, they are tested for the following criteria¹¹ (Table 7):

- Filtrating efficiency: Charge-neutralised sodium chloride aerosol with a median size of 0.3 µm is used to test for particle penetration. Filtration efficiency is reported in terms of the percentage of particles filtered.
- Leakage: Inward leakage is assessed, as it should be as low as possible to prevent exposure to airborne diseases. An inward leak of 8% or lower is acceptable. However, this is required only by the European and Chinese standards.
- Flow rate: The respirator is assessed for fast air movement in and out so that the user can wear with ease even with heavy/fast breathing. A flow rate of about 85 L/min is required.

N95	Filters at least 95% of airborne particles	Not resistant to oil
N99	Filters at least 99% of airborne particles	
N100	Filters at least 99.97% of airborne particles	
R95	Filters at least 95% of airborne particles	Somewhat resistant to oil
R99	Filters at least 99% of airborne particles	
R100	Filters at least 99.97% of airborne particles	
P95	Filters at least 95% of airborne particles	Strongly resistant to oil
P99	Filters at least 99% of airborne particles	
P100	Filters at least 99.97% of airborne particles	

Table 5. American National Institute for Occupational Safety and Health (NIOSH-42CFR84)–Approved Particulate-Filtering Facepiece Respirators Are Defined by Their Filtering Efficiency and Specific Characteristics

- Inhalation and exhalation resistance: Breathing resistance is assessed and should be kept as low as possible at a given flow rate of air to minimise the work of breathing.

Throughout the test, the filtration ability of the respirators must stay above their certification class level at all times. In addition to these criteria, the respirators should be flame resistant, hypoallergenic and resistant to fluids.

The terms *surgical N95 respirators* and *medical respirators* refer to NIOSH-approved N95 respirators that have also been validated by the US Food and Drug Administration (FDA) to be used as surgical masks at medical facilities. They are recommended only for health care professionals who need protection from both airborne and fluid hazards, in comparison with other ‘industrial’ N95 respirators. If high-velocity splashes, sprays, or splatters of blood or body fluids are anticipated, then standard N95 respirators should be used in conjunction with face shields. Face shields prevent surface contamination and soiling of the respirators but do not add to the filtration. Some models of respirators have exhalation valves. These are designed to reduce expiratory airflow resistance and contribute to the comfort of prolonged mask wearing. However, they do not protect others from potential exposure if the person wearing the mask is infected.¹²

How the Respirators Are Designed to be Worn by Health Care Workers

NIOSH subdivides respirators into 3 categories depending on how the filters are designed to be worn by health care workers (Table 8).

- FFRs: These are relatively inexpensive and lightweight. They are disposable, do not affect mobility and require no maintenance or cleaning if disposed after a single use. They do not provide eye protection, and a suboptimal seal is an issue for individuals with facial hair.

Respirator class EU (EU-OSHA)	Filter penetration limit (at 95L/min air flow)	Inward leakage	Respirator class US (NIOSH)
FFP1	Filters at least 80% of airborne particles	<22%	
FFP2	Filters at least 94% of airborne particles	<8%	N95
FFP3	Filters at least 99% of airborne particles	<2%	N99

Table 6. European Standard EN 149-2001 Defined Filtering Facepieces (FFPs) in 3 Classes

Class Standard	American standard N95 (NIOSH-42CFR84)	European standard FFP2 (EN149-2001)	China standard KN95 (GB2626-2006)
Filtering Efficiency	≥ 95%	≥ 94%	≥ 95%
Total inward leakage	N/A	≤ 8% leakage	≤ 8% leakage
Inspiratory flow rate and expiratory flow rate	85L/min and 85L/min	30 ~ 95 L/min and 160 L/min	85L/min
Inhalation resistance	≤ 343 Pa	≤ 70 Pa (at 30 L/min)* ≤ 240 Pa (at 95 L/min) ≤ 500 Pa (clogging)	≤ 350 Pa
Exhalation resistance	≤ 245 Pa	≤ 300 Pa	≤ 250 Pa

