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TWO STEPS FOR A REASON: THE CASE FOR CLEANING PRIOR TO DISINFECTION

EXECUTIVE SUMMARY

Cleaning and disinfection have long been routine components of any facility's operations. Yet, they have been moved from the sidelines to center stage by the recent COVID-19 pandemic.[1] Yet, as facilities seek to enhance these practices, it is imperative to bear in mind that there is a necessary order to the process. As stated by the Centers for Disease Control and Prevention (CDC), cleaning is "the necessary first step of any sterilization or disinfection process" or, more simply, you must clean before you can disinfect.[2]

The rationale for this two-step approach is rooted in the very reasons we clean and disinfect in the first place: to render surfaces aesthetically appealing by removing debris and soils and, most importantly, to reduce environmental infection transmission risk. Research continues to show that contact with contaminated surfaces can lead to infection transmission in a variety of settings, ranging from hospitals to hotels.[3-11] It has also shown just how pervasive that contamination can be.[12-22] Cleaning, in this context, is designed to remove as many microorganisms as possible, but also to remove the debris and matter that can interfere with the disinfection process.[2-3,23-26]

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Mechanical action is a key element in this removal.[2] The force or friction applied is what actually facilitates the removal of matter, be it dirt or microbes, which is why the CDC acknowledges that the physical act of wiping or scrubbing a surface to remove microorganisms and soil is "as important, if not more so than the antimicrobial effect" of any chemical applied to it.[2] This is critical, because a disinfectant can only work if it makes direct contact with a microorganism—a process hindered when soils remain on a surface, "protecting" the microbe from the chemical.[3,23-24] Further, many disinfectants are inactivated in the presence of soils and organic matter.[23,25,27]

The physical act of cleaning a surface also mitigates a longer-term risk—that of biofilm formation.[28-29] One of the first stages in the formation of these notoriously challenging public health threats is the build-up of a conditioning film or layer of matter, from dirt to detergent residue, left on a surface.[28-31] Put simply, if left on a surface, these residues can serve as the building blocks for biofilms.

This has important ramifications in the era of so-called "no touch" disinfection technologies such as UV-C light, misting/fogging, or electrostatic spraying. Experts caution that these technologies are a successful adjunct, but not substitute, for manual cleaning.[3,32-33] In fact, studies have shown that many of these technologies have reduced efficacy in the presence of organic matter and soils. Accordingly, while the CDC's recommendation to clean first, then disinfect predates the widespread use of these technologies, it remains both valid and necessary and the reason why a two-step process is endorsed by an overwhelming consensus of government, accrediting, and professional organizations across a range of industries.[23,34-42]

INTRODUCTION

Cleaning surfaces prior to disinfection has long been established as a necessary step to achieve optimal removal and elimination of surface contamination.[2] Both the Centers for Disease Control and Prevention (CDC) and the Environmental Protection Agency (EPA), the regulatory body for chemical disinfectants used on noncritical surfaces, strongly endorse this principle.[2,43] In the Guidelines for Environmental Infection Control, the CDC unequivocally states "Cleaning is the necessary first step of any sterilization or disinfection process. Cleaning is a form of decontamination that renders the environmental surface safe to handle or use by removing organic matter, salts, and visible soils, all of which interfere with microbial inactivation."[2]

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Although a timeless principle, the role of cleaning and disinfection has garnered heightened attention owing to the COVID-19 pandemic.[1] As facilities of all types seek to ensure a safe environment for their occupants by developing and implementing environmental infection control procedures, it is critical to understand the research and rationale behind the recommendation to "clean first" in order to achieve the desired outcome—a reduced risk of environmental infection transmission.

WHY WE CLEAN AND DISINFECT

There are a number of reasons why we clean (remove dirt, debris, and microbes) and disinfect (kill microbes) surfaces,[2] beginning with the obvious goal of rendering a surface or space aesthetically appealing. A dusty or soiled surface arguably holds little appeal, whether it is a classroom desk, a hotel sink, or a hospital bedside table. It could also be argued that, regardless of the setting, "clean" facilities imply a certain degree of care and attention to operational detail that could only help how a business or organization is perceived.[44] Hospitals are, in fact, reimbursed for services by the Centers for Medicare and Medicaid Services based in part on how clean patients perceive them.[45]

There is, however, a more pressing reason to clean and disinfect—the risk of environmental infection transmission.[3] When it comes to contaminated surfaces, the chain of events for environmental infection is relatively straightforward: surfaces to hands to self-inoculation or inoculation of others. Research has shown that when people make hand contact with a contaminated surface, their hands can become contaminated with the same pathogens on that surface and they can subsequently inoculate or infect themselves or another individual if proper hand hygiene is not performed.

