Disinfection and the prevention of infectious disease

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This article reviews published literature to determine the role environmental disinfection plays in the prevention of infectious disease. Health benefits from disinfection have been established through studies of applications such as critical instrument sterilization, water treatment, and food production. Guidelines by the Centers for Disease Control and Prevention, the Food and Drug Administration, the Environmental Protection Agency, and the International Scientific Forum on Home Hygiene acknowledge the incidence of disease due to insufficient disinfection and that one of the means for prevention of disease is through proper disinfection. Studies conducted in day care centers, long-term care facilities, and laboratorie show that disinfectants containing a variety of active ingredients demonstrated efficacy against a broad spectrum of pathogens and interrupted microbial transmission and that the use of disinfectants results in public health benefits. (Am J Infect Control 2003;31:243-54.)

Although several studies have established the efficacy of disinfectants against microorganisms and the interruption of transmission through surface disinfection, controlled studies to establish the public health benefits of surface disinfection are difficult to conduct. “The intrinsic role of surfaces in dissemination of a nosocomial pathogen … is sometimes difficult to evaluate because of its intimate interaction with other mechanisms of transmission, such as the direct patient-to-patient contact or through the hands of hospital personnel.”1

Previously, infection control authorities believed that the environment played a little or no role in the transmission of infectious disease. “By 1970, the Centers for Disease Control [and Prevention] (CDC) and the American Hospital Association were advocating that hospitals discontinue routine environmental culturing, since rates of nosocomial infection had not been related to levels of general microbial contamination of air or environmental surfaces ....”2 Until 1987, hospital isolation precautions were focused on the diagnosis of infected patients.3 Subsequently, body substance isolation was proposed as a means to prevent nosocomial infections. This method failed to address contact transmission from dry skin or environmental sources.

Recently the role of the inanimate environment in disease transmission has been reconsidered. The CDC stated that contact transmission—direct from body surface to body surface or indirect transmission via contaminated inanimate objects—is one of the main routes of microorganism transmission.3,4 A survey of 369 infection control professionals revealed that 63% strongly or somewhat agreed that the inanimate environment plays a role in nosocomial transmission of organisms.4 This divergence of opinion among infection control professionals illustrates the need for evidence regarding the role of environmental surface disinfection in infection control.

The purpose of this review was to survey literature to establish whether the following occur: (1) disinfectants demonstrate efficacy against pathogens in laboratory and field settings; (2) environmental disinfection interrupts the transmission of microbial
pathogens; and (3) through the reduction and interruption of transmission of pathogens, environmental surface disinfection creates a public health benefit.

A search of numerous electronic databases, including PubMed, PubSCIENCE, MEDLINE, and AGRICOLA, was conducted. Search terms included but were not limited to “biocides,” “hygiene,” “germicide,” “disinfection,” “sanitization,” “hard surface,” “alcohol,” “iodine,” “povidone-iodine,” “quaternary ammonium compounds,” “phenolic,” “glutaraldehyde,” “peroxide,” “peracetic acid,” “antimicrobial,” “virucidal,” and “germicidal.” The electronic search was limited to literature from the mid-1960s through the beginning of 2001 because of the construct of the databases used in this study. Through review of the literature, publications preceding the mid-1960s were secondarily collected and reviewed. For the purposes of our review, benefit was defined as a reduction in disease, reduction in transmission of disease-causing organisms, or reduction of disease-causing organisms as measured in an in-use study. Literature describing benefits derived from topical products or topical test methods were excluded from the review. More than 400 pieces of literature were collected through the search.

