THE ROLE OF THE HOME ENVIRONMENT IN THE TRANSMISSION OF INFECTIOUS DISEASES

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ABSTRACT: The purpose of this paper is to examine current health care literature (1980–2000) regarding the microbiology of the home environment, to summarize evidence of transmission within the home, and to assess effectiveness of cleaning practices and products. The home environment, particularly the kitchen and bathroom, serves as a reservoir of large numbers of microorganisms, particularly *Enterobacteriacae,* and infectious disease transmission has been demonstrated to occur in 6–60% of households in which one member is ill. Current food preparation and cleaning practices provide multiple opportunities for intra-household member spread. Routine cleaning is often sufficient, but in cases of household infection, may not adequately reduce environmental contamination. The effectiveness of disinfectants varies considerably and depends on how they are used as well as their intrinsic efficacy. The behavioral aspects of infection prevention in the home (e.g., foodhandling and cleaning practices) warrant increased public attention and education.

KEY WORDS: hygiene; foodborne illness; disinfection.

INTRODUCTION

During the past few decades, research on the epidemiology of infections has focused on hospitals, day care facilities, and schools, but little attention has been paid to the home. Recent events, including widespread media coverage of foodborne outbreaks and increased marketing of a variety of antibacterial products for personal hygiene and hard surface disinfection, have resulted in a resurgence of interest and public concern about hygiene and cleanliness in the home.[1] Hygiene refers to conditions or practices by which people maintain or promote health by keeping them and their surroundings clean. The question that persists is: How do house-

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hold cleanliness and personal hygiene affect the risk of infectious disease transmission? The purpose of this paper is to examine current health care literature (1980–2000) regarding the microbiology of the home environment, to summarize evidence of transmission within the home, and to assess the effectiveness of cleaning and disinfecting practices and products in controlling transmission. It is our intention that this information will provide perspective regarding microbial risks in the home environment and a basis for developing more appropriate strategies for home hygiene based on what has been shown to effectively reduce infection risk rather than on fear or speculation.

METHODS

Medline, the New York Public Library's Health Center Resources Database, and Columbia University's on-line catalogue were searched for research articles related to home hygiene during the years 1980–2000. Key words included: home hygiene, domestic hygiene, food hygiene, and cross-contamination. Open searches, using the same key words, also were conducted on Internet search engines, including Yahoo and Excite. The search was restricted to developed countries, and only to articles in English or with English abstracts. Excluded were articles pertaining to assisted living facilities, nursing homes, schools, and hospitals.

THE MICROBIOLOGY OF THE HOME

Studies have shown that areas in the home, particularly the kitchen, bathroom and possibly the laundry, can serve as reservoirs for microbial colonization. Dirty dish rags, cloths and wet sponges have been shown to spread microbial contamination throughout the kitchen.[2-6] Changes in laundering processes have also made transmission of disease via the washing machine a possibility.[2-4,7]

Despite the fact that globalization of food distribution and international travel can transport microorganisms around the world in a matter of hours, in England, Wales, and the Netherlands 80% of salmonella and campylobacter infections are acquired in the home.[8-9] Further, social and demographic changes have increasingly led to the care of certain "at risk" groups within the home, not only neonates and the elderly, but other per-

sons with compromised immune systems as well. In the United States, 20% of the population is estimated to fall into these categories.[10]

Kitchen

In one of the early studies of the domestic kitchen, De Wit et al. used an indicator organism, *Escherichia coli* K12, to determine the extent of cross contamination from frozen chickens. Cross-contamination occurred in a large proportion of those kitchens surveyed and in many cases the indicator organism persisted even after washing and rinsing of the kitchen surfaces.[11] Scott et al. measured numbers and types of bacteria at various sites in more than 200 English homes. The highest counts were isolated from wet areas such as U-tubes, kitchen sink, draining board, cleaning cloths and mops, and dishcloths, and pseudomonads were isolated in over 90% of the homes.[2] In a subsequent study Enterobacteriaceae were detected in 69% of the homes surveyed.[4]