* When an inspiratory flow rate of 30L/min is achieved, the pressure difference across the mask should be no more than 70 Pa, and when the inspiratory flow rate reaches 95L/min, the pressure difference should be no more than 240 Pa

Table 7. Testing Criteria for N95 Versus FFP2 Versus KN95. When an inspiratory flow rate of 30 L/min is achieved, the pressure difference across the mask should be no more than 70 Pa, and when the inspiratory flow rate reaches 95 L/min, the pressure difference should be no more than 240 Pa

- Elastomeric facepiece respirators (EFRs) with or without eye coverage: These provide higher filtration efficiency against airborne pathogens and can be used for many hours, depending on the manufacturers' specifications. However, they are bulky and may hinder mobility and communication. The Centers for Disease and Control and Prevention (CDC) has raised concerns regarding the use of respirators with valves in surgical settings, as droplets spreading through their expiratory valves is still a potential risk. Some advise wearing a standard surgical mask over these respirators to minimise this risk.¹³
- Power air-purifying respirators (PAPRs): These devices provide full head coverage including hair, eyes, face and mouth (and neck coverage with some models). They provide a better seal for individuals with facial hair, missing teeth, or facial scars.

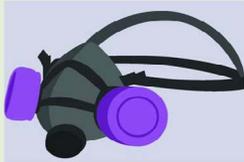
Particulate filtering facepiece respirators (FFRs)	<ul style="list-style-type: none"> • Also known as disposable respirators or commonly referred as N95s • Further classified into N, R, P series with different efficiency level of 95, 99, 100 • Fit test required 	
Elastomeric respirators	<ul style="list-style-type: none"> • Also known as reusable respirators because the facepiece is cleaned and reused but the filter cartridges are discarded and replaced when they become unsuitable for further use • Fit test required 	
Powered air-purifying respirators (PAPRs)	<ul style="list-style-type: none"> • A portable battery powered air filtering system that blows air into a tight fitting overhead-piece • Provides face and eyes protection • Can protect against gases, vapour, or particles given appropriate filter cartridge • Can be use with facial hair 	

Table 8. NIOSH-Approved Respirators Are Subdivided Into 3 Categories

Protection	Recommended PPE guide
Respiratory protection	FFP2 or FFP3 respirator
Eye protection	Goggles or face shield
Body protection	Long-sleeved water-resistant gown
Hand protection	Gloves
ECDC emphasized the importance of fit tests, and that <i>FFP 3 respirator equivalent should always be used when performing aerosol-generating procedures</i> . Single-use plastic aprons can be used on top of non-water-resistance gowns should there be a shortage. [NB guideline last updated in Feb 2020]	

Table 9. European Centre for Disease Prevention and Control (ECDC)–Recommended Composition of PPE for Management of Suspected or Confirmed Cases of 2019-nCoV. The ECDC emphasised the importance of fit tests and that an FFP 3 respirator equivalent should always be used when performing aerosol-generating procedures. Single-use plastic aprons can be used on top of non–water-resistance gowns should there be a shortage. NB guideline last updated in February 2020

Compared with N95 respirators, PAPRs provide superior filtration efficiency, lower breathing resistance and higher comfort level during prolonged usage despite the added weight of the headpiece, battery and pump. However, they are more expensive, the battery requires charging and regular maintenance is required to ensure all connections remain secure. Despite initial concerns, more recent studies have shown that PAPR utilisation in the operating room does not increase particulate transfer to the surgical field, unlike EFRs.¹³

RECOMMENDATIONS FOR COVID-19

Tables 9 and 10 summarise the European Centre for Disease Prevention and Control (ECDC) and the World Health Organization (WHO) recommendations for PPE that health care providers should wear when caring for COVID-19 patients. Table 11 summarises CDC’s PPE recommendations for health care providers while caring for COVID-10 patients. In contrast to the ECDC and WHO recommendations, the CDC recommendations take supply availability into consideration.¹⁴