PATHOGENIC ORGANISMS PERSIST IN THE ENVIRONMENT

The risk of infection from pathogenic microorganisms on environmental surfaces derives not only from their presence but also from their ability to survive on many surfaces. The persistence of pathogenic microorganisms has been established in studies of their survival on surfaces in institutional, commercial, and domestic settings. Mbtihi et al.48 showed that hepatitis A virus (HAV) can survive and be transferred 4 hours after drying, while Noskin et al.49 determined that vancomycin resistant enterococci (VRE), Enterococcus faecium, and E. faecalis could be recovered several days after inoculation on hospital surfaces. Escherichia coli, Klebsiella aerogenes, K pneumoniae, Pseudomonas aeruginosa, Salmonella species, S abony, and Staphylococcus aureus were recovered 4 hours after inoculation, whereas Salmonella and S aureus were recovered 24 hours after inoculation onto simulated kitchen surfaces by Scott and Bloomfield.47 Ward et al.50 reported rotavirus survival of up to 6 days in distilled water, and a review by Dobbbling51 stated that respiratory syncytial virus could survive on inanimate objects for prolonged periods. Separate studies by Boyce et al.52 and by Weber and Rutala53 found extensive environmental contamination in rooms of patients infected by methicillin-resistant S aureus (MRSA) and Enterococcus. An endemic Clostridium difficile strain contaminated the patient environment and was transmitted for 25 months in a hospital.1 This outbreak was linked to an index case that occurred 21 months before the outbreak. These studies demonstrate that environmental surfaces act as reservoirs of pathogenic microorganisms with the potential for transmission of infectious disease.

PATHOGENIC MICROORGANISMS IN THE ENVIRONMENT CAUSE INFECTIOUS DISEASE

Although the role of the inanimate environment in the transmission of disease has been questioned, contaminated medical instruments, water, laundry, food, and pets have all been associated with the transmission of disease.26,44,54-73 Boyce et al.52 found that the proportion of hospital surfaces contaminated with MRSA was greater in areas near patients infected with MRSA than near patients colonized by MRSA. Not only were positive cultures isolated from infected patients’ rooms and on gloves, gowns, and uniforms of nurses contacting the patients, but 42% of personnel with no direct patient contact contaminated their gloves by touching contaminated surfaces. The authors suggested that the inanimate environment may serve as a reservoir-disseminator of MRSA. In an earlier review, Boyce74 suggested a similar reservoir-disseminator mechanism for nosocomial VRE transmission.

Nosocomial infections have been linked to medical devices; public water supplies; food contact surfaces; laundry; dialysis machines; ice machines; carpets; ventilation systems; patient care items; walls; hydrotherapy equipment; contaminated medication; and bathroom, operating room, and patient room surfaces.5,53,75-80 Dobbbling51 related evidence of epidemic keratoconjunctivitis spread via tonometry equipment and towels. Foodborne nosocomial infections caused by Salmonella, Klebsiella, gram-negative bacteria, Enterobacter sakazakii, Leuconostoc mesenteroides, and P aeruginosa were transmitted through contaminated equipment such as blenders and breast pumps.79 Martin79 reported that salmonella, staphylococci, smallpox, hepatitis B virus (HBV), C difficile, tinea pedis, and nosocomial urinary tract infections were transmitted to patients and hospital personnel through contaminated laundry, whereas nosocomial pneumonia and P aeruginosa-associated endotoxemia were linked to nebulizers and inadequately disinfected dialysis machines.
Environmental contamination was the cause in each of 8 outbreaks of mycobacterial cardiac bypass infections.\textsuperscript{80} Investigation of an \textit{M fortuitum} outbreak among 6 cardiac and 2 noncardiac patients revealed contamination by the same phenotype/electrophoretic type in the municipal water supply, hospital ice machines, and an operating room water bath. Another outbreak (5 cases) was caused by a phenotype/electrophoretic type identical to a strain isolated from an operating room settling plate.

Environmental contamination is recognized as an infection source by federal and international agencies. The CDC\textsuperscript{75} “Draft Guideline for Environmental Infection Control in Healthcare Facilities, 2001” cited evidence of nosocomial infections associated with fomites. \textit{Aspergillosis}, \textit{P aeruginosa}, \textit{Acinetobacter} species, \textit{A baumanii}, \textit{Citrobacter freundii}, \textit{E cloacaee}, \textit{Legionella} species, \textit{Mycobacterium} species, adenovirus, \textit{C difficile}, and \textit{Pneumocystis carinii} contamination and/or infections have been linked to carpets, ventilation systems, arm boards, walls, moist surfaces, hydrotherapy equipment, patient care items, bathroom surfaces, and inadequately sterilized instruments. Another CDC\textsuperscript{76} report described bacterial, HBV, hepatitis C virus (HCV), and HIV infections transmitted to hemodialysis patients from environmental surfaces, inadequately disinfected supplies/equipment, inadequate dialyzer reprocessing, inadequate treatment of dialysis water, delayed cleaning of blood, health care workers, and contaminated medication.