Contaminated dishcloths and other cleaning utensils also may act both as reservoirs and disseminators of pathogenic organisms.[2,6] Although drying reduces the number of organisms on clean, laminate surfaces, large numbers of bacteria have been recovered from contaminated surfaces and both clean and soiled cloths as much as 24 to 48 hours after drying.[3] Thus, drying alone is not sufficient to eliminate contaminating organisms. Further, finger contact with contaminated surfaces and cloths resulted in the transfer of large numbers of organisms to the hands.[3] Cloths used for cleaning and/or drying kitchen utensils may transfer contamination throughout the kitchen especially when the same cloth is used for multiple purposes. In some households, the same cloth is used to wash cooking and eating cutlery and then to wipe down the drain board and counters.[4] Since plain soap does not necessarily kill microorganisms, soap and water cleaning of contaminated surfaces and hands may actually spread microbial contamination in the environment.[12]

Speirs et al. sampled 46 kitchens including the following key sites: worktop, chopping board, draining board, sinks, water tap handles, insides of rubber gloves, refrigerator shelf, and dish washing cloth. They isolated various enterobacteria including *Enterobacter cloacae, Klebsiella pneumoniae* and *Escherichia coli.* In addition, *Bacillus subtilis, Pseudomonas aeruginosa,* staphylococcal and micrococcal species were isolated. The highest counts were found in the wet areas around the sink and the cloths used for wiping and/or drying kitchen surfaces and appliances.[4] In another study, the sink

drain was the most contaminated site, harboring 5.9–6.2 $\log_{10}$ (>99.999% reduction) of microorganisms.[13]

Enriquez et al. studied 140 cellulose sponges and 56 cotton dishcloths from households in four U.S. cities and isolated 23 and 13 different bacterial species, respectively. Most commonly isolated were pseudomonads, but salmonella was also isolated in 15.4% of the sponges and 13.8% of the cloths. Other commonly isolated gram-negative bacteria included species of enterobacter, serratia, and klebsiella.[5] Salmonella can be transferred to sponges and towels and survive there, resulting in contamination of other areas of the kitchen.[6]

Specific risk factors for domestic outbreaks of foodborne pathogens include improper food storage, undercooking, and cross-contamination, which may be responsible for 30% of salmonella outbreaks in the home.[14] During food preparation salmonella can be spread throughout the workspace by such actions as whisking batter; bacteria have been found one meter away from each side of the site. Powered cooking equipment like the electric blender can also lead to widespread distribution, up to a 3–4 meter radius around the site. In experiments with chickens contaminated with salmonella and campylobacter, a variety of sites in the kitchen, including cutting boards, sinks, handles, faucets, and work areas tested positive after the usual meal preparation procedures were used.[14,15]

In a case control study of food preparation, salmonella was isolated from dishcloths not only in case homes in which salmonella infection persisted but also in control homes. Salmonella from dried foods that have contact with moist foods, such as fruit or meat, can transfer within 5 seconds to the wet foods. Within a few hours potentially infective doses can be reached as the bacteria multiply under moist conditions.[14]

Temperature of the water used for "washing up" can also influence microbial survival. For dishes washed by hand, the dishwashing water temperature often is below 50°C at the start and will continue to drop during the dishwashing process. This temperature is not high enough to destroy most organisms. A few studies have demonstrated that when sterile cookware was washed in water inoculated with salmonella or campylobacter, transfer of the pathogen to the dishes occurred.[6,14]

Bathroom

Like the kitchen, the bathroom can be a reservoir of large numbers of microorganisms, particularly in wet areas. In homes in which a family member had salmonellosis, four of six toilets tested positive for salmonella under the recess of the toilet bowl rim, an area difficult to reach with

domestic toilet cleaners. In one toilet, salmonella was still present four weeks after the infection, despite the use of cleansers. After artificial contamination of the toilet, flushing led to contamination of the toilet seat and lid, and in one instance salmonella was isolated from an air sample taken after flushing.[16]

