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COVID-19 in indoor environments — Air and surface disinfection measures

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Introduction

The COVID-19 pandemic has led to the closure of workplaces, public facilities, retail and commercial spaces, entertainment venues, and other indoor spaces where groups of people congregate. As cities and provinces reopen, jurisdictions have adopted common measures to mitigate the risks of transmission of SARS-CoV-2, the virus responsible for COVID-19, in indoor environments. Beyond closure, a variety of control measures have been proposed as potential interventions in indoor environments, but their effectiveness against SARS-CoV-2 has not been widely studied. This document provides an overview of commonly used approaches to mitigate the transmission of SARS-CoV-2 indoors and presents three additional control measures based on disinfection — ultraviolet germicidal irradiation (UVGI), electrostatic spraying of disinfectants and disinfectant fogging.

Brief overview of transmission risks in indoor spaces

Current consensus is that SARS-CoV-2 is primarily transmitted via prolonged close contact with an infected person, through respiratory secretions passed in the air, and secondarily due to transmission via contaminated surfaces (fomites).[1,2] The vast majority of COVID-19 outbreaks have taken place indoors and are most often associated with close contacts in the home environment, or in indoor spaces where there is a high density of people and long duration of contact.[3-5] Risks of becoming infected by SARS-CoV-2 vary depending on the prevalence of COVID-19 transmission in the community, personal behaviour, and local environments. Public indoor environments may be conducive to viral transmission due to both the physical characteristics of the space (size, layout, and environmental controls) and how users interact within the space (density of users, duration of interaction and nature of activities).

Spaces characterized by crowding or by proximity of interactions (e.g., within 2 m including hugging, shaking hands, sharing meals), activities that require heavy breathing (e.g., exercise, singing, cheering), long duration of contact (e.g., > 15 minutes), shared equipment (shopping carts, lockers, machinery, etc.) or high-touch surfaces (faucets, elevator buttons, light switches, door handles, chairs, tables, dispensers, etc.), and enclosed spaces with limited ventilation can be of higher risk.[6-9] These characteristics can increase the potential to be exposed directly to respiratory droplets, indirectly to accumulated bioaerosols, or through contact with fomites.

Additional information on transmission of SARS-CoV-2 is provided in the NCCEH document An Introduction to SARS-CoV-2.[1]

Current approaches to risk mitigation in indoor spaces

While preventive measures in indoor spaces may not be able to eliminate the risk of SARS-CoV-2 transmission entirely, they can help to reduce these risks and should be adopted in light of how prevalent COVID-19 is locally.[7] Ensuring that persons who are sick or have confirmed or suspected COVID-19 stay home wherever possible is essential to reducing transmission but will not curb the spread from asymptomatic or pre-symptomatic persons infected with SARS-CoV-2.[1] This uncertainty about the infectivity of persons encountered in the course of daily activities requires a focus on universal reduction of transmission, through distancing measures, behaviour changes, and hygiene. Many indoor facilities have adopted several common measures, including physical barriers,[10] face coverings,[11] physical distancing, and increased surface disinfection,[12] among others.

The hierarchy of controls framework has been applied widely to modify practices or spaces to reduce transmission of SARS-CoV-2.[13] As an example, the Public Health Agency of Canada (PHAC) has established a Framework for risk assessment and mitigation in community settings during the COVID-19 pandemic, using the hierarchy, and similar approaches are used elsewhere.[8,14] Control measures under each of the tiers of the hierarchy are described below.[3,7,11-13] Although frameworks for mitigation measures place engineering controls above administrative controls in the hierarchy, some engineering measures may be more difficult to implement due to cost, practicality, or ease of implementation, which leads to administrative controls receiving priority.

Elimination or substitution

Elimination or substitution involves removing the hazard, or separating occupiers from the hazard to eliminate risk of transmission. Measures can include:

- Closing of public places such as shops, schools, businesses, and facilities or stopping some activities to eliminate or reduce person-to-person interactions.
- Replacing services with online or contactless options, limiting, or discouraging activities that result in contact (e.g., no handshaking), sharing of items, food, equipment, or supplies.

Engineering controls

Engineering controls include changes to the physical structure, equipment or layout of a space that reduce risks of transmission. This could also include changes to operation of building systems such as alterations to heating, ventilation and air conditional (HVAC) settings. Engineering control measures can include:

- Changes to the structure or layout of the facility to allow for a minimum of 2 m physical distancing or other measures to keep people apart (e.g., installation of barriers).
- Use of passive or mechanical means to reduce the concentration of bioaerosols inside and to dilute indoor air with clean outside air (e.g., natural ventilation or HVAC systems to increase the inflow of outdoor air).
- Modified infrastructure to reduce the need for and likelihood of touching surfaces (e.g., automatic doors, motion-activated lighting), removal of high-touch objects such as turnstiles or touch pads.
- Providing facilities for handwashing and/or hand hygiene stations, separating clean/non-clean items or furniture into different areas.

Administrative controls

Administrative controls include changes to how people interact, work, play or socialize in a space to minimize opportunities for close contact and to reduce interactions with shared spaces, items, or surfaces. Administrative control measures can be quite diverse. Some examples include:

- Increased messaging by email, websites, or social media before users arrive at a facility, to emphasize appropriate practices and encourage individuals with COVID-19 symptoms to stay home.
- Physical distancing measures including reducing maximum occupancy, moving activities to larger spaces or outside to reduce potential for transmission via respiratory droplets.
- Use of signage and physical or visual cues to encourage one-way foot traffic, maintaining 2 m distancing, and promoting hand hygiene.
- Enhanced cleaning and disinfection practices (ensuring adequate supplies of disinfectant, soap, sanitizer, tissues).
- New working practices such as the removal of communal workstations, staggering of start/end times or extending hours for activities or shifts to avoid crowding in communal spaces and entry or exit points.
- Discouraging practices such as shared food, communal coffee stations.
- Removing objects in waiting rooms, such as magazines or toys.
- Recording contact details of facility users for future contact tracing.

Personal protective equipment (PPE)

PPE has traditionally been considered to be an additional control measure when other measures have already been considered and implemented where practical to do so. PPE is not intended to be a substitute for enacting other control measures but may be complementary to reduce transmission risks further. The use of masks in public spaces is increasingly being recommended and has been mandated in many jurisdictions where there is a high level of community spread in the local population. Mask wearing may not be appropriate for all people, including children under two, or persons with difficulty breathing due to existing medical conditions. Appropriate use of PPE includes carrying out hand hygiene before and after donning or doffing, and appropriate disposal of disposable PPE. PPE control measures for public indoor spaces are limited but can include:

- Non-medical masks, with or without face shields for use in spaces or situations where physical distancing is difficult to maintain, or when close contact is necessary.
- Disposable gloves may be considered for some activities, such as handling of shared objects or cleaning of surfaces or objects.

Additional control measures

Additional control measures and technologies that can fall within the hierarchy of controls are continually being considered and developed, whether these are new approaches to ventilation, new concepts of design and layout of indoor spaces, new viricidal surfaces and materials, different ways of working or interacting with clients or the public, or new materials or design of PPE. Some of these control measures are still being developed, whereas other measures that have been used in different settings and industries for many years are now being considered for their effectiveness against SARS-CoV-2. This includes technologies that allow for the disinfection of air and surfaces.[15] The remainder of this document assesses three of these established technologies for their potential use against SARS-CoV-2 in indoor spaces. Ultraviolet germicidal irradiation (UVGI), electrostatic spraying, and disinfectant fogging are being considered as options for disinfecting the air or surfaces indoors. A review of these alternative disinfection techniques is presented below.