Though the risk of environmental infection transmission has been widely acknowledged in healthcare settings for a number of years, the COVID-19 pandemic has brought the issue into greater focus across a wide range of facilities.[1] Evidence that SARS-CoV-2, the virus responsible for COVID-19, can persist on a variety of surface materials for hours to days has fueled concerns about the risk for a contaminated surface, or fomite, to transmit infection.[46-49] Research has shown that surface contamination in the rooms of COVID-19 patients can be widespread, with some studies demonstrating as many as 50 to 87 percent of surfaces testing positive for the virus, though the extent to which this recovered virus remains infectious is not clear.[50-51] This information, along with what researchers know about how other respiratory viruses can be spread, has led to recommendations for enhanced cleaning and disinfection methods during the pandemic from a broad range of government, accrediting, and professional organizations.[43,52-56] The goal is simple: by removing the virus from surfaces with effective cleaning and disinfection, the risk of people touching contaminated surfaces, subsequently touching their eyes, nose, or mouth (i.e. mucous membranes) with contaminated hands, and ultimately becoming infected can be reduced.[47]

Fomite transmission is not a new concept. Scientific literature includes a robust body of evidence demonstrating the important role that contaminated surfaces play in the transmission of a variety of pathogens.[3-6] Much of this evidence comes from the healthcare setting in which it has become well-established that a contaminated environment increases the risk of acquiring a healthcare-associated infection.[3]

As stated by Drs. Rutala and Weber in their review of best practices for disinfection of non-critical surfaces and equipment in healthcare facilities, research has shown that clinically relevant "pathogens have been demonstrated to persist in the environment for days (in some cases months), frequently contaminate the environmental surfaces in rooms of colonized or infected patients, transiently colonize the hands of health care personnel, can be transmitted by health care personnel, and cause outbreaks in which environmental transmission was deemed to play a role."[3]

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Infected or colonized individuals can shed pathogens onto surfaces where they can survive and be passed on to the next individual who touches that contaminated surface.[3] Studies have even shown that a healthcare provider caring for a patient colonized or infected with multidrug-resistant organisms are as likely to contaminate their hands after contact with a contaminated surface in the patient's room as they are after contact with the patient themselves.[7]

Though less well studied, fomite transmission has also been documented in a variety of non-healthcare settings. Outbreaks of infection have occurred in venues ranging from hotels to schools to cruise ships to airplanes.[8-11] Research has also shown the extent to which surfaces in homes, office spaces, schools, and public transportation can be contaminated with microorganisms, including those known to cause infectious disease.[12-17] For example, norovirus, a highly contagious virus and the most common cause of epidemic gastroenteritis,[57] has been recovered from surfaces ranging from light switches and door handles in office buildings, to desktops and paper towel dispensers in classrooms, to carpets and curtains in homes.[14,17-19] Human parainfluenza viruses (HPIV), a common source of respiratory illness and a pathogen known to be transmitted via fomites, have been recovered from computer keyboards, telephones, and desktops in office buildings with one study showing as many as 37 percent of surfaces sampled to be contaminated.[14] Another culprit, rhinovirus, which is responsible for the majority of common colds in humans, was found on 41 percent of 160 surfaces in the homes of infected individuals.[15] In a study of 14 day care centers and 8 homes, influenza A virus was recovered from 53 and 59 percent of surfaces, respectively, during flu season.[17]

Bacteria are similarly implicated in environmental contamination. A study of 291 households in New York City found environmental contamination with Staphylococcus aureus in 54 percent of homes while a study of athletic facilities in 10 Ohio schools found methicillin-resistant Staphylococcus aureus (MRSA) on 46.7 percent of sampled surfaces.[20-21] Other research has recovered MRSA from surfaces ranging from cellular phones to handrails on public buses to handbags.[14] The risk doesn't just lie with MRSA. A study of bacterial bioburden in office buildings in three different cities identified over 500 different genera of bacteria on sampled surfaces.[16] And the most contaminated culprits may not always be the most obvious, as evidenced by Kandel et. al who found that elevator call buttons had a higher degree of bacterial colonization than toilet surfaces (43%) with the most common bacteria on both surfaces being Staphylococcus, Streptococcus, and coliform bacteria.[22]

As Stephens et al. state in a review of fomite transmission, "We live in a microbial world…inanimate objects in the built environment…are host to an entire community composed of a wide variety of bacterial, viral, archaical, protistan, and fungal organisms, including potential pathogens and microbial metabolic products harmful to humans."[14] In other words, microbial contamination of inanimate surfaces, including with potential pathogens, is ubiquitous—whether it is a school, an office, a house, or a public space. Cleaning, in this context, is designed to mitigate infection risk—to clean or remove dirt, debris, and potential pathogens from the surfaces and thereby reduce the chance that contact with that surface will result in hand contamination and, ultimately, infection.[3]

THE “MUSCLE” OF MECHANICAL ACTION

The CDC’s definition of cleaning describes what the process accomplishes—the removal of organic matter, salts, and visible soils, all of which interfere with microbial inactivation—but it also describes how it is achieved: “The physical action of scrubbing with detergents and surfactants and rinsing with water removes large numbers of microorganisms from surfaces.”[2] This is a critical point, because it underscores the fact that, according to the CDC’s definition of cleaning, you cannot technically “clean” a surface without first physically removing the matter found on it.