Target personnel	Activity	Recommended PPE guide
Health care workers	Providing direct care to COVID 19 patients	Medical mask Gown Gloves Eye protection (goggles or face shield)
	Aerosol-generating procedures performed on COVID-19 patients	Respirator N95 or FFP2 standard, or equivalent Gown Gloves Eye protection Apron

Table 10. World Health Organization–Recommended Composition of PPE for Management of Suspected or Confirmed Cases of 2019-nCoV. An extended list of recommendations is also available with various classifications of settings, personnel and activities

Degree of shortage	Recommended implementation
Conventional capacity	Continue patient care without any change in daily practices. This set of measures, consisting of engineering, administrative, and personal protective equipment (PPE) controls should already be implemented in general infection prevention and control plans in healthcare settings
Contingency capacity	Measures may change daily standard practices but may not have any significant impact on the care delivered to the patient or the safety of healthcare personnel. These practices may be used temporarily during periods of expected PPE shortages
Crisis capacity	Strategies that are not commensurate with U.S. standards of care. These measures, or a combination of these measures, may need to be considered during periods of known PPE shortages

Table 11. CDC 3 Tiers of Recommendations for PPE Usage Are Based on Availability of PPE Supplies

Extended Use and Limited Reuse of Respirators

Because of dramatically increased demands for N95 or equivalent (FFR), many countries have adopted strategies to conserve respirators.¹⁵ The CDC guidelines include a variety of approaches to conserve supplies while safeguarding health care workers during times of shortage. The most basic strategy includes extended use and limited reuse.

Extended use refers to the practice of wearing the same FFR continuously for repeated close contact with several patients, without removing the respirator between patient encounters. It may be implemented when the same respiratory pathogen infects multiple patients and the patients are located together in dedicated wards. Health care workers may be required to wear the same FFR for a few hours until they can remove it, such as at mealtime or the end of a shift.

Limited reuse refers to the practice of using the same FFR for multiple encounters with patients but removing it ('doffing') in between patient encounters. The FFR is stored in between encounters and placed on again ('donned') prior to the next encounter with the same or different patient. The number of times the same FFR is reused should be restricted and it is often referred to as 'limited reuse.'

Although extended use and limited reuse are being practiced out of necessity in many countries during the COVID-19 pandemic, NIOSH specifies that such practice should still take into account FFR hygiene, damage and breathing resistance. FFR should still be replaced whenever they are noticeably damaged or soiled or there is difficulty breathing due to increased resistance. Table 12 lists some steps recommended by the CDC to reduce contact transmission if reuse of N95 or equivalent FFR is permitted.¹⁶

Decontamination and Reuse of FFRs

The US FDA does not recommend disposable N95 respirators to be reused or shared.¹⁷ However, FFR decontamination and reuse may need to be considered during a crisis, such as with the COVID-19 pandemic, to ensure continued availability. As a result, the CDC and N95 DECON group suggest 3 potential decontamination processes: vaporous hydrogen peroxide, ultraviolet germicidal irradiation and moist heat.^{18,19} Regardless of which method is used, an individual FFR should be clearly labeled with the user's name and stored individually. A decontamination log should also be maintained so the FFR can be identified and returned to its owner.²⁰

Vaporous Hydrogen Peroxide

Hydrogen peroxide (H₂O₂) vapor and plasma decontamination is an established industrial decontamination method used in hospitals and health care and pharmaceutical industries.²¹ Hydrogen peroxide vapor (wet HPV or dry VHP™) and hydrogen peroxide gas plasma (HPGP) inactivate highly resistant pathogens, including nosocomial bacterial spores and viruses. In a recent study, it was found to inactivate SARS-CoV-2 on all N95 mask types tested.²²

A possible concern for its use is that harmful concentrations of hydrogen peroxide may remain on the mask for days after decontamination.²³ In addition, repeat decontamination cycles can lead to deformation of the masks and affect filtration efficiency.²⁴

Recommendation by the CDC to reduce contact transmission if reuse of N95 or equivalent FFR is permitted.