Ultraviolet Germicidal Irradiation (UVGI)

Description of the technology

Ultraviolet germicidal irradiation (UVGI) has been used for the control of respiratory diseases such as tuberculosis (TB) in healthcare and other high-risk settings for decades.[16,17] In the COVID-19 pandemic it has been proposed as a control measure for reducing transmission of SARS-CoV-2 in indoor environments.[18-20] Ultraviolet (UV) radiation is categorized by wavelength as UV-A (320–400 nm), UV-B (280–320 nm) and UV-C (100–280 nm).[17] Natural sunlight delivers UV-A and UV-B, whereas UV-C is produced by low-pressure mercury or xenon lamps for specific applications. Germicidal effects occur between 200–320 nm, which covers both UV-B and UV-C ranges. Although UV-B from natural sunlight can provide a disinfectant effect under a high UV index over a sustained period,[21] UV-C around 254 nm is much more effective due to the higher intensity provided at lower wavelengths.[17,22] The disinfectant effect results from UV-C causing damage to the cellular material of bacteria or viruses, including their DNA or RNA. This damage prevents the pathogens from replicating, rendering them non-infectious.[23] UV-C can also cause damage to human skin and eyes, and to prevent human exposure to harmful levels of UV-C, precautions should be considered when the technology is used.

How it works

UVGI can be used in a range of applications that disinfect by irradiating air, surfaces, or objects. Applications can be used with either natural or mechanical ventilation to disinfect air or as stand-alone and mobile systems to disinfect surfaces or objects. Table 1 describes the various applications of UVGI in greater detail and their effectiveness as a disinfection strategy.[16,17,19,24-28] The disinfectant effect is determined by the dose of UV-C applied, the configuration of the lamp array, the duration of exposure, the level of shadowing, and characteristics of the target microorganism(s).[17,28,29] For disinfection of air, UVGI works best on air flowing past lamps at a rate and distance that allows for disinfection, without shadowing or dust on the lamps. For disinfection of surfaces or objects, UVGI works best on clean surfaces free of dirt or grease, which may shield microorganisms from UV-C, and with minimized shadowing that can prevent UVGI reaching surfaces.

Effectiveness of UVGI against SARS-CoV-2

The literature on the effect of UVGI on coronaviruses indicates that it can be an effective means of treatment, with the structure of coronaviruses (enveloped single-stranded RNA viruses) being more sensitive to UV-C compared to some other viruses such as double stranded RNA viruses and non-enveloped viruses.[17,28,30,31] UV-C has been found to be effective against other enveloped, single-stranded RNA viruses including SARS-CoV (SARS) and MERS-CoV (MERS) at levels used by existing disinfection systems; however, evidence specific to SARS-CoV-2 is lacking. Early evidence suggests that SARS-CoV-2 may be rapidly inactivated by UV-C exposure in studies on surfaces and for disinfection of personal protective equipment (PPE), but studies on optimum UVGI doses for different settings and purposes are still lacking.[20,23,32,33]

Table 1 provides additional considerations for effectiveness of different UVGI applications for disinfection of air, surfaces, and objects.

Table 1. Review of UVGI application.

UVGI Technology	Description	Effectiveness as a disinfection strategy
In-duct and cooling coil systems	UV lamps (single or multiple) are placed in exhaust or duct work to disinfect air as it passes the UV lamp(s) or near cooling coils to prevent mould or bacterial growth, and disinfect ambient air passing the lamps.	• Most effective for reducing the risk of redistributing of infectious viruses in ***buildings with mechanical systems that recirculate air***.[19] • Limited benefit if applied to incoming clean air or to room air exhausted to the outside. • Disinfection efficiency is affected by airflow rates, UV-C dose, and placement of lamps. • Lamp efficiency is affected by deposition of dust on lamp surfaces, which can be resolved with an upstream dust filter and routine inspection and maintenance.
Upper room	UV lamps (single or multiple) are mounted on walls or ceilings to disinfect air in the upper part of a room. Shielding or baffles direct irradiation upwards to minimize exposure to occupants below, and upward air flow ensures air is exposed to UV.	• Has been effective in ***healthcare environments, homeless shelters, and prisons*** for reducing transmission of infectious viruses; may also be suitable ***for locations with heavy footfall or where people gather (e.g., hallways, lobbies, cafeterias)*** • Upward airflow by either natural or mechanical ventilation is needed to ensure air is exposed to the lamps. Disinfection efficiency is affected by the number and location of fixtures, and reflectivity of the walls and ceilings. • The devices are most effective when pathogens are in proximity to the lamps and unshielded from UV radiation.[16]
UV barrier	UV lamps are placed above doorways to disinfect the air that passes between rooms.	• Provides targeted disinfection of air moving between rooms or spaces but can present risks to occupants passing below due to unshielded UV-C irradiation. • May be more suitable for ***high-risk areas such as intensive care units in healthcare settings***.
Lower room	UV lamps are placed in the lower 30-60 cm with shielding directing UV towards the floor.	• Provides targeted disinfection to floor areas, reducing viability of infectious virus that deposits on the floor in ***high footfall areas such as building entrances***. • Can present exposure risks to lower extremities and children.
Recirculation or air cleaning units	UV lamps housed in mounted or stand-alone units, which may also include air filters, draw room air through the system past UV lamps, and expel cleaner air.	• Provides localized air treatment but the effectiveness may depend on the size of room being treated, exposure time within the system, and the rate of air changes due to ventilation.[25] • Limited effect in large spaces but ***may be more beneficial in small unventilated rooms***.

UVGI Technology	Description	Effectiveness as a disinfection strategy
Area disinfection systems	Portable or mounted units direct high levels of unshielded UV-C irradiation over a large area for periodic disinfection of walls, floors, tables, chairs, equipment, or surfaces.	• Provides effective treatment of air and surfaces depending on intensity and duration of exposure. • Shadowed or dirty surfaces or objects may receive less exposure. • It is not intended for use when there are occupants in the room and is ***more suitable for intermittent or routine after-hours disinfection in settings such as healthcare or industry.***
Disinfection chambers	An enclosed chamber or room, which may include a conveyor or rotation system, to apply high levels of UV-C to objects.	• This technology has been shown to be effective for disinfecting objects used in a range of applications such as medical equipment, mail, and laundry. • Effectiveness is determined by UV-C intensity, exposure time, and shadowing on object surfaces.
UV-C wands	Hand-held UV devices, which can be battery powered, are used to apply localized UV-C to surfaces or objects that may be difficult to disinfect using traditional approaches.	• Effective for ***disinfection of objects or complex surfaces*** and has been used for disinfection of mattresses and surfaces in vehicles (e.g., buckle or latches in air ambulances).[34] • May be more effective with a short target distance and direct (overhead) exposure but can present risks of UV-C damage to skin or eyes to the user or those nearby.

Additional considerations and precautions

Health concerns: Prolonged exposure to UV-C can penetrate the outer surface of human skin and eyes, damaging cells and presenting additional risks to health. The WHO has issued a warning that UV lamps should not be used on hands or other areas of the skin as a disinfection method.[23] UVGI devices may be best used where these risks can be avoided or minimized such as integrated into mechanical ventilation systems or in an upper room application with sufficient shielding to protect occupants below, directed away from the user and reflective surfaces.[3,24] For portable and hand-held devices without shielding, users should be aware of the risks of severe eye damage and erythema (sunburn) that can result from unshielded exposure.[35] An additional concern for prolonged use of UV lamps is the potential to generate ozone, (around 175–210 nm), which can be hazardous to human health. This can be avoided by using non-ozone producing lamps or low-pressure lamps that produce minimal ozone.

Effectiveness over time: Effectiveness of UV-C lamps can decrease over time due to lamp age or deposition of dust or dirt, which can reduce output. Lamps have a limited lifespan of around 9000 hours, or one year but manufacturer guidance on change out, operation and maintenance should be reviewed. UV irradiation can cause damage and discolouration to objects, paintings, and books, or degrade some types of surfaces and materials so may not be suitable for some settings, such as museums or art galleries. There may be a limit to the number of times an object can be disinfected by UV-C and still retain its original function, as studies on UVGI for N95 respirators have found.[36] The choice of UV-C application should include consideration of the effect of prolonged or repeated UV exposure on equipment, fixtures, and fittings within the space.