That friction or mechanical action is at the heart of cleaning is a message that resonates throughout cleaning and disinfection recommendations and guidelines. Defining mechanical action as “the physical action of cleaning—rubbing, scrubbing, and friction,” the CDC advises when cleaning, “Wipe surfaces…making sure to use mechanical action” as “the actual physical removal of microorganisms and soil by wiping or scrubbing is probably as important, if not more so, than any antimicrobial effect of the cleaning agent used.”[2,58] Similarly, the EPA defines cleaning as “the process that physically removes debris from the surface by scrubbing, washing, and rinsing” and the Canadian Provincial Infectious Diseases Advisory Committee states, “It is a fundamental principle that microorganisms can only be successfully removed and/or inactivated if dirt and debris are completely removed. To achieve the removal of dirt and debris, friction (e.g. elbow grease) is critical.”[35,59]

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Studies have supported that friction or mechanical action is at the heart of cleaning—it is what facilitates the actual removal of dirt, debris, microbes, and soils, rendering a surface ready for disinfection when necessary.[60-61] In a study comparing the efficacy of three disinfectants delivered by conventional hydraulic spraying, electrostatic spraying, or wiping with towelettes, Bolton et al. found wiping with the towelette, after saturating it in the disinfectant, to be most effective, concluding that, “the mechanical action of the wipe application likely helped to dislodge viruses from the surface and to facilitate greater penetration of the sanitizer into the inoculated area.”[60]

There is also evidence that the amount of friction applied is important,[23,61] suggesting that the cleaning outcome from a light swipe might be very different from a heavier hand. The Minnesota Department of Health advises that “the amount of mechanical action (i.e. friction produced by wiping or scrubbing) will affect how greatly the microbial population is reduced.”[23] In a study of different wiping techniques, Rigotti et al. conclude, “it seems that the cleaning/disinfection efficiency is more based on its dirtiness removal capacity by means of applying enough friction than on the mere rubbing of moistened cloth in predetermined directions.”[61] Accordingly, use of friction or mechanical action is a component of a wide range of cleaning recommendations and guidelines, including those from the aforementioned government agencies as well as those from accrediting organizations such as The Joint Commission and professional organizations such as the National Association for the Education of Young Children, and the American Federation of Teachers.[2,23,35,59,62-63]

A MATTER OF INTERFERENCE

The mechanical action involved in effective cleaning plays an important role in the recommended sequence of cleaning and disinfection or the “2-step” clean first, then disinfect method.[2,64] This is because cleaning not only reduces the microbial population on a surface, but also removes organic and inorganic matter that can significantly interfere with disinfection.[2-3,23-24-26] The CDC defines cleaning as the “necessary first step” in any disinfection process for “at least two” important reasons: it removes any barrier between the disinfectant and the targeted pathogen and it removes matter that could potentially inactivate the disinfectant.[27]

In order to effectively kill pathogens, disinfectant chemicals must have direct contact with the pathogen; however, soils, dirt, and debris can coat or protect microorganisms, essentially serving as a protective barrier between the chemical and the target.[3,23-24] Additionally, many disinfectants are inactivated in the presence of soils and organic matter, rendering them unable to kill microbes.[23-27] Research has shown that chemical and/or electrostatic interactions between the disinfectant and organic matter are responsible for this inactivation,[65] rendering many common chemical agents including bleach, quaternary ammonium compounds, alcohols, and iodophors unable to exert their disinfective action.[3,27,66-67] In their mathematical modeling study of the effect of interfering substances on the disinfection process, Lambert and Johnston conclude "disinfection without substantive cleaning may limit effectiveness or even simply be a wasteful exercise…disinfection without cleaning is known to lead to a reduction in efficacy. Whether the hygiene standards are borne in a hospital, factory, or home, the same criteria apply: the reduction of risk can be accomplished by good practices—actively encouraged and seen to be operating with a good cleaning and disinfection regime."[25]

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More recently, the EPA has registered products designated as "cleaner-disinfectants" intended for use as both a cleaning and disinfecting agent. These are products that have demonstrated efficacy in the presence of a quantified amount of soiling (5 percent organic matter), though they caution that with heavy soiling a cleaning step must be performed prior to the application of the antimicrobial agent.[68] EPA guidance on cleaning and disinfection, however, including that recently published for public spaces, workplaces, businesses, schools and homes to reduce the risk of COVID-19, continues to recommend cleaning surfaces prior to disinfecting them.[43] Additionally, some organizations advise against the use of cleaner-disinfectant products without first cleaning because of the challenge in identifying whether the amount of surface soiling exceeds the threshold (5 percent) with which the product was tested.[64,68] The City of San Francisco's Department of the Environment states, "Although some products are labeled as one-step cleaner-disinfectants, it is not advisable to use them because it is difficult to monitor whether they are being used properly. Such products demonstrated their efficacy to U.S. EPA in the presence of 5% organic matter. However, if a surface exceeds that level, the product will no longer be effective."[68] Guidance from the University of California San Francisco Center for Environmental Research and the California Department of Pesticide Regulation goes so far as to identify use of a cleaner-disinfectant without first cleaning a visibly soiled surface "incorrect use."[64] Similarly, in a 2019 review of disinfection for child care sites, Holm et al. advise a 2-step process, arguing that "all disinfectants are less effective in the presence of organic material."[24]