Disease transmission through the domestic environment has been demonstrated in several studies.\textsuperscript{25,81,82} A 26-month study of children younger than 4 years infected with \textit{Salmonella} led Schutze et al\textsuperscript{83} to conclude that environmental contamination was a likely source of infection. Approximately 26\% of sites in homes sampled, such as vacuum bags, refrigerators, countertops, soil, and cutting boards, yielded isolates of the same serotype as those infecting the children. Another study\textsuperscript{84} of homes with infants infected with \textit{Salmonella}, which showed contamination by identical serotype/phage types on kitchen sinks and surfaces as well as in human and animal contacts, led the authors to conclude that infant caretakers may spread the organism in the home, causing cogenic infections. An epidemiologic review by Scott\textsuperscript{85} emphasized the role of cross-contamination in the spread of disease in the home. Of \textit{Salmonella} and \textit{Campylobacter} infections reported in England and Wales, 80\% were acquired in the home. Reports of \textit{E coli} \textit{0157} “hamburger disease” in New Jersey revealed that 80\% of cases were related to hamburger eaten at home. The author reported evidence of \textit{Salmonella}, \textit{S aureus}, and viral cross-contamination via rags, sponges, kitchen surfaces, pets, and family members.

A review by the International Scientific Forum on Home Hygiene (IFH) presented evidence that more than 50\% of foodborne infection outbreaks in the Netherlands, Germany, and Spain occur in the home, that \textit{Shigella sonnei} spread among household contacts of infected children, and that bacteria and fungi caused by poor housing conditions were related to the incidence of respiratory allergies.\textsuperscript{86} Larson and Gomez-Duarte\textsuperscript{86a} surveyed 398 households and concluded that a potential link between laundry and the risk of disease transmission in homes existed when the subjects used commercial laundries or failed to use bleach when washing laundry. Sanborn\textsuperscript{73} linked \textit{S typhimurium} and \textit{S chester} outbreaks at a naval station to suspect turkey and a cutting board, respectively.

**ENVIRONMENTAL SURFACES FACILITATE THE TRANSMISSION OF PATHOGENS**

The potential for infectious disease transmission from the environment is further demonstrated by clinical and laboratory studies showing the transmission of microorganisms from person-to-person and via inanimate surfaces, water, hands, food, and household surfaces.\textsuperscript{43,47,48,55-63,87-103} Autio et al\textsuperscript{104} showed transmission of \textit{S aureus}, \textit{Actinomyces} species, \textit{Bacteroides} species, \textit{Haemophilus} species, \textit{Streptococcus mutans}, and enterococci from patients’ mouths to clinic surfaces by dental operators. \textit{E aerogenes}, used as an indicator organism by Chen et al,\textsuperscript{105} was transferred from food, hands, cutting boards, and water spigots at rates ranging from 0.0005\% to 100\%, depending on the contact surfaces and the efficiency of handwashing. De Wit et al\textsuperscript{106} showed that 60\% to 100\% of tested sites in domestic kitchens were contaminated by \textit{E coli} from inoculated chickens during food preparation. Humphrey and coworkers\textsuperscript{107} found that \textit{S enteritidis} from inoculated eggs contaminated hands and work surfaces 40 cm from food preparation sites, although visible splashing was not apparent. In separate reviews, Doyle et al\textsuperscript{108,109} identified domestic kitchens as the most crucial area in addressing control of pathogen transmission. An epidemiologic study by Kundsin\textsuperscript{87} implicated hospitals as the initial source of staphylococcal disease in a student community. The author concluded that the only experience common to the affected families was hospitalization for childbirth and that housekeep-
ing and communal laundries perpetuated the status of carriers and the incidence of infection.