Emerging UV-C applications: Emerging UV-C technologies such as low-energy UV light-emitting diodes (LEDs) have been proposed as an alternative to mercury lamps. UV-LEDs have been found to be less effective for disinfection purposes as they provide a lower disinfectant dose.[23] They many be more effective if used in an array of multiple UV-C LEDs to increase dose, but there has been limited study of UV-C LEDs for disinfection. Another emerging application of UVGI is far-UVC, which produces a germicidal effect at shorter wavelengths (205–230 nm) without damaging human cells. This technology has been proposed for retrofitting in existing fixtures in public spaces. Research on H1N1 and two human coronaviruses (229E and OC43) has found disinfectant effects at low doses of far-UVC, but more research is needed to confirm the effectiveness of the technology and to evaluate health and safety concerns.[37,38]

Additional technical guidance on UVGI applications is available from ASHRAE, including standards for evaluating effectiveness and performance of UVGI devices in different applications (ASHRAE 185.1 and 185.2), and the International Ultraviolet Association (IUVA).[18,39]

Key messages

- UVGI has been demonstrated to be effective against enveloped single-stranded RNA viruses including human coronaviruses; there is limited study on the effective doses for inactivation of SARS-CoV-2.

- Upper room UVGI may provide the most practical option for disinfecting large indoor spaces while shielding occupants from UV-C radiation that could damage human skin and eyes. This technology is only effective with adequate upward air movement.
- Other air disinfection systems may be appropriate for certain applications such as in-duct UVGI systems for recirculating air or stand-alone air cleaners or recirculating systems for localized air disinfection in small unventilated spaces.
- Mounted or portable area cleaners that provide direct intense UVGI to air and unshielded surfaces may be effective in providing intermittent or after-hours disinfection of an entire space. This technology is not suitable in occupied rooms or spaces and can present a risk of harmful UV-C exposure.[35]
- UV-C wands for disinfection of surfaces and objects may provide some benefit for localized treatment of hard-to-treat surfaces and objects, but present exposure risks to human skin and eyes and should not be used for disinfection of hands or other parts of the body.[23]

Electrostatic Disinfectant Spray Systems

Description of the technology

Interventions to reduce surface (fomite) transmission of SARS-CoV-2 must include frequent cleaning and disinfecting to reduce viability of the virus on potentially contaminated surfaces. Electrostatic spray technology has emerged as an alternative disinfection application strategy in indoor environments and has been advertised to provide more uniform and efficient application of surface disinfectants, especially for hard-to-reach areas.

Electrostatic disinfectant spray systems use electrodes to apply either a positive or negative charge to disinfectant particles as they are expelled from the application nozzle to allow better adhesion to surfaces.[40] Typically, a disinfectant solution is added to the reservoir or chamber of the spray device and delivered via a spray nozzle onto surfaces. The size of the atomized droplets, the width of distribution, and coverage of the electrostatic spray will vary depending on the targeted use and application.[41] Electrostatic spray technology has been used in many industries, such as agriculture, food processing, pest control, medical, transportation, painting, and even space research.[42]

How it works

As most surfaces are neutral or negatively charged, applying a positive charge to disinfectant particles through the spray nozzle allows the particles to better adhere to uneven surfaces compared to traditional spray techniques.[40] The spray nozzle of electrostatic spray system contains an electrode that charges and atomizes the disinfectant solution as it leaves the nozzle, allowing the atomized droplets to wrap around the application surface (Figure 1). These attractive forces are stronger than the force of gravity, thereby ensuring uniformity of adhesion to surfaces regardless of the direction of spray or gravitational pull towards the ground.[43] Electrostatic spraying has been found to allow sanitizer solution to better adhere to the backside of surfaces.[43]

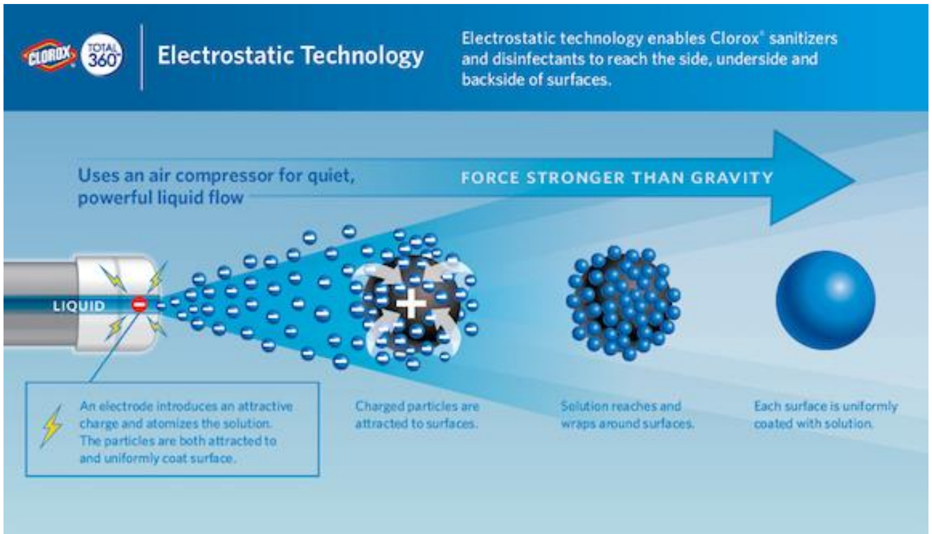

Figure 1. Use of electrostatic spraying to apply charged solution to surfaces.[44] Clorox copyright, used with permission. Inclusion of product images is for informational purposes only and is not an endorsement of these products.

In comparison, traditional spray technology is a passive form of application. Disinfectant droplets expelled from spray nozzles are larger in size, and adhesion to surfaces is influenced by direction of spray, distance from the application surface, airflow in the immediate area, and gravitational forces, among other factors.[42]

Effectiveness against SARS-CoV-2

SARS-CoV-2 is an enveloped virus that is susceptible to detergents and lipid solvents including hydrogen peroxide, alcohol (ethanol or isopropyl alcohol), sodium hypochlorite (bleach), benzalkonium chloride (found in most Lysol™ products), and peroxyacetic acid (found in surface cleaners and sanitizers), among others, that are able to destroy the outer lipid layer of the virus.[12] Electrostatic spray systems are advertised to allow disinfectant solutions to be applied more uniformly onto surfaces, including the backside or underside of surfaces. A study comparing a specific electrostatic spray system with a conventional spray system to apply an active ingredient found that the electrostatic sprayer was 29-times better than the conventional sprayer in depositing the active ingredient onto the backside of the target surface.[43] To date, no studies have been found to compare effectiveness of electrostatic spray systems with conventional spray systems to inactivate SARS-CoV-2.