There is limited evidence of antibiotic-resistant organisms being present in the home environment. In both the bathrooms and the kitchens of 25 randomly selected homes in North Carolina, four of 58 enterococcal isolates were vancomycin-resistant and one of 17 *Escherichia coli* isolates was ampicillin-resistant. Klebsiella and enterobacter strains had the highest frequency of resistance to ampicillin, and pseudomonal strains were uniformly susceptible to 4 of the 10 tested antibiotics. Rutala et al. concluded that in comparison to organisms causing clinical infections in hospitals, those isolated in homes are less likely to be antimicrobial resistant.[13]

Laundry

While the kitchen and the bathroom are logical places for the introduction and transmission of pathogens, one area of the home that may seem less likely to allow the survival and dissemination of microorganisms is the washing machine. Various common laundering practices allow bacteria at varying levels to remain in laundered items. Standard detergent washing and rinsing practices do not always produce large reductions in microbial contamination. Damp cloths that had been washed in detergent and then stored at room temperature over a 24-hour period showed an increase in contamination indicative of the survival and multiplication of microbes. Drying was the most reliable method of decontamination when carried out at a temperature of 80 °C for 2 hours.[17]

In a study to evaluate the survival of bacteria and enteric viruses during washing and drying as performed in U.S. homes, sterile cotton swabs were inoculated with *Mycobacterium fortuitum, Salmonella typhimurium, Staphylococcus aureus, E. coli,* rotavirus SA1, hepatitis A virus, and adenovirus type 40. The contaminated swabs were then added to sterile cotton underwear, T-shirts, and a pillowcase that contained an organic load typical of homes. All test organisms survived the wash process; wash and rinse cycles alone reduced enteric viruses by 87–98% and bacteria by >99%. During the drying cycle, viruses were more resistant to killing than bacteria. Drying was most effective, in decreasing order, for *S. typhimurium, S. aureus,* and *M. fortuitum.* Detectable levels of *E. coli* were not found after drying. Together, washing and drying reduced all bacteria by at least 99.99%, adenovirus type 40 by 99.91%, hepatitis A virus by 99.8% and

rotavirus by 98.6%. The test organisms contaminated other laundry in the machine, as well as the washing machine itself, which led to the contamination of subsequent loads of laundry.[18]

Using the Petrocci and Clarke (1969) method,[19] several powder and liquid laundry detergents that are now on the market were tested for activity against *S. aureus* and *K. pneumoniae* from wash water and fabric (Table 1; Personal Communication, J. Kain, Procter and Gamble, Cincinnati, OH, August 2001) Sanitizing powder detergents reduced *S. aureus* and *K. pneumoniae* in the laundry fabric by >99%. All other laundry detergents were less active.

TABLE 1

Summary of Current Laundry Products Antimicrobial Performance
(USEPA Accepted Petrocci and Clarke Laundry Sanitizer Method[19])

Product[1]	Staphylococcus Aureus		Klebsiella Pneumoniae	
	Wash Water % Reduction[2]	Fabric % Reduction	Wash Water % Reduction	Fabric % Reduction
Powders				
Sanitizing Detergent with Oxygen Bleach	99.99	99.98	99.93	99.99
Non-sanitizing Detergent with Oxygen Bleach[3]	64.36	20.67	86.19	66.37
Non-sanitizing Detergent (without Oxygen Bleach)	62.30	20.67	76.66	65.27
Liquids				
Non-sanitizing Detergent with Bleach Alternative	83.33	81.30	74.72	90.05
Non-sanitizing Detergent with Bleach Alternative	42.22	30.49	75.00	92.17