ENVIRONMENTAL DISINFECTION REDUCES PATHOGENIC MICROORGANISMS

Quaternary ammonium (quat), iodine, alcohol, aldehyde, organic acid, peroxide, and halogenated compounds have proven effective against a broad spectrum of microorganisms. The disinfection of water, medical devices, food products, fabric/laundry, and hard surfaces in domestic as well as institutional settings has been detailed in numerous in vitro and field studies. Likewise, the improper use of disinfectants and the limited spectrum of certain germicides have been detailed in various studies. The nature of the surface to be disinfected may influence the degree of disinfection that can be achieved. The germicide-surfactant system, germicide concentration, and contact time also can significantly affect antimicrobial activity. Vesley and Michaelsen showed that phenolic and quat disinfectants killed bacteria on the hospital floor but were not significantly better than detergent and hot water. In contrast, a 6-month hospital study by Kundsin and Walter showed that use of a phenolic germicide on floors decreased the number of microorganisms in the environment and maintained low levels of organisms in patient and operating rooms. Studies in commercial settings showed the reduction of fecal bacteria on drinking glasses by quat disinfection and removal of Listeria monocytogenes biofilm from food processing surfaces (eg, stainless steel and polyester/polyurethane) by detergent/germicide combinations such as enzyme cleaner plus iodophor, quat, acid anionic or chlorine sanitizer and alkaline cleaner plus quat sanitizer. Similarly, domestic site studies showed reductions in the number of microbially contaminated sites through quat or hypochlorite disinfection.

DISINFECTANTS INTERRUPT THE TRANSMISSION OF PATHOGENIC MICROORGANISMS

The interruption of microorganism transmission, vital to disease prevention, has been established through laboratory research. Sattar et al determined that chlorine, phenolic, and phenol/ethanol products prevented rotavirus transmission from stainless steel disks to fingerpads and that rhinovirus transmission could be prevented by phenol/ethanol and chlorine. In a subsequent study, Sattar and Springthorpe reported that a phenol/ethanol spray also interrupted the transmission of poliovirus. Disinfection of cutting boards and knives with quat used in conjunction with antiseptic hand gel by food preparers reduced the transmission of E. coli to vegetables prepared on previously contaminated cutting boards. Pao and Davis tested orange juice contamination to determine that sanitizing juice extractors with quat resulted in a 1.5-log/mL reduction of total microorganism counts and 1.4-log/mL reduction of yeast and mold counts.

Field studies also have demonstrated the interruption of microbial transmission through surface disinfection. A hypochlorite cleanser reduced bacterial transmission from food-contaminated surfaces more effectively than cleansers normally used in homes. Antimicrobial-treated sponges used in domestic kitchens reduced the transmission of bacteria to hands and kitchen surfaces by 2 to 3 log, compared with untreated sponges or cloths. Quat-saturated cloths interrupted bacterial transmission in 2 studies by Scott and Bloomfield. In-use studies at a university kitchen showed that quat-treated cloths reduced the frequency of food preparation surface contamination by K. pneumoniae, E. cloacae, Pseudomonas species, P. fluorescens, A. calcoaceticus, and Achromobacter species. The percentage of sites contaminated by 2 log bacteria or greater was as high as 100% when detergent-treated cloths were used, whereas a maximum of 17% of sites were contaminated when quat-treated cloths were used. In addition, the occurrence of enterobacteria and pseudomonads was consistently less on treated cloths and food preparation surfaces cleaned with treated cloths.

DISINFECTANTS PROVIDE AN INCREMENTAL PUBLIC HEALTH BENEFIT

Field and laboratory studies have repeatedly shown the importance of environmental disinfection as part of an integrated approach to infection control. In 2 laboratory trials, Ward et al demonstrated the prevention of rotavirus infection in human subjects via contaminated surfaces by disinfection of the surfaces with a phenolic/ethanol spray. Infection occurred in 63% to 100% of volunteers who licked rotavirus-contaminated fingers/surfaces, but no volunteers became infected after licking contaminated surfaces that had been disinfected with the phenolic/ethanol spray. Despite growing evidence, some studies have cast doubt on the need for surface dis-
infection, showing health benefits through improved handwashing, barrier protection, natural intervention, or cleaning without disinfection. A 3-year hospital study by Sharbaugh showed that an infection control program that included daily patient surveillance, isolation of infected patients, and education of staff significantly reduced the nosocomial infection rate. Many reports, however, have questioned the efficacy of infection control programs that discount environmental surface disinfection by demonstrating the link between environmental disinfection and reduced infection. Appropriate disinfection and sterilization of medical devices have long been accepted as necessary infection control practices and are supported by field studies as well.