- Discard FFR following use during aerosol generating procedures.
- Discard FFR contaminated with blood, respiratory or nasal secretions, or other bodily fluids from patients.
- Discard FFR following close contact with any patient co-infected with an infectious disease requiring contact precautions.
- Consider use of a cleanable face shield over a FFR and/or masking patients to reduce surface contamination of the FFR.
- Hang used FFR in a designated storage area or keep them in a clean, breathable container such as a paper bag between uses. To minimize potential cross-contamination, store FFR individually so that they do not touch each other and the person using the FFR should be clearly identified. Storage containers should be single used or cleaned regularly.
- Hand hygiene with soap and water or an alcohol-based hand sanitizer before and after touching or adjusting the respirator.
- Avoid touching the inside of the respirator.
- Use a pair of clean (non-sterile) gloves when donning a used FFR and performing a user seal check. Discard gloves after the FFR is donned and any adjustments are made to ensure the respirator is sitting comfortably on your face with a good seal.

Table 12. Recommendation by the CDC to Reduce Contact Transmission If Reuse of N95 or Equivalent FFR Is Permitted¹²

The Bioquell Battelle Decontamination System is an HPV system for decontaminating N95 masks. It received emergency use authorization from the FDA on 28 March 2020 and can be used for up to 20 cycles without degrading filter quality or straps for FFR 3M model 1860.²⁵ It is important to note that HPV, VHP™, and HPGP are not compatible with cellulose, which is absent in 3M model 1860 N95 masks but may be present in other FFR such as 3M model 1870 and 1870+ masks. The presence of cellulose is an important consideration in the adoption of VHP-based strategies, because hydrogen peroxide degrades cellulose-based products (eg, cotton, present in some head straps or some FFR layers). In addition, cellulose absorbs hydrogen peroxide, and this can lower hydrogen peroxide vapor concentration in the devices, affecting the sterilisation performance.

Ultraviolet Germicidal Irradiation

Ultraviolet germicidal irradiation (UVGI) uses short-wavelength ultraviolet, mainly ultraviolet C (UVC), to kill or inactivate microorganisms by disrupting their DNA and vital cellular functions. UVC has the shortest wavelength (100 to 280 nm) and greatest energy compared with ultraviolet A and ultraviolet B. UVGI is a promising method, but the disinfection efficacy is dependent on the following factors.^{26,27}

Dose (Energy Level and Duration of Exposure)

UVGI at 1 J/cm² was found to be effective in inactivating various viruses, including MERS-CoV and SARS-CoV, at the exterior surface of the face mask from 99.9% to >99.999% in about 60 seconds.²⁶ A higher dose of UVC may improve the effectiveness in terms of penetration but may degrade the materials and affect the fit for reuse.

Shadow Effects

The presence of shadows indicates the blocking of ultraviolet (UV) light, thus lowering the decontamination efficiency at the unexposed area. This shadow effect is particularly relevant for masks that have horizontal ridges or folding across the front of the facepieces.²⁶ Multiple UV lamps are required to facilitate sufficient exposure from different directions. In addition, cosmetics and sunscreen left by the wearer on N95 may reduce decontamination efficacy.

Mask and Strap Composition

The FFR facepiece and the straps vary in design (eg, material, thickness, shapes and elasticity), which may influence the effectiveness of decontamination. Because UV light primarily acts on surfaces, absorption of the viral inoculum below its surface could potentially shield the virus from exposure, hence limiting the UVGI decontamination efficiency. Hydrophilic material tends to absorb both mucin and virus, thus affecting the UVGI effectiveness.²⁶