Past studies on the effectiveness of electrostatic sprayer systems have revealed that disinfectants applied via electrostatic sprayers are effective in reducing a variety of microorganisms from surfaces.[45] Other studies have found that while electrostatic sprayers and conventional disinfectant application techniques (manual or conventional sprayer) are both effective in reducing certain types of pathogens from a variety of surfaces, electrostatic sprayer systems are found to be more efficient than manual application.[45,46] Another study comparing electrostatic and conventional sprayer effectiveness on eggs and spinach found that electrostatic spray provided a significant additional reduction of *Salmonella*.[47,48]

Electrostatic sprayers may also use disinfectant more efficiently. The electrostatic sprayer used in one study produced 75% less disinfectant wastage compared to the traditional backpack sprayer.[46] Additionally, disinfectant solutions applied via an electrostatic sprayer were found to be better able to encapsulate and inactivate the inoculated pathogen directly on the surface, compared with the traditional backpack sprayer, which wash the pathogen spores off the test surface and potentially cross-contaminate other areas.[46] However, characteristics in certain materials such as latex and waxed cardboard may reduce the effectiveness of disinfectants applied via electrostatic spray as the droplets tend to coalesce and run off.[43,46] Electrostatic spray systems are best suited for disinfection of pre-cleaned surfaces as they lack the benefit of manual removal of debris and microorganisms.[49,50]

While electrostatic spray systems promote better adhesion of disinfectants to surfaces, the effectiveness for inactivating SARS-CoV-2 depends on the disinfectant solution used. Health Canada has provided a list of approved disinfectants[51] that have been found likely to be effective against SARS-CoV-2, as well as other products that have been approved under interim measure[52]. Only approved disinfectant products designed for use with electrostatic spray systems should be used in the machines to ensure effectiveness. As the effectiveness of the disinfectant applied via an electrostatic sprayer depends on its distribution, concentration, and contact time, it is important to follow manufacturer's instructions for specified uses and machine settings.[50] As debris such as dirt and organic materials may reduce the effectiveness of disinfectants, surfaces should be pre-cleaned with a detergent prior to application of disinfectants.[12]

Examples of applications

Electrostatic application systems have been used in many industries for decades, such as agriculture, automobile, and food processing. The use of electrostatic systems reduces off-target spray drift, which is the movement of sprayed droplets and aerosols away from the target surfaces. Controlling spray drift ensures efficient use of disinfectants and protects the surrounding environment from accidental contamination due to unintended deposition of the product.[42]

Electrostatic application systems have been used in food processing to apply antimicrobial agents to sanitize contact surfaces throughout the food production chain, as well as the application of waxes and other agents onto surfaces of perishable food products to provide post-harvest protection from processing to retail.[42] Another application of electrostatic application is in aerial pest-control spraying of large area forests, via an electrostatic spray system mounted on a helicopter.[42]

In healthcare settings, electrostatic application of disinfectants can be an efficient and cost-effective method to kill or inactivate pathogens present on various environmental surfaces.(Robertson, 2016) Some businesses and facilities have adopted enhanced cleaning and disinfection procedures, including the use of electrostatic disinfectant spray systems that have been approved by US EPA and US CDC to disinfect private and public access areas.[53]

Safety precautions

Electrostatic application systems have been shown to be a more efficient method of applying various types of chemical solutions onto surfaces, including disinfectants. However, it is important to consider the compatibility of disinfectant solutions with the electrostatic spray systems, as well as compatibility with the target surface and the indoor space in which they are being applied. Only disinfectant products designed for use with electrostatic spray systems should be used to ensure safety and effectiveness.[54] The use of disinfectant solutions incompatible with the electrostatic spray method or the surface being treated may lead to potential safety hazards.[55] Safety Data Sheets of some disinfectant chemicals containing information on ingredients, handling and storage, hazard warnings, and first-aid measures can be found online.[12] Only trained individuals should be allowed to operate electrostatic spray devices.

Both manufacturers and users should ensure that features such as droplet size, spray patterns and outputs, device mechanisms, and chemicals used are optimized and designed for intended use to ensure safety and effectiveness.[55] Manufacturer's instructions and safety recommendations, such as personal protective equipment to prevent accidental exposure or the grounding of users to prevent accidental electric shock, should be followed.[56]

Disinfectant Fogging Systems

Description of the technology

Fogging technology that disperses fine particles of liquid sanitizers or disinfectants to provide whole-room decontamination has been utilized in the pharmaceutical and food processing industries for decades, and more recently in hospital settings.[57,58] There are three main types of fogging technologies: **dry vapour process**, **micro-condensation** (sometimes referred to as "wet process"), and **activated or ionized process**.[57,58]

- **Dry vapour process:** Vaporization of a liquid disinfectant into its gaseous form (1-10 μm).
- **Micro-condensation:** Production of very fine microscopic aerosols (> 10μm).[59]
- **Activated or ionized process:** Similar to electrostatic sprays in which vaporized aerosols are charged by electrodes in a cold plasma arc as they are expelled into the environment.[58]

Methods for producing dry vapour and micro-condensation aerosols differ depending on the type of liquid, manufacturer, and apparatus design.[59] Fogging systems may be stationary, portable, or mounted onto surfaces. Vaporized disinfectants are smaller and are able to remain airborne for a longer period of time compared to micro-condensation aerosols, thereby providing both air and surface disinfection.[59,60] The effectiveness of each of these technologies depends on the type of liquid sanitizer or disinfectant, type of pathogen being targeted, type of surface, size of indoor space, location of the fogging apparatus, pre-cleaning practices, organic load, air movement, relative humidity, volume of disinfectant, and contact time, among many other factors worthy of consideration.[59,61,62]

Figure 2. A type of dry fog system to apply disinfectants. Ikeuchi, used with permission.[63] Inclusion of product images is for informational purposes only and is not an endorsement of these products.

Earlier fogging technologies typically used formaldehyde, phenol-based agents, or quaternary ammonium compounds and are not recommended for air and surface disinfection in healthcare settings due to lack of effectiveness and adverse health effects.[62,64] Evidence on the effectiveness of recently developed fogging technologies using hydrogen peroxide and peracetic acid against norovirus and other pathogens are under review by the US CDC.[62]

How it works

Vapours and aerosols emitted from fogging devices are propelled into the indoor space, whether assisted by forced convection from the fogging apparatus or through passive diffusion aided by the airflow in the room.[65] Aerosols produced by the dry vapour process are smaller than those from the micro-condensation process, allowing better distribution and longer airborne time. However, aerosols that rely on passive diffusion are influenced by airflow and ventilation in the indoor space. Gravity also influences the dispersal path of the aerosols as larger droplets settle onto environmental surfaces faster than smaller droplets.[64] Aerosolized disinfectants have been found to be able to reduce the number of airborne microorganisms.[61,64] Once settled onto surfaces, the disinfectants inactivate microorganisms found there.[61,64]

Depending on the location of the fogging device and the size of aerosols, fogging may only be effective in reducing the number of microorganisms on upward-facing surfaces, not on vertical or downward-facing surfaces as the disinfectant aerosols are not able to reach them.[64] Disinfectant fogging should not replace regular cleaning and disinfection practices but serve to augment routine cleaning and disinfection, such as terminal room disinfection between patients, or weekly/monthly whole-room disinfection in laboratories or food processing facilities.[61] Similar to other disinfectant application methods, disinfectant fogging requires thorough pre-cleaning of surfaces to remove organic contaminants to ensure effective inactivation and pathogen reduction.[12,66]

Activated or ionized fogging works similarly to other fogging technologies; vapours are produced from liquid sanitizers or disinfectants. Electrodes create a cold plasma arc, which charges the droplets before they exit the fogging nozzle.[58] This ionization causes the droplets to become mutually repulsive, thereby encouraging dispersal in the air.[58] Ionized particles are attracted to airborne particulates as well as to surfaces, providing effective air and surface disinfection once in contact with microorganisms. Ionization also improves adhesion to surfaces compared to other fogging technologies, leading to more effective disinfection.[58]

Fogging devices differ in aerosol production time and volume of liquid emitted. The room being treated should be unoccupied during treatment.[65] Typically, the fogging apparatus can operate for 15 minutes to an hour, during which the vapour disperses throughout the space.[61,64] After appropriate contact time, the space needs to be ventilated for up to a few hours before re-entry to reduce adverse reactions to the vapours.[61,65] The long aeration time may be challenging for applications in which treated rooms need to be reoccupied as soon as possible.[67] In certain circumstances, longer aeration times may be required than is recommended by the manufacturer to achieve safe indoor air-quality levels.[67]

Effectiveness against SARS-CoV-2

Currently, there is no published literature on the effectiveness of fogging technology against SARS-CoV-2, and limited literature on other human viruses. Being an enveloped virus, SARS-CoV-2 is comparatively easier to inactivate than other classes of viruses such as human norovirus. The fatty layer surrounding the viral genetic material can be disrupted by a variety of cleaning agents and disinfectants with adequate concentration and contact time.[12] As the process of vaporization may change the properties of certain liquid disinfectants, only compatible liquid disinfectants may be used in fogging devices.[68] Manufacturer's instructions must be followed for approved disinfectants against SARS-CoV-2, and alternative application methods must not be used. Only disinfectants approved for use in fogging devices in Health Canada's list of approved disinfectants[51] against SARS-CoV-2 should be employed.