Health benefits from environmental surface disinfection have been demonstrated in several studies. Krilov et al demonstrated that significant reductions in total illnesses, respiratory illnesses, doctor visits, antibiotic courses, and days absent from school were achieved in a specialized preschool when environmental disinfection with quat, and phenolic- and acid-based disinfectant/cleaners were used as part of an infection control intervention. Though isolation, hygiene monitoring, and disinfectant hand dips controlled S. sonnei dysentery outbreaks in primary and secondary schools, Thomas and Tillett found that environmental disinfection with phenolic was needed to halt outbreaks in day care facilities. Sanborn reported an unspecified illness affecting students and instructors at a naval underwater swimmers school that was controlled when a mouthpiece, identified as the transmission route, was cleaned and sanitized. Hiipakka and Buffington linked upper respiratory disease and allergy symptoms among workers at a communications center to airborne fungal spores found in a poorly maintained heating and cooling system. They reported anecdotal information from physicians, noting a qualitative reduction in patient visits after maintenance and cleaning of the system (including washing with bleach solution) that reduced contamination in the building. Although environmental disinfection was not addressed, Uhari and Mottonen demonstrated the benefit of an integrated approach to infection control. The incidence of infections and absenteeism due to infection among children and staff at day care centers was significantly reduced through an infection control program that emphasized intensified handwashing, hand disinfection with an alcohol product, regular toy washing or rotation, attention to diaper changing practices, and monitoring and reinforcing compliance with the program.

Health benefits from disinfection of the domestic environment have been reported as well. Rose et al suggested that a significant reduction in the risk of infection by fecal coliforms could be achieved by the use of hypochlorite disinfectants on domestic kitchen surfaces and by educating consumers on the proper use of disinfectants. Although some have questioned the benefits of widespread disinfectant use in regard to possible antibiotic resistance, Rutala et al reported that the antibiotic resistance of pathogens isolated from homes where antimicrobials were used at least weekly were less than those reported for clinical isolates. Likewise, Addison and coworkers compared isolates from 40 homes (50% used antimicrobial products, 50% did not) to clinical isolates to determine that no association between antimicrobial products and increased antibiotic resistance existed. Although many studies have shown transmission of pathogens through laundry, few controlled studies have been conducted to measure the health benefits derived from disinfection of laundry. An 8-week study showed that washing diapers with hypochlorite reduced bacteria and that irritation scores were less among babies who wore treated diapers than those in the placebo group. In addition, Larson and Gomez-Duarte showed a significant link between disease transmission through laundry and failure to use bleach.

A review of chlorine use in food plants revealed that chlorination prevented or reduced the accumulation of bioslime on surfaces, prevented fermentation and decay odors, reduced bacterial counts on food, reduced canned food spoilage as much as 33-fold when used in cooling water, and effected a decreased accident rate from falls caused by bacterial slime. Reduction of soft drink plant yeast contamination, decreased bacterial contamination in canned food, reduced bacterial counts in milk, and the elimination of Campylobacter jejuni colonization in broiler chickens are among the benefits proven in other studies of various commercial settings.