[1]Test products were all commercially available detergents with built in oxygen-based bleach systems. All products were purchased at local grocery stores in the Cincinnati Ohio area during 1998. No additional laundry additives, such as chlorine bleach, were tested either alone or in conjunction with detergents.
[2]Percent Reduction (% Reduction) refers to the calculated reduction in bacteria relative to a water + 0.5% polysorbate 80 baseline control. Polysorbate 80 was added to the water as a non-toxic surfactant control to improve the relevancy of organism removal characteristics of the control relative to the high surfactancy test treatments.
[3]A "sanitizing detergent with oxygen bleach" is one that meets US EPA criteria for sanitization claims and a "non-sanitizing detergent with bleach" is a detergent that has a bleaching ingredient that may also have antimicrobial properties but not at the concentration and in the formulation matrix of this detergent and, therefore, does not meet US EPA's criteria for sanitization claims. (Unpublished data. D. J. Kain, Principal Scientist, The Procter and Gamble Company, Cincinnati, OH, 9/01).

TRANSMISSION OF INFECTIONS IN THE HOME

Although there are large numbers of microorganisms present in the home, it does not necessarily follow that this will result in infectious disease transmission. In this section, routes of transmission and evidence of actual transmission in the home are reviewed.

Routes of Transmission

Bacteria, viruses, and fungi exist throughout our environment and can be transmitted to individuals through a variety of methods. Direct contact includes person-to-person spread or contact with blood and other body fluids, such as occurs in fecal-oral spread. Endogenous infection occurs when an individual contaminates one region of the body with microbial flora from another area. Other modes of transmission include contact with droplets and airborne spread by droplet nuclei.[20] Indirect contact is transmission through a contaminated intermediate object. Usually, the intermediary is the hands. For example, a parent who changes a diaper of a baby infected with shigella and proceeds to prepare a meal for the family without handwashing could transmit the pathogen to the entire family. Another example of indirect transmission is use of a cutting board to prepare raw chicken and then to slice fresh fruits and vegetables. Common source transmission is often responsible for *E. coli* O157:H7 outbreaks caused by consuming undercooked, contaminated meat.

Although we did not find any data published between 1980–2000 regarding viral contamination in the home, viruses are a major cause of common illnesses and can survive in the home environment. Worldwide, respiratory syncytial virus (RSV) is the primary cause of childhood viral respiratory infection.[20] RSV is transmitted via inanimate objects and direct contact with infected persons.[21] The virus is capable of surviving for a number of hours on inanimate objects and surfaces, providing ample opportunities to contaminate the hands of caregivers. Contaminated hands can indirectly spread the virus to others in the home, including the caregivers if they touch their eyes or nose without handwashing. While barrier precautions have proven effective in lowering the rates of transmission in a hospital setting, Goldmann asserts that it is entirely probable that careful handwashing after contact with infected infants would have been equally effective.[20]

Perhaps more widespread than RSV among people of all ages is the common cold. Children can expect to average 4 to 8, and adults, three to five episodes per year. There are more than 100 serologic types of rhi-

novirus, and contracting one type provides no immunity against another.[20] Influenza is spread via airborne nuclei droplets, but the most likely route of transmission of rhinovirus is contaminated hands.[22]

In the United States, the second most common community infection is gastroenteritis. An important cause of gastroenteritis is rotavirus, which is transmitted by the fecal-oral route and possibly through respiratory spread and contaminated hands and surfaces. Rotavirus has been implicated in outbreaks in hospitals, daycare centers, schools, and nursing homes. There is the potential for transmission of rotavirus within the home since it is present on hands, various surfaces and objects.[23] Other gastrointestinal pathogens, such as hepatitits A virus, parvovirus, adenovirus, and other enteroviruses follow a similar transmission pattern as rotavirus.[24,25] Hepatitis A, for example, has been implicated in numerous foodborne outbreaks and in various settings such as hospitals, day-care centers, and schools.[26] It is commonly spread via contaminated food and water. In laboratory experiments, Bidawid et. al simulated cross contamination of fresh lettuce with hepatitis A from fingers of adult volunteers.[27]