Effectiveness of fogging devices is greatly influenced by relative humidity, pathogen type, and location of the apparatus. Humidity in the room affects the condensation of the disinfectant solution and its effectiveness.[65] Therefore, dehumidification is sometimes necessary to ensure effective disinfection. More research is needed to determine how humidity, temperature, and type of disinfectant used influence the effectiveness of fogging technology.[61] The majority of published research focuses on the effectiveness of fogging technology to reduce or eliminate airborne and fomite contamination in laboratories, the food industry, and hospital settings. Depending on the size of the room and the volume of disinfectant dispensed, uniform dispersal may not be possible and variations in aerial concentration may exist, leading to inadequate disinfection in some zones.[65]

Hydrogen peroxide fogging is commonly used in hospitals to reduce or eradicate air and surface contamination in patient rooms. Hydrogen peroxide vapour reduced feline calicivirus, a surrogate for norovirus, on experimental surfaces by 4 $\log_{10}$ and inactivated biological indicators on all sampled surfaces in hospital rooms.[69,70] Peracetic acid fogging achieved log reductions of reovirus, parvovirus, and avian polyomavirus by 9, 6.4, and 7.65, respectively.[71] A study found that at least 10.6 ml/m^3 of fogged hydrogen peroxide was required to achieve 4 $\log_{10}$ reduction in feline calicivirus under experimental conditions.[72]

Several studies have found dry vapour and micro-condensation fogging of hydrogen peroxide to be effective against a variety of bacterial pathogens, including *C. difficile*, *Escherichia coli*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Enterococcus faecalis*, *Aspergillus fumigatus*, and methicillin-resistant *Staphylococcus aureus*, under experimental conditions and on environmental surfaces in hospital rooms and ambulances.[67,73-76] Hydrogen peroxide vapour has been found to be more effective against *Clostridium difficile* than 0.5% sodium hypochlorite (bleach) solution under experimental conditions.[77]

Another study comparing the effectiveness of reducing *C. difficile* by incorporating hydrogen peroxide fogging after routine deep cleaning, versus deep cleaning alone, found that the addition of hydrogen peroxide fogging improved the disinfection outcome.[66] Hydrogen peroxide fogging in hospital rooms and air conditioning ducts after thorough cleaning was found to reduce *Staphylococcus aureus* counts by 99.7%–100%.[78] Hydrogen peroxide vapour and peracetic acid-based fogging have been found to reduce or eliminate airborne microorganisms in treated rooms in food processing facilities.[61] It is worth noting that hydrogen peroxide, which is often used in whole-room fogging decontamination, may decompose rapidly in certain conditions.[65]

While many research studies have shown that disinfectant fogging is effective against some viruses and a variety of bacterial pathogens, fogging devices, concentrations, humidity, and experimental conditions in the studies differ. Therefore, effectiveness of any fogging device and disinfectant used against SARS-CoV-2 and other pathogens needs to be independently verified and approved before use.

Safety precautions

As disinfectant fogging may pose inhalation exposure risks to occupants, the indoor space being treated should be vacated prior to treatment. Accidental inhalation of or exposure to disinfectant chemicals may cause adverse reactions such as coughing, shortness of breath, or burning or watery eyes.[12] Safety Data Sheets of some disinfectant chemicals containing information on ingredients, handling and storage, hazard warnings, and first-aid measures can be found online.[12] Only trained technicians or staff should operate the fogging devices. Vapour leakage may cause accidental exposure and adverse reactions to occupants in nearby areas; therefore, ventilation ducts, windows, and doors should be sealed unless otherwise indicated.[57] Prior to re-entering the space, the treated space should be thoroughly vented or aerated to reduce the likelihood of adverse reactions. Only approved disinfectants should be used in the fogging devices. Manufacturer’s instructions should be followed.

Conclusion

It is now widely recognized that the vast majority of COVID-19 outbreaks have been linked to interactions in indoor environments. Factors influencing the transmission of COVID-19 in an indoor environment include its physical characteristics, level of close contact, community prevalence of COVID-19, and control measures that have been implemented.[5,79,80] The suite of control measures currently applied based on the hierarchy of controls appear to be effective in many settings. Despite this, the reopening of many public spaces has resulted in resurgence of the virus in some jurisdictions, resulting in shutdown measures being reinstated.

There is widespread concern about how long the cycle of shutdown and reopening will continue, and there are significant implications for public facilities such as schools. There are still many unanswered questions as to the root causes of outbreaks, but additional control measures to reduce persistence of the virus indoors may be needed. While measures such as improving ventilation, reducing occupancy, ensuring physical distancing, and encouraging proper hand hygiene and face coverings should continue to be encouraged, strategies that reduce or inactivate SARS-CoV-2 on surfaces and in the air could be considered.

The disinfection technologies discussed in this document provide options for the disinfection of indoor surfaces and air, and evidence suggests that they could be effective in reducing transmission of infectious viruses; however, there has been limited study of their effectiveness specifically against SARS-CoV-2. In addition, these technologies are not without their own inherent health and safety risks, which should be taken into consideration prior to implementation of any disinfection strategy.

UVGI technologies have a long track record of providing disinfection of infectious viruses, including those similar in structure to SARS-CoV-2, but careful consideration of the type of application, appropriateness for the spaces, and relevant safety precautions to prevent eye and skin exposure is needed. Upper-room applications (UVGI) are likely to be the most appropriate for most indoor spaces, but the level of exposure to UV-C and potential health effects due to prolonged exposure for occupants of spaces should be considered. Emerging technologies such as far-UVC that provide effective disinfection of air and surfaces but with decreased health risks should be evaluated further for suitability in public spaces.

Disinfectant spray technologies could provide more efficient application of disinfectant indoors. While disinfectant products have been approved as effective against SARS-CoV-2 by the US EPA, Health Canada and other agencies, the widespread use of different application technologies has not been widely assessed. Approved disinfectant products should only be applied according to manufacturer instructions with approved delivery systems by trained persons, whether it is electrostatic or fogging systems. Electrostatic spraying is likely to improve coverage of disinfectant on surfaces and reduce wastage of disinfectant, but caution should be used in handling and applying the products. Disinfectant fogging also appears to be effective in providing disinfection of air and surfaces; however, the disinfectants used can be harmful if inhaled, and caution should be used in both the duration, timing, and substances applied.