BUILD-UP TO BIOFILM

Another important rationale for cleaning prior to disinfecting has less to do with the immediate action of a disinfectant on a surface and more to do with the prevention of a future problem—biofilm formation.[28-29] Biofilms are populations of microorganisms that are attached to a solid surface and protected by a "slime layer" or extracellular matrix of polysaccharides and noncellular materials.[30,69-70] In the environment, they present a significant challenge because they are difficult to remove from surfaces and difficult to penetrate with disinfectants. Biofilms can form on virtually any hard surface, from a countertop to a water pipe and have been implicated in a range of infectious diseases.[30,69-74] They are particularly notorious in the food industry in which outbreaks caused by pathogens such as Bacillus cereus, enterohemorrhagic Escherichia coli, and Listeria monocytogenes have been linked to biofilms on food processing equipment or surfaces.[73] Other examples of biofilm-mediated infectious disease include spread of Legionella pneumophila from biofilms on showerheads and Pseudomonas aeruginosa from biofilms on faucets/taps, sink and shower drains.[72,74]

Importantly, one of the first stages in biofilm formation is the development of a layer of adsorbed material called a conditioning film which plays an integral role in the attachment of the biofilm to the surface.[28,30,31] This layer or conditioning film can be comprised of a variety of materials left on a surface—from dirt to detergent residue, underscoring the importance of cleaning surfaces in order to remove all types of matter.[28,31] In an article on biofilms and the food processing environment, Koo et al. state, "Frequent cleaning on a regular basis is required to remove and prevent any adsorbed organic material (food, soil, and environment), inorganic material (residue of cleaning agent) and microorganisms. With failure of removing chemical and biological residue, this will create conditioning films for the initial step of biofilm formation, facilitate cell attachment, and eventually become hard to remove."[29] In this context, cleaning serves not only to remove dirt, debris and microorganisms to facilitate the short-term cleaning and disinfection of a surface, but also to mitigate the potential long-term consequences of leaving particulate traces behind.

CLEANING IN THE NO-TOUCH TECHNOLOGY ERA

The past decade has heralded a new dimension in cleaning and disinfection with the development of automated or "no-touch" decontamination technologies.[3] The growing evidence behind environmental transmission risk, the emergence of pathogens such as SARS-CoV-2 and Candida auris, and studies highlighting the often suboptimal performance of manual cleaning and disinfection have fueled the expansion of these technologies across a spectrum of settings. While research has shown that many of these systems, from ultraviolet (UV-C) light to hydrogen peroxide vapor (HPV) to electrostatic sprayers, can reduce microbial contamination, experts caution that they should be used as an adjunct to standard manual cleaning and disinfection rather than as a substitute.[3,32-33] This is owing to the fact that none of these technologies are capable of cleaning a room in accordance with the CDC's definition, and, in fact, many of the technologies have reduced efficacy in the presence of organic matter or soils.[3,33,75-77]

Organic load—dirt, soils, etc.—has been well established as a limiting factor for UV-C technology.[3,75,78] In a comparison of two different UV-C devices, Nerandzic et al. found that "both a light and heavy organic load had a significant negative impact on the killing efficacy of the devices."[75] Similarly, research has also shown that organic load limits the efficacy of no-touch hydrogen peroxide technologies.[76] Fu et al. found that both HPV and aerosolized hydrogen peroxide systems demonstrated reduced efficacy against certain pathogens, including methicillin-resistant Staphylococcus aureus, in the presence of organic load.[76] While the decontamination efficacy of electrostatic sprayers has been less well studied, in the aforementioned study by Bolton et al. in which mechanical wiping with sanitizer proved more effective than electrostatic spraying of the sanitizer for the removal of a norovirus, the authors conclude that, "electrostatic spray application methods are best suited for pre-cleaned surfaces where there is no soil to dislodge."[60] Further, they advise, "Our findings…suggest that the cleaning of surfaces prior to sanitation will result in greater virus removal and inactivation."[60]

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Bolton et al.'s conclusion is one echoed by many experts in the field, including those whose research advocates for the use of no-touch technologies.[3,32-33] In his review of modern technologies for improving cleaning and disinfection of environmental surfaces in hospitals, Boyce states that despite the advancements in new technologies, manual cleaning and disinfection of surfaces remain "essential elements of infection prevention programs."[32] Weber et al, in their review of UV-C and HPV technologies, conclude, "Because UV devices and hydrogen peroxide systems will not physically clean a room (e.g., remove dust or stains), room cleaning must precede disinfection. 'No touch' systems should be seen as adjunctive methods of room decontamination."[33] Similarly, Rutala and Weber, in a review of best practices for disinfection of noncritical surfaces and equipment in healthcare, caution that no-touch technologies, "supplement, but do not replace, standard cleaning and disinfection because surfaces must be physically cleaned of dirt and debris."[3]