Potential Transmission

The potential for cross-contamination in the kitchen has already been briefly discussed. When not properly cleaned and/or disinfected, countertops, cutting boards, and other kitchen surfaces provide an optimum milieu for survival of microbes.[11] According to the Centers for Disease Control and Prevention, between 1983–1992 the primary food preparation practices contributing to foodborne disease were improper storage temperatures and poor personal hygiene of the food handler,[28] and these faulty practices are common in the home. In a study of kitchens in 40 Australian homes, daily practices were videotaped over the course of 1 to 2 weeks. The most common unhygienic practices viewed included infrequent and poor handwashing technique, lack of handwashing prior to preparing meals, pets in the kitchen, hand contact with the face, mouth, nose, and hair during food preparation, and an all-purpose towel for hands and dishes. In addition to these lapses in hygiene, deli meat was left outside the refrigerator and uncovered for 2 hours; a dish towel that had fallen to the floor and been stepped on was subsequently used to wipe off the counter; and a dishtowel was also used to cover cooked meat and thereby cross-contaminate it.[29] Practices caught on film in American homes did not differ substantially from their Australian counterparts. The same towel used to wipe up raw meat juice was then used to dry washed hands. In only 1 in 4 homes were raw meat and seafood properly stored on the

bottom shelf of the refrigerator so as to prevent dripping liquids from contaminating other foods; 35% of those preparing meatloaf undercooked it, 42% undercooked the chicken, and 17% did not completely cook the fish.[30]

Further, the American Society for Microbiology conducted a telephone survey of more than 7,000 people in the United States. Eighty-one percent of respondents claimed to wash their hands prior to handling or eating food. After petting an animal, 48% reported that they do not wash their hands, nor do 33% after coughing or sneezing, or 22% after handling money.[31] In a telephone survey conducted in Australian homes, 40% of respondents allowed raw meat to thaw at room temperature, 85% cooled cooked food to room temperature prior to refrigeration, and close to 70% did not know the right temperature for refrigeration of perishables.[32] In addition, 1 in 4 respondents did not recognize handwashing as important in the reduction of cross-contamination and foodborne illness.[32]

Based on these findings, it is likely that everyday activities in the home will result in microbial spread. A study of the transfer of Serratia rubidea and the virus PRD-1 from common household articles to the hands confirmed that infection is possible from daily contact with contaminated objects.[33] Transmission of the bacterium and the virus were demonstrated on telephone receivers, faucet handles, and sponges, and transfer to hands was highest from hard, nonporous surfaces.[34] If a small amount of stool from a person infected with salmonella were transferred from the individual's contaminated hands to the receiver, the next user could pick up $>10^5$ colony-forming units (CFU) on his/her fingertips, and could transfer $>3.5 \times 10^4$ CFU, or 35% of the total, to the mouth, a dose sufficient to cause disease.[33] After wringing out a household sponge, 10^5–10^6 bacteria and viruses were found on the hands of test subjects.[34]

In another study, bacteriophage [phis] X174 was applied to door handles and the hands of volunteers. Test persons touched the handles and shook hands with the volunteers. The hands of the test persons were then sampled for the virus. Both skin surfaces and contaminated door handles were efficient sources for transfer. Up to 14 people became contaminated after touching the same door handle, and subsequent transmission was traced to six additional people from these primary contacts.[35]

Evidence of Transmission in Homes

Each year 76 million Americans develop food poisoning,[29] and about 20% of reported foodborne illnesses occur in the home.[30] Ninety percent of salmonella infections are thought to be associated with the

home environment.[28] In the UK, cross-contamination has been implicated in about 6% of foodborne outbreaks within the home, while poor hand hygiene is responsible for about 4%.[36] In addition, it has been estimated that cross-contamination in the home contributed to 14% of salmonellosis outbreaks.[36]

In a household in which one person has been sick with salmonella, it has been estimated that there is a 60% chance that at least one other member of the household will also be infected.[8] Both hands and inanimate surfaces are responsible for the cross-contamination that leads to secondary infections in the home. Other bacteria and viruses transmitted via the fecal-oral route most likely spread throughout the home in the same manner.