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References

1. National Collaborating Centre for Environmental Health. An introduction to SARS-CoV-2 [evidence review]. Vancouver, BC: NCCEH; 2020 Apr 17. Available from: https://ncceh.ca/documents/evidence-review/introduction-sars-cov-2.
2. US Centers for Disease Control and Prevention. Coronavirus disease 2019 (COVID-19) - How COVID-19 spreads. Atlanta, GA: US Department of Health and Human Services; 2020 [updated Jun 16]; Available from: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html.
3. Dietz L, Horve P, Coil D, Fretz M, Wymelenberg K. 2019 novel coronavirus (COVID-19) outbreak: a review of the current literature and built environment (be) considerations to reduce transmission. Preprints. 2020 Mar 20. Available from: https://www.preprints.org/manuscript/202003.0197/v1.
4. Qian G, Yang N, Ma AHY, Wang L, Li G, Chen X, et al. COVID-19 transmission within a family cluster by presymptomatic carriers in China. Clin Infect Dis. 2020. Available from: https://doi.org/10.1093/cid/ciaa316.
5. Qian H, Miao T, Liu L, Zheng X, Luo D, Li Y. Indoor transmission of SARS-CoV-2. medRxiv. 2020;Pre-print. Available from: https://www.medrxiv.org/content/10.1101/2020.04.04.20053058v1.
6. Andrade A, Dominski FH, Pereira ML, de Liz CM, Buonanno G. Infection risk in gyms during physical exercise. Environ Sci Pollut Res Int. 2018;25(20):19675-86. Available from: https://doi.org/10.1007/s11356-018-1822-8.
7. Public Health Agency of Canada. Community-based measures to mitigate the spread of coronavirus disease (COVID-19) in Canada. Ottawa, ON: PHAC; 2020 Mar 25. Available from: https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection/health-professionals/public-health-measures-mitigate-covid-19.html.
8. Rivers C, Martin E, Gottlieb S, Watson C, Schoch-Spana M, Mullen L, et al. Public health principles for a phased reopening during covid-19: guidance for governors. Baltimore, MD: John Hopkins Bloomberg School of Public Health, Center for Health Security; 2020 Apr 17. Available from: https://www.centerforhealthsecurity.org/our-work/publications/public-health-principles-for-a-phased-reopening-during-covid-19-guidance-for-governors.
9. Somsen GA, van Rijn C, Kooij S, Bem RA, Bonn D. Small droplet aerosols in poorly ventilated spaces and SARS-CoV-2 transmission. Lancet Respir Med. 2020:S2213-600. Available from: https://dx.doi.org/10.1016%2FS2213-2600(20)30245-9.
10. Eykelbosh A. Physical barriers for COVID-19 infection prevention and control in commercial settings [blog]. Vancouver, BC: National Collaborating Center for Environmental Health; 2020 May 13. Available from: https://ncceh.ca/content/blog/physical-barriers-covid-19-infection-prevention-and-control-commercial-settings.
11. O'Keeffe J. Masking during the COVID-19 pandemic. Vancouver, BC: National Collaborating Centre for Environmental Health; 2020 Apr 17. Available from: https://ncceh.ca/documents/guide/masking-during-covid-19-pandemic.
12. Chen T, Nicol A-M. Reducing COVID-19 transmission through cleaning and disinfection of household surfaces [guidance document]. Vancouver, BC: National Collaborating Centre for Environmental

Health; 2020 Apr 28. Available from: https://ncceh.ca/documents/guide/reducing-covid-19-transmission-through-cleaning-and-disinfecting-household-surfaces.

13. US Centers for Disease Control and Prevention. Hierarchy of controls. Atlanta, GA: National Institute for Occupational Safety and Health; 2020; Available from: https://www.cdc.gov/niosh/topics/hierarchy/default.html.
14. British Columbia Public Safety and Emergency Services. Key steps to safely operating your business or organization and reducing COVID-19 transmission. Victoria, BC: Government of British Columbia; 2020; Available from: https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/gdx/go_forward_strategy_checklist_web.pdf.
15. Nardell EA, Nathavitharana RR. Airborne spread of SARS-CoV-2 and a potential role for air disinfection. JAMA. 2020. Available from: https://doi.org/10.1001/jama.2020.7603.
16. Byrns G, Barham B, Yang L, Webster K, Rutherford G, Steiner G, et al. The uses and limitations of a hand-held germicidal ultraviolet wand for surface disinfection. J Occup Environ Hyg. 2017;14(10):749-57. Available from: https://doi.org/10.1080/15459624.2017.1328106.
17. Kowalski W. Ultraviolet germicidal irradiation handbook. New York, NY: Springer; 2009. Available from: https://link.springer.com/book/10.1007/978-3-642-01999-9.
18. International Ultraviolet Association. IUVA Fact sheet on UV disinfection for COVID-19. Chevy Chase, MD: IUVA; 2020 Mar. Available from: https://www.iuva.org/IUVA-Fact-Sheet-on-UV-Disinfection-for-COVID-19.
19. Morawska L, Tang JW, Bahnfleth W, Bluyssen PM, Boerstra A, Buonanno G, et al. How can airborne transmission of COVID-19 indoors be minimised? Environ Int. 2020 May 27;142:105832. Available from: https://doi.org/10.1016/j.envint.2020.105832.
20. Simmons S, Carrion R, Alfson K, Staples H, Jinadatha C, Jarvis W, et al. Disinfection effect of pulsed xenon ultraviolet irradiation on SARS-CoV-2 and implications for environmental risk of COVID-19 transmission. medRxiv. 2020 May 11;Pre-Print. Available from: https://www.medrxiv.org/content/10.1101/2020.05.06.20093658v1.
21. Seyer A, Sanlidag T. Solar ultraviolet radiation sensitivity of SARS-CoV-2. Lancet Microbe. 2020 2020;1(1):e8-e9. Available from: https://dx.doi.org/10.1016%2FS2666-5247(20)30013-6.
22. McDevitt JJ, Rudnick SN, Radonovich LJ. Aerosol susceptibility of influenza virus to UV-C light. Appl Environ Microbiol. 2012 2012;78(6):1666-9. Available from: https://dx.doi.org/10.1128%2FAEM.06960-11.
23. Houser KW. Ten racts about UV radiation and COVID-19. LEUKOS. 2020;16(3):177-8. Available from: https://doi.org/10.1080/15502724.2020.1760654.
24. American Society of Heating Refrigerating and Air-Conditioning Engineers Inc. ASHRAE Handbook - Heating, ventilating, and air-conditioning systems and equipment (SI Edition) - Knovel. Atlanta, GA: ASHRAE; 2016. Available from: https://www.ashrae.org/about/news/2016/ashrae-2016-handbook-focuses-on-hvac-systems-and-equipment.
25. Kujundzic E, Matalkah F, Howard CJ, Hernandez M. UV air cleaners and upper-room air ultraviolet germicidal irradiation for controlling airborne bacteria and fungal spores. J Occup Environ Hyg. 2006;3(10):536-46. Available from: https://doi.org/10.1080/15459620600909799.
26. Petersson LP, Albrecht U-V, Sedlacek L, Gemein S, Gebel J, Vonberg R-P. Portable UV light as an alternative for decontamination. Am J Infect Control. 2014 2014;42(12):1334-6. Available from: https://doi.org/10.1016/j.ajic.2014.08.012.
27. Scarpino PV, Jensen NJ, Jensen PA, Ward R. The use of ultraviolet germicidal irradiation (UVGI) in disinfection of airborne bacteria and rhinoviruses. J Aerosol Sci. 1998 1998;29:S777-S8. Available from: https://link.springer.com/article/10.1007/s100220100046.
28. Walker CM, Ko G. Effect of ultraviolet germicidal irradiation on viral aerosols. Environ Sci Tech. 2007;41(15):5460-5. Available from: https://pubs.acs.org/doi/10.1021/es070056u.