The CDC has not yet published recommendations supporting the use of no-touch technologies, including UV-C, HPV, and electrostatic spraying, citing a need for additional research.[27] The EPA, though expediting review of disinfectants for indoor use with electrostatic sprayers against SARS-CoV-2, advises that "for now" the CDC recommends use of liquid disinfectant products on contaminated surfaces, providing a link to the CDC's guidance which includes the directive to clean surfaces prior to disinfecting.[79] Organizations that do promote the use of some of these technologies, including for example, the U.S. Army Public Health Center and Public Health Ontario, both of whom support use of electrostatic sprayers, recommend cleaning surfaces prior to disinfection with the technology.[77,80] Similarly, in their 2019 guidance, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) advise, "UVC surface disinfection should only be applied as an adjunct to normal surface cleaning procedures of the facility."[78] "Even among manufacturers of the no-touch technologies, there are directives to clean surfaces prior to use of the various systems in keeping with the CDC's 2-step cleaning and disinfection recommendation.[81-83] Collectively, the message is simple: no-touch technologies do not eliminate the need for the physical cleaning of surfaces; in fact, their efficacy is dependent on it.

AN OVERWHELMING CONSENSUS

The COVID-19 pandemic has heightened the focus on cleaning and disinfection for many facilities and, thereby increased demands on resources, including time and expense. Faced with these demands, facilities are looking for the most efficient methods and means to achieve success and compliance with recommendations such as those issued by the CDC and EPA for cleaning and disinfection in public spaces, workplaces, businesses, schools, and homes.[43,56] It is imperative, however, to ensure that facilities are following evidence-based guidance on best practice in order to achieve optimal outcomes. When it comes to disinfecting surfaces, bypassing the critical cleaning step and proceeding straight to disinfection—whether with electrostatic spraying, UV-C/HPV decontamination or even hydraulic spraying with cleaner-disinfectants—can potentially undermine the goal of reducing infection transmission risk, because as the CDC states, "the effectiveness of…disinfection…mandates effective cleaning."[27]

Among government, accrediting, and professional organizations, the consensus to clean prior to disinfecting is an overwhelming one. From the American Hotel and Lodging Association to the National Restaurant Association, The Joint Commission to the Department of Education, or the American Academy of Pediatrics, or any of a number of other entities, the guidance is clear: cleaning prior to disinfection provides the best risk reduction for lowering the spread of infection, which is the ultimate goal of any cleaning and disinfection program and a public health imperative today.[23,34,35-36,37-42]