In another study, the home environment was implicated in the spread of salmonellosis among children under four years of age.[37] Isolates were obtained from children infected with salmonella and samples were taken from multiple locations in the home. Pulsed-field gel electrophoresis patterns showed identical serotypes from the index case and the home environment. Isolates which exhibited identical serotypes were found in locations such as vacuum cleaner, dirt surrounding front door, and refrigerator shelf as well as in household members and pet animals. Children can carry the infections acquired in nursery schools or play groups into the home, where up to 50% of household members may become infected via cross-contamination.[8]

In a study of an outbreak of diarrhea caused by *E. coli* O157 in New Jersey, 80% of contaminated hamburgers were consumed in the home.[38] While the home may not have been the primary source of contamination, proper cooking may have prevented the spread of the organism.

The use of communal laundry facilities also has been correlated with the transmission of microbes and higher rates of infectious disease symptoms among household members.[39] In this study, a variety of home hygiene practices in 398 households were examined, including personal hygiene, food handling and general cleaning and laundry practices. In a logistic regression analysis of these potential risk factors only communal laundry practices ($p = 0.009$) and lack of bleach ($p = 0.04$) were significantly associated with increased risk of infectious illnesses among household members.

In households in which one member had a primary infection of *Campylobacter jejuni,* 15% of household contacts were symptomatic during the same time period. While most instances were attributed to a common source, intrafamilial spread of infection was implicated in 6/21 (28.6%) cases.[40] A Welsh study concluded that the secondary household transmission rate for sporadic Shiga toxin-producing E. coli O157 (STEC O157)

infection was between 4% and 15%.[41] In another study, colonization of one family member with *S. aureus* had no bearing on the observed carriage rate of another family member. When both child and guardian were colonized with methicillin resistant *S. aureus,* however, the same strain was most often seen, indicating that transmission between household members probably occurred.[42]

Recently, risk models such as the Hazard Analysis and Critical Control Point (HACCP) and Quantitative Microbial Risk Assessment (QMRA) based on early detection and prevention of future health risks within the home and community have been proposed.[12,43,44]

CLEANING AND DISINFECTION PRODUCTS

Cleaning refers to the mechanical removal of dirt and soil from an object or area. Disinfection, on the other hand, is the chemical destruction, inactivation, or killing of microbes. Detergents and water are the preferred products for cleaning; products containing substances such as alcohol, bleach, quaternary ammonium compounds , and phenolics can be disinfectants depending on the formulation and use of the product. Under normal conditions, cleaning is adequate for households, but in some circumstances such as an outbreak or the handling of potentially contaminated food, disinfection may be indicated.

Laboratory Studies

In a study designed to test the effectiveness of a variety of household products against several enteric bacterial pathogens, commercial products containing ammonia resulted in a 4–6 log reduction and phenolic and alcohol based products were associated with a reduction of 4 logs. Baking soda and vinegar were generally ineffective (<3 log reduction). The commercial disinfectants inactivated both antibiotic-susceptible and resistant bacteria.[46] In another study, only bleach was effective against *S. aureus, Salmonella typhi,* and *E. coli*. While concentrated ammonia and vinegar were effective against *S. typhi* and *E. coli,* none of the other products—borax, ammonia, baking soda, vinegar, or dishwashing detergent—demonstrated antimicrobial activity against *S. aureus*.[47]