29. Atci F, Cetin YE, Avci M, Aydin O. Evaluation of in-duct UV-C lamp array on air disinfection: a numerical analysis. Sci Technol Built Environ. 2020. Available from: https://doi.org/10.1080/23744731.2020.1776549.
30. Blázquez E, Rodríguez C, Ródenas J, Navarro N, Riquelme C, Rosell R, et al. Evaluation of the effectiveness of the SurePure Turbulator ultraviolet-C irradiation equipment on inactivation of different enveloped and non-enveloped viruses inoculated in commercially collected liquid animal plasma. PLoS ONE. 2019;14(2). Available from: https://doi.org/10.1371/journal.pone.0212332.
31. Heßling M, Hönes K, Vatter P, Lingenfelder C. Ultraviolet irradiation doses for coronavirus inactivation – review and analysis of coronavirus photoinactivation studies. GMS Hyg Infect Control. 2020;15. Available from: https://dx.doi.org/10.3205%2Fdgkh000343.
32. Bianco A, Biasin M, Pareschi G, Cavalleri A, Cavatorta C, Fenizia C, et al. UV-C irradiation is highly effective in inactivating and inhibiting SARS-CoV-2 replication. medRxiv. 2020;Pre-Print. Available from: https://www.medrxiv.org/content/10.1101/2020.06.05.20123463v2.
33. US Centers for Disease Control and Prevention. Decontamination and reuse of filtering facepiece respirators. Atlanta, GA: US Department of Health and Human Services; 2020 [updated 2020]; Available from: https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html.
34. Schulz-Stübner S, Kosa R, Henker J, Mattner F, Friedrich A. Is UV-C “light wand” mobile disinfection in air ambulance helicopters effective? Infect Control Hosp Epidemiol. 2019 2019;40(11):1323-6. Available from: https://doi.org/10.1017/ice.2019.225.
35. Leung KCP, Ko TCS. Improper use of germicidal range ultraviolet lamp for household disinfection leading to phototoxicity in COVID-19 suspects. Cornea. 2020;[Online ahead of print]. Available from: https://doi.org/10.1097/ico.0000000000002397.
36. Liao L, Xiao W, Zhao M, Yu X, Wang H, Wang Q, et al. Can N95 respirators be reused after disinfection? How many times? ACS Nano. 2020;14(5):6348-56. Available from: https://dx.doi.org/10.1021%2Facsnano.0c03597.
37. Buonanno G, Stabile L, Morawska L. Estimation of airborne viral emission: Quanta emission rate of SARS-CoV-2 for infection risk assessment. Environ Int. 2020;141:105794. Available from: https://www.medrxiv.org/content/10.1101/2020.04.12.20062828v1.
38. Welch D, Buonanno M, Grilj V, Shuryak I, Crickmore C, Bigelow AW, et al. Far-UVC light: a new tool to control the spread of airborne-mediated microbial diseases. Sci Rep. 2018;8(1):2752. Available from: https://www.nature.com/articles/s41598-018-21058-w.
39. American Society of Heating Refrigeration and Air-Conditioning Engineers. Ultraviolet air and surface treatment. Chapter 62. ASHRAE Handbook HVAC Applications. Atlanta, GA: ASHRAE; 2019. p. 62.1-.18. Available from: https://www.ashrae.org/file%20library/technical%20resources/covid-19/i-p_a19_ch62_uvairandsurfacetreatment.pdf.
40. Robertson JT. Electrostatic technology for surface disinfection in healthcare facilities. Infect Control. 2016 Oct 14. Available from: https://infectioncontrol.tips/2016/10/14/electrostatic-in-healthcare/#:~:text=Electrostatic%20application%20for%20healthcare%20surface,it%20leaves%20the%20spray%20nozzle.
41. Castaño N, Cordts S, Jalil MK, Zhang K, Koppaka S, Paul R, et al. Fomite transmission and disinfection strategies for SARS-CoV-2 and related viruses. arXiv. 2020 May 23;Pre-print:40. Available from: https://arxiv.org/abs/2005.11443.
42. Patel MK, Ghanshyam C. Fundamentals of electrostatic spraying: Basic concepts and engineering practices. Hershey, PA: IGI Global; 2020. Available from: https://www.igi-global.com/chapter/fundamentals-of-electrostatic-spraying/135106.

43. Lyons SM, Harrison MA, Law SE. Electrostatic application of antimicrobial sprays to sanitize food handling and processing surfaces for enhanced food safety. J Physics Conf Series. 2011;301:012014. Available from: https://iopscience.iop.org/article/10.1088/1742-6596/301/1/012014.
44. Clorox Company. Clorox Commercial Solutions® Clorox® Total 360™ system and solutions. [updated n.d.; cited 2020 Jul 17]; Available from: http://www.cloroxprofessional.ca/products/clorox-total-360-system/.
45. Cadnum J, Livingston S, Sankar Chittoor Mana T, Jencson A, Redmond S, Donskey C. 1218. Evaluation of a novel sporicidal spray disinfectant for decontamination of surfaces in healthcare. Open Forum Infect Dis. 2019;6(Suppl_2):S438-S. Available from: https://dx.doi.org/10.1093%2Fofid%2Fofz360.1081.
46. Archer J, Karnik M, Touati A, Aslett D, Abdel-Hady A. Evaluation of electrostatic sprayers for use in a personnel decontamination line protocol for biological contamination incident response operations. Washington, DC: U.S. Environmental Protection Agency; 2018 Oct. Report No.: EPA/600/R-18/283. Available from: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=342750&Lab=NHSRC&fed_org_id=1253&subject=Homeland%20Security%20Research&view=desc&sortBy=pubDateYear&showCriteria=1&count=25&searchall=%27indoor%20outdoor%20decontamination%27%20AND%20%27biological%27.
47. Ganesh V, Hettiarachchy NS, Ravichandran M, Johnson MG, Griffis CL, Martin EM, et al. Electrostatic sprays of food-grade acids and plant extracts are more effective than conventional sprays in decontaminating salmonella typhimurium on spinach. J Food Sci. 2010;75(9):M574-M9. Available from: https://doi.org/10.1111/j.1750-3841.2010.01859.x.
48. Jiang W, Etienne X, Li K, Shen C. Comparison of the efficacy of electrostatic versus conventional sprayer with commercial antimicrobials to inactivate Salmonella, Listeria monocytogenes, and Campylobacter jejuni for eggs and economic feasibility analysis. J Food Prot. 2018 2018;81(11):1864-70. Available from: https://doi.org/10.4315/0362-028X.JFP-18-249.
49. Bolton S, Kotwal G, Harrison MA, Law SE, Harrison J, Cannon JL. Sanitizer efficacy against murine norovirus, a surrogate for human norovirus, on stainless steel surfaces when using three application methods. Appl Environ Microbiol. 2013;79(4). Available from: https://dx.doi.org/10.1128%2FAEM.02843-12.
50. National Environment Agency. Advisory on surface cleaning and disinfection for COVID-19. Atlanta, GA: NEA; 2020 [updated 2020 07 01]; Available from: https://www.nea.gov.sg/our-services/public-cleanliness/environmental-cleaning-guidelines/cleaning-and-disinfection/advisories/advisory-on-surface-cleaning-and-disinfection-for-covid-19.
51. Health Canada. Hard surface disinfectants and hand sanitizers: list of hard-surface disinfectants for use against coronavirus (COVID-19). Ottawa, ON: Health Canada; 2020 [updated 2020 Mar 30]; Available from: https://www.canada.ca/en/health-canada/services/drugs-health-products/disinfectants/covid-19/list.html.
52. Health Canada. Hard surface disinfectants and hand sanitizers (COVID-19): disinfectants and hand sanitizers accepted under COVID-19 interim measure. Ottawa, ON: Health Canada; 2020 [updated 2020 Apr 17]; Available from: https://www.canada.ca/en/health-canada/services/drugs-health-products/disinfectants/covid-19/products-accepted-under-interim-measure.html.
53. Kelleher SR. Marriott rolls out 'hospital-grade disinfectant' in hotels for next-level cleanliness. Forbes. 2020 Apr 21. Available from: https://www.forbes.com/sites/suzannerowankelleher/2020/04/21/marriott-rolls-out-hospital-grade-disinfectant-in-hotels-for-next-level-cleanliness/#42cecd8943c1.