**DISCUSSION**

The potential public health benefits of environmental disinfection are recognized by infection control experts and government agencies, including the CDC and the Food and Drug Administration (FDA). Both agencies recommended addressing infection
control or prevention as a multilayered process, including barrier precautions, personal hygiene, environmental monitoring, facility maintenance, medical device sterilization/disinfection, and environmental disinfection.²,⁷,⁵,⁷,⁶,¹⁹⁰,²¹⁶,²¹⁷ According to a CDC draft guideline, environmental surface disinfection is supported by epidemiologic, clinical, or experimental studies and is important to the control of MRSA, vancomycin intermediate resistant S. aureus, and VRE transmission.⁷⁵ In a review of nosocomial gastrointestinal infections, Cookson⁵ concluded, “Inadequate handwashing and inadequate sterilization or disinfection of patient care equipment increases the risk of nosocomial gastroenteritis.” Surfaces more frequently touched by hands, according to the author, should be cleaned/disinfected more often. According to Rutala,²¹⁸ noncritical items (eg, bedpans and blood pressure cuffs) that pose little risk of transmitting infectious agents to patients could contribute to transmission via health care workers’ hands or contact with other fomites. CDC guidelines to prevent M. tuberculosis and HIV transmission recommend sterilization or disinfection of patient care items and environmental surfaces with Environmental Protection Agency registered disinfectants.²¹⁹,²²⁰ Arduino et al²²¹ reported that incorrect implementation of infection control practices, including the failure to disinfect equipment properly, may have led to dialysis-associated HBV and HCV outbreaks and that the prevention of HBV transmission through separation practices is linked to other infection control practices, including cleaning and disinfection. Weber and Rutala⁶ determined that “rigorous adherence to Standard Precautions, Contact Precautions for patients with infectious diarrhea, disinfection of environmental surfaces, and appropriate disinfection of endoscopes are adequate to prevent nosocomial acquisition of¹ pathogens such as E. coli 0157:H7, Helicobacter pylori, HCV, and Cryptosporidium.⁵ FDA dairy and produce industry guidelines recommended sanitization of food contact surfaces with heat or antimicrobial chemicals as well as worker and facility hygiene to prevent disease transmission through contaminated produce or milk products.¹⁹⁰,²¹⁶ This integrated approach to safety in food production was supported by an FDA report on retail food facilities and by the Food Safety and Inspection Service.²¹⁷,²²²

Disinfection in the domestic environment also can contribute to infection control. Rubino stated, “When followed, simple hygienic practices such as handwashing and surface disinfection along with proper food handling techniques can have a positive impact on the health of families and individuals in nonmedical settings like homes, day care and long term care facilities.”²²³ Kundsin⁸⁷ concluded that “the use of germicidal detergents is essential for area disinfection and laundry use in homes where staphylococcal disease persists.” The IFH stressed the need for surface disinfection in the domestic environment, addressing the pathogens encountered as well as risk assessment through hazard analysis critical control point principles.⁸⁶,²²⁴-²²⁶ Highly contaminated reservoirs (eg, toilet bowls) pose low risk of pathogen transmission due to their low hand/food contact frequency and can be effectively disinfected with sustained-action disinfectants to prevent rapid regrowth of organisms. Reservoir-dissemminators with high contamination and intermediate hand contact (eg, wet mops) should be treated by hot machine washing, boiling, or chemical disinfection. Surfaces with high hand/food contact frequency (eg, tap handles, cooking utensils) though not as frequently contaminated by significant pathogen levels pose a constant risk of transmission. IFH recommended “hygienic cleaning” of these surfaces after contamination and before use to reduce the number of microorganisms present as well as regular decontamination with a cleaner or disinfectant. In the case of known risks, such as MRSA and bodily fluid contamination, the authors considered regular disinfection of carpets, walls, and furniture essential.

CONCLUSIONS

Although there is insufficient evidence concerning the role of the environment in regard to transmission of infectious disease, the CDC, FDA, and IFH recognize the health benefits achieved through proper environmental disinfection. In addition, the published literature provides evidence that the environment can act as a reservoir and disseminator for infection and that pathogens persist and grow in the environment. These studies also demonstrate that environmental disinfection reduces the incidence of infection, creating a public health benefit by reducing the number of pathogenic microorganisms on surfaces. Several studies have shown a public health benefit derived from environmental surface disinfection as part of an infection control program. There remains, however, a need for additional controlled studies directly demonstrating the role environmental surface disinfection plays in the prevention of disease.
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