Four disinfecting agents were evaluated for their ability to prevent the transfer of a human rotavirus from stainless steel disks to the fingers of volunteers: disinfectant spray (0.1% o-phenylphenol and 79% ethanol), domestic bleach (6% sodium hypochlorite diluted to 800ppm of free chlo-

rine), quaternary ammonium-based product (7.1% quaternary diluted 1: 128 in tap water), and a phenol-based agent (14.7% phenol diluted 1:256 in tap water). Viral reductions on disks treated with the disinfectant spray were >99.9%, 97.9% for bleach, 95% for phenolic, 54.7% for quaternary, and 52.3% with tap water. Virus was not detected on the fingers that had contact with disks treated with disinfectant, bleach, and phenolic, but contact with tap water or quaternary-treated disks resulted in transfer of 5.6% and 7.6% of the residual virus, respectively.[23] The same products were tested against rhinovirus. After 1 to 10 minutes of contact with the virus, the alcohol and phenolic-based disinfectant spray reduced virus infectivity by >99.9%. Virus was not detected on the fingers of volunteers who had contact with the treated disks. Bleach reduced the viral load by 99.7% after 10 minutes of contact, and once again no detectable virus was transferred to fingers. The quaternary-based product inactivated only 14.7% of the virus, and the phenolic only 62.3%. Contact with the quaternary-based treated disk resulted in the transfer of 8.4% of the residual infectious virus, while the phenolic-treated disks resulted in the transfer of 3.3%.[48]

A particularly impressive study was one in which 8 volunteers licked dried human rotavirus that had not been treated with anything, and all became infected. An alcohol and phenolic-based disinfectant spray applied to the virus interrupted the transfer of the virus; none of the 14 volunteers who consumed the spray-treated virus became infected, whereas 13 of 14 who ingested the unsprayed virus became infected.[49]

Studies of the Home Environment

Disinfection in the home is dependent not just on the product, but also on how it is applied. During a 30 week study in Arizona, 15 homes were supplied with a variety of disinfectant products, but no specific use instructions were given. Subsequently, most of the disinfectants were removed, specific ones were introduced, and a cleaning schedule was established. While the greatest reductions in coliforms occurred after initial introduction of products, introduction of the cleaning schedule led to even greater microbial reductions in the 14 kitchen and bathroom sites studied.[50] These results are consistent with the findings of an earlier study demonstrating that disinfectants used in a timely manner after contamination by food or hands reduced further contamination.[51]

Kitchen. Studies in the UK have demonstrated that cleaning with detergent and hot water alone did not significantly reduce campylobacter and salmonella from contaminated kitchen areas. However, when cleaning was supplemented with hypochlorite there was a significant reduction in

the number of bacteria from contaminated sites. In addition, detergent and water washing of dishware was only effective if followed by a rinsing process.[15] In fact, soap and water can actually increase contamination in the home when not followed by rinsing.[52] This suggests that when rinsing is impractical or not feasible, cleaning alone may be insufficient and disinfection may be indicated. In the UK, antibacterial dishwashing liquid has been shown to effectively reduce numbers of recoverable microorganisms on dishes, but not on used sponges.[53,54]

Zhao et al., inoculated raw chicken with an indicator organism, *Enterobacter aerogenes.* The same cutting board was then used to prepare chicken and chop raw vegetables, and 10^3–10^4 CFU of bacteria was transferred to the vegetables. Treating the cutting board with a kitchen disinfectant after preparing the chicken reduced the transmission of bacteria to almost undetectable levels.[55] Disinfection in conjunction with paper towel wiping are reported to be the best procedure for cleaning surfaces contaminated with raw meat.[56]

Laundry. Standard laundry practices have changed over the years, and may also contribute to the transmission of microbes in the home. People less frequently hang their clothing and linens outside where the sunlight can aid in denaturing many of the microbes, and ironing, which allows steam to penetrate and reduce the microbial load in the fabric, has become less common. Finally, lower water temperatures with smaller volumes of water are used for washing.[7,8] Jaska and Fredell (1980) found no significant differences between a phosphate or a phosphate substitute detergent on *S. aureus* survival on laundered fabrics and reported that the most important predictor of bacterial reduction in the laundry was the water temperature.[57]