Methods	Vaporous hydrogen peroxide	Ultraviolet Germicidal irradiation	Moist heat
Approved by FDA	Yes	No	No
Duration of treatment	2 hours to 8 hours	~ 5 minutes	~ 1.5 hours
Use on cellulose contained N95 or equivalent FFRs	No	Yes	Not specified
Effectiveness on coronavirus	No data (studies based on B. anthracis, G. stearotherophilus and other viruses)	99.9 to 99.999% inactivation	No data (studies based on influenza and other viruses)
Considering factors	Various methods – dry, wet or ionized gas plasma	Dose, shadow effects and materials	Temperature, humidity and pressure
Max number of decontamination cycles	2 to 20 depends on which methods	2 to 5	Not specified

Table 13. Three Types of Decontamination Methods

Moist Heat

With this method, warm moist heat (60-75°C at 80% relative humidity) for at least 30 minutes acts as a biocidal decontamination process. This process has been found to be preferred over dry heat sterilisation. Moist heat is more effective in killing microorganisms through protein denaturation and less likely to cause degradation in filter performance.²⁷

Moist heat has been shown to effectively disinfect FFRs contaminated with H1N1, although no data on similar inactivation in case of coronaviruses, other bacteria and mould spores has been published. Although the CDC has released guidelines on the use of moist heat for decontaminating N95 or equivalent FFRs, this method has not been validated by the FDA and its use should be used cautiously.

Table 13 summarises important characteristics of the various proposed decontamination processes.

CONCLUSION

In general, face masks used in the health care settings can be divided into 2 groups: surgical face masks and FFRs. Surgical face masks are loose fitting and are used widely to prevent the spread of droplet-transmissible diseases such as SARS-CoV-2. They are made up of nonwoven materials and tested against strict standards. On the other hand, respirators are tight fitting and have higher filtering efficiency and are designed to protect the wearer from droplets as well as airborne particles. They can be found in the forms of N95, EFRs, or PAPRs. Because of limited supplies and dramatically increased demands, decontamination and reusing FFRs may be needed. Current recommended methods for decontamination include UV germicidal irradiation, vaporous hydrogen peroxide and moist heat decontamination. Familiarization with the various types of potentially AGPs and choosing the most appropriate level of face mask based on exposure risk is recommended.

REFERENCES

1. Access Continuing Education, Inc. Element II: the modes and mechanisms of transmission of pathogenic organisms in the healthcare setting and strategies for prevention and control. <https://www.accesscontinuingeducation.com/ACE1000-10/c2/index.htm>. Accessed April 4, 2020.
2. Van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med*. 2020;382(16):1564.
3. Tang C, Chan A. Perioperative management of suspected/confirmed cases of COVID-19. *ATOTW*. 2020;421:1-13
4. Wilson NM, Norton A, Young FP, Collins DW. Airborne transmission of severe acute respiratory syndrome coronavirus-2 to healthcare workers: a narrative review. *Anaesthesia*. 2020;75(8):1086-1095.
5. Cowling BJ, Zhou Y, Ip, Leung GM, Aiello AE. Face masks to prevent transmission of influenza virus: a systematic review. *Epidemiol Infect*. 2010;138:449-456.
6. Science Direct. Melt blown process. <https://www.sciencedirect.com/topics/engineering/melt-blown-process>. Accessed April 5, 2020.
7. Chellamani KP, Veerasubramanian D, Vignesh Balaji RS. Surgical face masks: manufacturing methods and classification. *J Acad Indust Res*. 2013;2(6):320-324.