REFERENCES

1. Firshein S. The Most Important Word in the Hospitality Industry? ‘Clean’ https://www.nytimes.com/2020/06/03/travel/the-most-important-word-in-the-hospitality-industry-clean.html
2. Centers for Disease Control and Prevention. Guidelines for Environmental Infection Control in Healthcare Facilities. https://www.cdc.gov/infectioncontrol/guidelines/environmental/background/services.html
3. Rutala WA, Weber DJ. Best Practices for Disinfection of Noncritical Environmental Surfaces and Equipment in Healthcare Facilities: a Bundle Approach. Am J Infect Control 2019; 47: A96-A105.
4. Weber DJ, Anderson D, Rutala WA. The Role of the Surface Environment in Healthcare-Associated Infections. Curr Opin Infect Dis. 2013;26(4):338-44.
5. Otter JA, Yezli S, Salkeld JA, French GL. Evidence that Contaminated Surfaces Contribute to the Transmission of Hospital Pathogens and an Overview of Strategies to Address Contaminated Surfaces in Hospital Settings. Am J Infect Control. 2013;41(5 Suppl):S6-11.
6. Chemaly RF, Simmons S, Dale C, Jr., Ghantoji SS, Rodriguez M, Gubb J, et al. The Role of the Healthcare Environment in the Spread of Multidrug-Resistant Organisms: Update on Current Best Practices for Containment. Ther Adv Infect Dis. 2014;2(3-4):79-90.
7. Stiefel U, Cadnum JL, Eckstein BC, Guerrero DM, Tima MA, Donskey CJ. Contamination of Hands with Methicillin-Resistant Staphylococcus aureus after Contact with Environmental Surfaces and after Contact with the Skin of Colonized Patients. Infect Control Hosp Epidemiol. 2011;32(2):185-7
8. Centers for Disease Control and Prevention. Norovirus Outbreak in an Elementary School—District of Columbia, February 2007 Morbidity and Mortality Weekly Report 2008; 56(51):1340-1343. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5651a2.htm
9. Love SS, Jiang X, Barrett E, Farkas T, Kelly S. A Large Hotel outbreak of Norwalk-like virus Gastroenteritis among Three Groups of Guests and Hotel Employees in Virginia. Epidemiol Infect 2002; 129: 127-132.
10. Isakbaeva ET, Widdowson MA, Beard RS, et al. Norovirus Transmission on Cruise Ship. Emerg Infect Dis. 2005;11(1):154-158. doi:10.3201/eid1101.040434
11. Thornley CN, Emslie NA, Sprott TW, Greening GE, Rapana JP. Recurring Norovirus Transmission on an Airplane. Clin Infect Dis 2011; 53:515-520.
12. Barker J, Stevens D, Bloomfield SF. Spread and Prevention of Some Common Viral Infections in Community Facilities and Domestic Homes. J Appl Microbiol 2001; 91:7-21.
13. Vargas-Robles D, Gonzalex-Cedillo C, Hernandez AM, Alcaraz LD, Peimbert M. Passenger-Surface Microbiome Interactions in the Subway of Mexico City. PLoS One 2020; 15(8): e0237272.
14. Stephens B, Azimi P, Thoemmes MS, Heidarinejad M, Allen JG, Gilbert JA. Microbial Exchange via Fomites and Implications for Human Health. Curr Pollut Rep 2019; 5: 198-213.
15. Winther B, McCue K, Ashe K, Rubino J, Hendley JO. Rhinovirus Contamination of Surfaces in Homes of Adults with Natural Colds: Transfer of Virus to Fingertips during Normal Daily Activities. J Med Virol 2011; 83(5):
16. Hewitt KM, Gerba CP, Maxwell SL, Kelley ST. Office Space Bacterial Abundance and Diversity in Three Metropolitan Areas. PLoS One. 2012;7(5):e37849. doi:10.1371/journal.pone.0037849
17. Boone S, Gerba C. The Occurrence of Influenza A Virus on Household and Day Care Center Fomites. J Infect 2005; 51: 103-9.
18. Stobnika A, Goloft-Szymczak M, Wojcik-Fatla A, Zajac V, Korczynska-Smolec J, Gorny RL. Prevalence of Human Parainfluenza Viruses and Noroviruses Genomes on Office Fomites. Food Environ Virol 2018; 10:133-40.
19. Boone SA, Gerba CP. Significance of Fomites in the Spread of Respiratory and Enteric Viral Disease. Appl Environ Microbiol. 2007 Mar;73(6):1687-96. doi: 10.1128/AEM.02051-06.
20. Knox J, Uhlemann AC, Miller M, et al. Environmental Contamination as a Risk Factor for Intra-Household Staphylococcus aureus Transmission. PLoS One. 2012;7(11):e49900. doi:10.1371/journal.pone.0049900
21. Montgomery K, Ryan TJ, Krause A, Starkey C. Assessment of Athletic Health Care Facility Surfaces for MRSA in the Secondary School Setting. J Environ Health. 2010 Jan-Feb;72(6):8-11; quiz 66. PMID: 20104827.
22. Kandel CE, Simor AE, Redelmeier DA. Elevator Buttons as Unrecognized Sources of Bacterial Colonization in Hospitals. Open Med. 2014;8(3):e81-e86. Published 2014 Jul 8.
23. Minnesota Department of Health. Evaluation of cleaners, sanitizers, and Disinfectants for Surfaces. 2017. https://www.health.state.mn.us/communities/environment/risk/docs/guidance/cleaners.pdf
24. Holm SM, Leonard V, Durrani T, Miller MD. Do We Know How Best to Disinfect Child Care Sites in the United States? A Review of Available Disinfectant Efficacy Data and Health Risks of the Major Disinfectant Classes. Am J Infect Control 2019; 47: 82-91.
25. Lambert RJW, Johnston MD. The Effect of Interfering Substances on the Disinfection Process: a Mathematical Model. J Appl Microbiol 2001; 91: 548-555.
26. Food Standards Agency. Cleaning Effectively. https://www.food.gov.uk/sites/default/files/media/document/cleaning-effectively.pdf
27. Centers for Disease Control and Prevention. Guidelines for Disinfection and Sterilization in Healthcare Facilities. 2008. https://www.cdc.gov/infectioncontrol/guidelines/disinfection/index.html
28. Whitehead KA, Smith LA, Verran J. The Detection of Food Soils and Cells on Stainless Steel using Industrial Methods: UV illumination and ATP Bioluminescence. Int J Food Microbiol 2008; 127:121-128.
29. Koo OK, Martin EM, Story R, Lindsay D, Ricke SC, Crandall PG. Comparison of cleaning fabrics for bacterial removal from food-contact surfaces. Food Control 2013; 30:292-297.