54. US Environmental Protection Agency. Can I apply a product using a method that is not specified in the directions for use? Washington, DC: US EPA; 2020 [updated 2020 May 15]; Available from: https://www.epa.gov/coronavirus/can-i-apply-product-using-method-not-specified-directions-use.
55. Gray R. Covid-19: How long does the coronavirus last on surfaces? BBC. 2020 Mar 17. Available from: https://www.bbc.com/future/article/20200317-covid-19-how-long-does-the-coronavirus-last-on-surfaces.
56. Diversey. Electrostatic sprayers and disinfectant use [technical bulletin]. Fort Mill, US: Diversey; 2018. Available from: https://www.emist.com/wp-content/uploads/2020/05/diversey-no-touch-disinfection-systems.pdf.
57. Boyce JM. New approaches to decontamination of rooms after patients are discharged. Infect Control Hosp Epidemiol. 2009;30(6):515-7. Available from: https://doi.org/10.1086/598999.
58. Webb JD. A fast track to zero environmental pathogens using novel ionized hydrogen peroxide technology. 2011; Available from: https://www.infectioncontroltoday.com/view/fast-track-zero-environmental-pathogens-using-novel-ionized-hydrogen-peroxide.
59. Kimball S, Bodurtha P, Gudgin Dickson EF. A roadmap for investigation and validation of dry fogging as a decontamination technology. Ottawa, ON: Defence Research and Development Canada; 2014. Report No.: RMC TR CPT-1304. Available from: https://cradpdf.drdc-rddc.gc.ca/PDFS/unc199/p800727_A1b.pdf.
60. Hayrapetyan H, Nederhoff L, Vollebregt M, Mastwijk H, Groot MN. Inactivation kinetics of Geobacillus stearothermophilus spores by a peracetic acid or hydrogen peroxide fog in comparison to the liquid form. Int J Food Microbiol. 2020;316. Available from: https://doi.org/10.1016/j.ijfoodmicro.2019.108418.
61. Masotti F, Cattaneo S, Stuknytė M, De Noni I. Airborne contamination in the food industry: an update on monitoring and disinfection techniques of air. Trends Food Sci Technol. 2019;90:147-56. Available from: https://doi.org/10.1016/j.tifs.2019.06.006.
62. Rutala WA, Weber DJ, Healthcare Infection Control Practices Advisory Committee. Guideline for disinfection and sterilization in healthcare facilities, 2008. Chapel Hill, NC: U.S. Centers for Disease Control and Prevention; 2019 May. Available from: https://www.cdc.gov/infectioncontrol/pdf/guidelines/disinfection-guidelines-H.pdf.
63. Ikeuchi USA Inc. Dry Fog Humidifier AKIMist® "E". Athens, GA: Ikeuchi. Available from: https://www.ikeuchi.us/eng/products/unit/1003.
64. Burfoot D, Hall K, Brown K, Xu Y. Fogging for the disinfection of food processing factories and equipment. Trends Food Sci Technol. 1999;10(6-7):205-10. Available from: https://doi.org/10.1016/S0924-2244(99)00045-X.
65. Malik DJ. The elephant in the room: on the routine use of hydrogen peroxide vapour decontamination systems in health care. J Hosp Infect. 2013 Apr;83(4):354-5. Available from: https://doi.org/10.1016/j.jhin.2012.08.022.
66. Best EL, Parnell P, Thirkell G, Verity P, Copland M, Else P, et al. Effectiveness of deep cleaning followed by hydrogen peroxide decontamination during high Clostridium difficile infection incidence. J Hosp Infect. 2014;87(1):25-33. Available from: https://doi.org/10.1016/j.jhin.2014.02.005.
67. Galvin S, Boyle M, Russell RJ, Coleman DC, Creamer E, O'Gara JP, et al. Evaluation of vaporized hydrogen peroxide, Citrox and pH neutral Ecasol for decontamination of an enclosed area: a pilot study. J Hosp Infect. 2012 Jan;80(1):67-70. Available from: https://doi.org/10.1016/j.jhin.2011.10.013.
68. Park GW, Boston DM, Kase JA, Sampson MN, Sobsey MD. Evaluation of liquid- and fog-based application of sterilox hypochlorous acid solution for surface inactivation of human norovirus. Appl Environ Microbiol. 2007 2007;73(14):4463-8. Available from: https://dx.doi.org/10.1128%2FAEM.02839-06.

69. Bentley K, Dove BK, Parks SR, Walker JT, Bennett AM. Hydrogen peroxide vapour decontamination of surfaces artificially contaminated with norovirus surrogate feline calicivirus. J Hosp Infect. 2012;80(2):116-21. Available from: https://doi.org/10.1016/j.jhin.2011.10.010.
70. Holmdahl T, Walder M, Uzcátegui N, Odenholt I. Hydrogen peroxide vapor decontamination in a patient room using feline calicivirus and murine norovirus as surrogate markers for human norovirus. Infect Control Hosp Epidemiol. 2016 2016;37(5):561-6. Available from: https://doi.org/10.1017/ice.2016.15.
71. Gregersen J-P, Roth B. Inactivation of stable viruses in cell culture facilities by peracetic acid fogging. Biologicals. 2012;40(4):282-7. Available from: https://doi.org/10.1016/j.biologicals.2012.02.004.
72. Montazeri N, Manuel C, Moorman E, Khatiwada JR, Williams LL, Jaykus L-A. Virucidal activity of fogged chlorine dioxide- and hydrogen peroxide-based disinfectants against human norovirus and its surrogate, feline calicivirus, on hard-to-reach surfaces. Front Microbiol. 2017;8:1031. Available from: https://www.frontiersin.org/articles/10.3389/fmicb.2017.01031/full.
73. Andersen BM, Rasch M, Hochlin K, Jensen F-H, Wismar P, Fredriksen J-E. Decontamination of rooms, medical equipment and ambulances using an aerosol of hydrogen peroxide disinfectant. J Hosp Infect. 2006;62(2):149-55. Available from: https://doi.org/10.1016/j.jhin.2005.07.020.
74. Cooper T, O'Leary M, Yezli S, Otter JA. Impact of environmental decontamination using hydrogen peroxide vapour on the incidence of Clostridium difficile infection in one hospital Trust. J Hosp Infect. 2011 Jul;78(3):238-40. Available from: https://doi.org/10.1016/j.jhin.2010.12.013.
75. French GL, Otter JA, Shannon KP, Adams NMT, Watling D, Parks MJ. Tackling contamination of the hospital environment by methicillin-resistant Staphylococcus aureus (MRSA): a comparison between conventional terminal cleaning and hydrogen peroxide vapour decontamination. J Hosp Infect. 2004;57(1):31-7. Available from: https://doi.org/10.1016/j.jhin.2004.03.006.
76. Hartley J, McQueen S, Hollis M, Philps A, McDonnell G. A new method of environmental disinfection and use in the control of MRSA outbreaks. Am J Infect Control. 2007;35(5):E124-E5. Available from: https://doi.org/10.1016/j.ajic.2007.04.156.
77. Barbut F, Menuet D, Verachten M, Girou E. Comparison of the efficacy of a hydrogen peroxide dry-mist disinfection system and sodium hypochlorite solution for eradication of Clostridium difficile spores. Infect Control Hosp Epidemiol. 2009;30(6):507-14. Available from: https://doi.org/10.1086/597232.
78. Taneja N, Biswal M, Kumar A, Edwin A, Sunita T, Emmanuel R, et al. Hydrogen peroxide vapour for decontaminating air-conditioning ducts and rooms of an emergency complex in northern India: time to move on. J Hosp Infect. 2011;78(3):200-3. Available from: https://doi.org/10.1016/j.jhin.2011.02.013.
79. Leclerc QJ, Fuller NM, Knight LE, Group CC-W, Funk S, Knight GM. What settings have been linked to SARS-CoV-2 transmission clusters? Wellcome Open Research. 2020 2020-6-5;5:83. Available from: https://wellcomeopenresearch.org/articles/5-83.
80. Nishiura H, Oshitani H, Kobayashi T, Saito T, Sunagawa T, Matsui T, et al. Closed environments facilitate secondary transmission of coronavirus disease 2019 (COVID-19). MedRxiv. 2020;Pre-print.

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