8. ISO 10993-5,10 Biological evaluation of medical devices. Part 10: Tests for irritation and skin sensitization. <https://www.iso.org/obp/ui/#iso:std:iso:10993:-5:ed-3:v1:en>. Accessed April 11, 2020.
9. Centers for Disease Control and Prevention. Standards for respirators with chemical, biological, radiological, and nuclear protection. <https://www.cdc.gov/niosh/npptl/RespStds.html>. Accessed April 7, 2020.
10. International Respirator Assessment Request. <https://www.cdc.gov/niosh/npptl/respirators/testing/NonNIOSH.html>. Accessed July 16, 2020.
11. 3M. Comparison of FFP2, KN95, and N95 and other filtering facepiece respirator classes. <https://multimedia.3m.com/mws/media/17915000/comparison-ffp2-kn95-n95-filtering-facepiece-respirator-classes-tb.pdf>. Accessed April 26, 2020.
12. Vincent M, Edwards P. Disposable surgical face masks for preventing surgical wound infection in clean surgery. *Cochrane Database Syst Rev*. 2016;4(4):CD002929.
13. The use of personal protective equipment by anesthesia professionals during the COVID-19 pandemic. <https://www.apsf.org/news-updates/the-use-of-personal-protective-equipment-by-anesthesia-professionals-during-the-covid-19-pandemic/>. Accessed August 2, 2020.
14. Centers for Disease Control and Prevention. Crisis capacity strategies (during known shortage). <https://www.cdc.gov/coronavirus/2019-ncov/hcp/respirators-strategy/index.html>. Accessed April 6, 2020.
15. ECRI. Safety of extended use and reuse of N95 respirators. Clinical evidence assessment. https://www.elsevier.com/___data/assets/pdf_file/0006/997863/COVID-ECRI-N95-Respirators_2020-03.pdf. Accessed April 8, 2020.
16. National Institute for Occupational Safety and Health. Recommended guidance for extended use and limited reuse of N95 filtering facepiece respirators in healthcare settings. <https://www.cdc.gov/niosh/topics/hcwcontrols/recommendedguidanceextuse.html>. Accessed April 8, 2020.
17. US Food and Drug Administration. Coronavirus (COVID-19) update: FDA issues second emergency use authorization to decontaminate N95 respirators. 2020. <https://www.fda.gov/news-events/press-announcements/coronavirus-covid-19-update-fda-issues-second-emergency-use-authorization-decontaminate-n95>. Accessed April 8, 2020.
18. Centers for Disease Control and Prevention. Decontamination and reuse of filtering facepiece respirators. <https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html>. Accessed April 8, 2020.
19. N95 Decon group. COVID N95 decon and reuse. <https://www.n95decon.org/publications>. Accessed April 8, 2020.
20. N95 respirators, surgical masks, and face masks. <https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-surgical-masks-and-face-masks>. Accessed May 15, 2020.
21. Viscusi D, Bergman M, Eimer B, et al. Evaluation of five decontamination methods for filtering facepiece respirators. *Ann Occup Hyg*. 2009;53(8):815-827.
22. Oral E, Wannomae K, Connolly R, et al. Vapor H₂O₂ sterilization as a decontamination method for the reuse of N95 respirators in the COVID-19 emergency. *medRxiv*. 2020;04.11.20062026.
23. N95 Decon. Technical report for H₂O₂-based N95 reuse risk management. N95 Decon research document. https://static1.squarespace.com/static/5e8126f89327941b9453eeef/t/5e86d8be51cbbf1de3b3688e/1585895615567/200402_N95DECON_HPVCtechnicalreport_v1.2_final.pdf. Accessed April 8, 2020.
24. RIVM. Reuse of FFP2 masks. National Institute for Public Health and the Environment. <https://www.rivm.nl/en/documenten/reuse-of-ffp2-masks>. Accessed April 8, 2020.
25. Battelle. FDA letter of approval (3/28/2020) for emergency use authorization for the Battelle Decontamination System, an HPV system for decontaminating N95 respirators. <https://www.battelle.org/inb/battelle-critical-care-decontamination-system-for-covid19>. Accessed April 8, 2020.
26. Mills D, Harnish D, Lawrence C, et al. Ultraviolet germicidal irradiation of influenza-contaminated N95 filtering facepiece respirators. *Am J Infect Control*. 2018;46(7):e49-e55.
27. Lore M, Heimbuch B, Brown T, et al. Effectiveness of three decontamination treatments against influenza virus applied to filtering facepiece respirators. *Ann Occup Hyg*. 2012;56(1):92-101.



This work by WFSA is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. To view this license, visit <https://creativecommons.org/licenses/by-nc-nd/4.0/>