30. Donlan RM. Biofilms: Microbial Life on Surfaces. Emerg Infect Dis. 2002;8(9):881-890. doi:10.3201/eid0809.020063
31. Verran J, Jones MV. Problems of Biofilms in the Food and Beverage Industry. Walker JT, Surman S, Jass J (Eds), Industrial biofouling, John Wiley and Sons Ltd, Chichester, UK 2000, pp145-173.
32. Boyce JM. Modern Technologies for Improving Cleaning and Disinfection of Environmental Surfaces in Hospitals. Antimicrob Resist Infect Control. 2016;5:10. Published 2016 Apr 11. doi:10.1186/s13756-016-0111-x
33. Weber DJ, Kanamori H, Rutala WA. 'No touch' Technologies for Environmental Decontamination: Focus on Ultraviolet Devices and Hydrogen Peroxide Systems. Curr Opin Infect Dis. 2016;29(4):424-431.
34. American Hotel and Lodging Association. Enhanced Industry-Wide Hotel Cleaning Guidelines in Response to COVID-19. https://www.ahla.com/sites/default/files/safestayguidelinesv3_081420_0.pdf
35. Ontario Agency for Health Protection and Promotion (Public Health Ontario), Provincial Infectious Diseases Advisory Committee. Best practices for environmental cleaning for prevention and control of infections in all health care settings. 3rd ed. Toronto, ON: Queen's Printer for Ontario; 2018
36. The Joint Commission. Protecting Patients and Staff from Infection Risks: Cleaning and Disinfecting environmental surfaces. https://www.jointcommission.org/-/media/jcr/jcr-documents/about-jcr/osha-alliance/osha_alliance_oct_2015_ec_newspdf.pdf
37. National Restaurant Association. Clean isn't enough: Avoid Cross-Contamination in Your Restaurant. https://www.restaurant.org/articles/operations/clean-isn't-enough-avoid-cross-contamination
38. United States Department of Education. School Guide: How to Clean and Disinfect Schools to Help Slow the Spread of the Flu. https://rems.ed.gov/Docs/How_to_Clean_and_Disinfect_Schools_to_help_Slow_the_Spread_of_the_Flu.pdf
39. American Academy of Pediatrics, American Public Health Association, National Resource Center for Health and Safety in Child Care and Early Education. Caring for Our Children: National Health and Safety Performance Standards Guidelines to Early Care and Education Programs. 4th edition. 2019. https://nrckids.org/files/CFOC4%20pdf-%20FINAL.pdf
40. Michigan State University Extension Food and Health: Clean, Sanitize, and Disinfect. https://www.canr.msu.edu/news/clean_sanitize_and_disinfect
41. International Products Corporation. Cleaning and Disinfecting…Why You Need to Do Both. https://www.ipcol.com/blog/cleaning-and-disinfecting
42. Iowa State University Extension and Outreach. Follow Proper Steps to Clean and Sanitize Surfaces during COVID-19. https://www.extension.iastate.edu/news/follow-proper-steps-clean-and-sanitize-surfaces-during-covid-19
43. Environmental Protection Agency. Guidance for Cleaning and Disinfecting: Public Spaces, Workplaces, Schools, and Homes. https://www.epa.gov/sites/production/files/2020-04/documents/316485-c_reopeningamerica_guidance_4.19_6pm.pdf
44. Zippia. 5 Reasons Why a Clean Workplace is Good for Business. https://www.zippia.com/employer/5-reasons-clean-workplace-good-business/
45. Centers for Medicare and Medicaid Services. HCAHPS: Patients' Perspectives of Care Survey. https://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/HospitalQualityInits/HospitalHCAHPS
46. Van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN, et al. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. New Engl J Med 2020; 382:1564-67. DOI:10.1056/NEJMc2004973
47. Centers for Disease Control and Prevention. Coronavirus Disease. Protect Yourself. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html
48. Centers for Disease Control and Prevention. CDC updates COVID-19 Transmission Webpage to Clarify Information about Types of Spread. https://www.cdc.gov/media/releases/2020/s0522-cdc-updates-covid-transmission.html
49. World Health Organization. Transmission of SARS-CoV-2: Implications for Infection Prevention Precautions. https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions
50. Ong SWX, Tan YK, Chia PY, Lee TH, Ng OT, Wong MSY, et al. Air, Surface Environmental, and Personal Protective Equipment Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) From a Symptomatic Patient. JAMA. Published online March 04, 2020. doi:10.1001/jama.2020.3227
51. Hu X, Xing Y, Ni W, et al. Environmental Contamination by SARS-CoV-2 of an Imported Case During Incubation Period. Sci Total Environ. 2020;742:140620. doi:10.1016/j.scitotenv.2020.140620
52. The Joint Commission. Preventing Coronavirus Transmission in the Hospital Setting. https://www.jointcommission.org/resources/news-and-multimedia/webinars/coronavirus-webinar-replays/preventing-coronavirus-transmission-in-the-hospital-setting/
53. American Federation of Teachers. COVID-19 Resources for Teachers and Others. https://www.aft.org/sites/default/files/covid19-tips-custodians032320.pdf
54. National Restaurant Association. National Restaurant Association Releases COVID-19 Specific Guidance for Operation Reopening. https://www.restaurant.org/news/pressroom/press-releases/national-restaurant-association-releases-covid-19
55. Minnesota Department of Health. Interim Guidance for Hotel Managers and Owners. https://www.health.state.mn.us/diseases/coronavirus/lodgingcleaning.pdf
56. Centers for Disease Control and Prevention. Coronavirus Disease 2019: Cleaning and Disinfecting Your Facility. https://www.cdc.gov/coronavirus/2019-ncov/community/disinfecting-building-facility.html
57. Centers for Disease Control and Prevention. Norovirus in Healthcare Facilities Fact Sheet. https://www.cdc.gov/hai/pdfs/norovirus/229110-ANoroCaseFactSheet508.pdf
58. Centers for Disease Control and Prevention. Best Practices for Environmental Cleaning in Healthcare Facilities: Resource-Limited Settings. https://www.cdc.gov/hai/pdfs/resource-limited/environmental-cleaning-RLS-H.pdf

59. California Department of Pesticide Registration. Sanitize Safely and Effectively: Bleach and Alternatives in Child Care Programs. https://cchp.ucsf.edu/sites/g/files/tkssra181/f/SanitizeSafely_En0909.pdf

60. Bolton SL, Kotwal G, Harrison MA, Law SE, Harriosn JA, 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) 1368-1377

61. Rigotti MA, Ferreira AM, Nogueria MCL, de Almeida MTG, Guerra OG, de Andrade D. Evaluation of Three Surface Friction Techniques for the Removal of Organic Matter. Texto contexto - enferm. [Internet]. 24(4): 1061-1070. Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0104-07072015000401061&lng=en. https://doi.org/10.1590/0104-0707201500003690014

62. National Association for The Education of Young Children. Cleaning, Sanitizing, and Disinfection Frequency Table. https://www.naeyc.org/sites/default/files/globally-shared/downloads/PDFs/accreditation/early-learning/clean_table.pdf

63. American Federation of Teachers. COVID-19 Resources for Custodians and Others. https://www.aft.org/sites/default/files/covid19-tips-custodians032320.pdf

64. University of California, San Francisco School of Nursing's Institute for Health and Aging, University of California, Berkley's Center for Environmental Research and Children's Health, Informed Green Solutions, California Department of Pesticide Registration. Green Cleaning, Sanitizing, and Disinfecting: a curriculum for early care and education. https://www.epa.gov/sites/production/files/documents/ece_curriculumfinal.pdf

65. Araújo PA, Lemos M, Mergulhão F, Melo L, Simões M. The Influence of Interfering Substances on the Antimicrobial Activity of Selected Quaternary Ammonium Compounds. Int J Food Sci. 2013;2013:237581. doi:10.1155/2013/237581

66. Chauret CP. Sanitization. In: Batt CA, Tortorello ML, eds. Encyclopedia of Food Microbiology. 2nd edition. Amsterdam: Elsevier; 2014; 360-364.

67. Dvorak G. Disinfection 101. The Center for Food Security and Public Health. Iowa StateUniversity. http://www.cfsph.iastate.edu/Disinfection/Assets/Disinfection101.pdf

68. San Francisco Department of the Environment. Safer Practices and Products for Disinfecting and Sanitizing Surfaces. https://sfenvironment.org/sites/default/files/fliers/files/sfe_th_safer_products_and_practices_for_disinfecting.pdf

69. Hollman B, Perkins M, Walsh D. Biofilms and Their Role in Pathogenesis. https://www.immunology.org/public-information/bitesized-immunology/pathogens-and-disease/biofilms-and-their-role-in

70. Rao V, Ghei R, Chambers Y. Biofilms Research—Implications to Biosafety and Public Health. App Biosafety 2005; 10(2): 83-90.

71. Rayner J, Veeh R, Flood J. Prevalence of Microbial Biofilms on Selected Fresh Produce and Household Surfaces. Int J Food Microbiol 2004; 95(1): 29-39.

72. Bédard E, Prévost M, Déziel E. Pseudomonas aeruginosa in Premise Plumbing of Large Buildings. Microbiologyopen. 2016;5(6):937-956. doi:10.1002/mbo3.391

73. Galie S, Garcia-Guitierrez, Miguelez EM, Villar CJ, Lombo F. Biofilms in the Food Industry: Health Aspects and Control Measures. Front Microbiol 2018; 9:898.

74. Environmental Protection Agency. Health Risks from Microbial Growth and Biofilms in Drinking Water Distribution Systems. https://www.epa.gov/sites/production/files/2015-09/documents/2007_05_18_disinfection_tcr_whitepaper_tcr_biofilms.pdf

75. Nerandzic MM, Fisher CW, Donskey CJ. Sorting through the Wealth of Options: Comparative Evaluation of Two Ultraviolet Disinfection Systems. PLoS One 2014; 9(9): e107444

76. Fu TY, Gent P, Kumar V. Efficacy, Efficiency and Safety Aspects of Hydrogen Peroxide Vapour and Aerosolized Hydrogen Peroxide Room Disinfection Systems. J Hosp Infect 2012; 80: 199-205.

77. Public Health Ontario. FAQ, COVID-19: Electrostatic Spray Disinfection Systems. https://www.publichealthontario.ca/-/media/documents/ncov/ipac/2020/07/faq-covid-19-electrostatic-sprayers.pdf?la=en

78. American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 2019 ASHRAE Handbook. Ultraviolet Air and Surface Treatment. https://www.ashrae.org/file%20library/technical%20resources/covid-19/si_a19_ch62uvairandsurfacetreatment.pdf

79. Environmental Protection Agency. Can I Use Fogging, Fumigation, or Electrostatic Spraying or Drones to Help Control COVID-19? https://www.epa.gov/coronavirus/can-i-use-fogging-fumigation-or-electrostatic-spraying-or-drones-help-control-covid-19

80. United States Army Public Health Center. Use of Electrostatic Sprayers (Foggers) with EPA-Registered Disinfectants in Response to COVID-19. https://www.ncoworldwide.army.mil/Portals/76/coronavirus/ref/Electrostatic-Sprayers.pdf

81. Emist®. FAQ. https://emist.com/faq/

82. Evaclean™. FAQ. https://evaclean.com/faq

83. Steris Life Sciences. VHP® Victory™ Biodecontamination Unit. Technical Data Sheet. https://www.sterislifesciences.com/en/products/equipment/vhp-sterilization-and-biodecontamination