The temperature of the water used for washing does not seem to affect the bacterial counts in the fabric in the presence of sodium hypochlorite bleach; that is, both hot and cold water in combination with the bleach cycle are equally successful in reducing bacteria counts,[58,59] but in the absence of bleach, warmer washing temperatures (55°C) are more effective[60] and colder temperatures may increase the cross-contamination rate of articles washed together.[61] Hence, attaining maximal bacterial reductions in both the machine and fabrics depends both on bleach and the water temperature.[58–60,62] Although relying on wash water temperatures to achieve meaningful bacterial reductions is impractical in North America since water heaters are typically set at 120şC, sodium hypochlorite bleaches for compatible fabrics and newer laundry products containing oxygenated bleach which can be used on colored fabrics will achieve such reductions.

Bathroom. In the bathroom, splashing and aerosol droplets are responsible for transfer of some contamination from toilets and sinks to surrounding areas in the bathroom, but a chlorine block effectively reduced the level of contamination in the toilet. Surrounding areas, however, were not affected by the chlorine, suggesting that direct shedding or hand contact was responsible for contamination of the toilet seat, handle, and floor.[63]

A summary of studies of the activity of various household cleaning and disinfecting products are summarized in Table 2. This body of research suggests that a product containing an ingredient with disinfectant properties, such as alcohol, bleach or a phenolic, may be indicated for home use if a household member is ill with an infectious disease or in other high-risk situations.

Hand Hygiene

Reviews of studies linking hand hygiene and reduced risk of infection have been recently published.[64,65] The major benefits of hand hygiene for the general public is for prevention of infectious agents found transiently on hands and spread by the fecal-oral route and from the respiratory tract.[22,66] In general, non-antimicrobial soaps are adequate to reduce such transient flora, but in 11 experimental studies reviewed by Keswick et al., use of antimicrobial soaps was associated with significant reductions in rates of superficial cutaneous infections. Another 15 experimental studies reviewed demonstrated a reduction in bacteria on the skin with use of antimicrobial soaps, but none of these studies assessed rates of infection as an outcome.[67]

Increasing public awareness stimulated by several highly publicized and serious outbreaks from commercially prepared foods has raised questions about food safety and the appropriate hygienic practices of food handlers. This concern extends to others such as child care providers, educators, sales personnel, and homemakers who have physical contact with members of the public. Despite public awareness, however, hand hygiene as practiced by the general public does not meet recommended standards—members of the public wash too infrequently and for very short periods of time.[68]

A single recommendation for hand hygiene practices in the home is probably inappropriate. Hand hygiene is clearly indicated before and after behaviors that are associated with microbial contamination, especially including toileting, diapering, and preparing or eating food.

Options for hand hygiene include plain soap and water or use of

TABLE 2

Studies of the Effectiveness of Cleaning and Disinfecting Products
Against Household Microbes, 1980–2000

Agent	Antimicrobial Activity
Detergent and Hot Water	Effective against campylobacter and salmonella when followed by rinsing[15, 52]
Antibacterial Dishwashing Liquid	Kills *Escherichia coli, Salmonella enteritidis PT4, Staphylococcus aureus, Bacillus cereus* on dishes, but not used sponges[53]
Ammonia	Effective against *E. coli* and *Salmonella typhi* (log reduction was not reported)[47]
	Eliminated 4 to ≥ 6 logs of *S. aureus, Salmonella choleraesuis, E. coli* O157:H7, *Pseudomonas aeruginosa*[46]
	Eliminated ~15% of rhinovirus type 14[48]
Vinegar	Effective against *E. coli* and *S. typhi*[47]
	Eliminated <3 logs of *S. aureus* and *E. coli*[46]
Baking Soda	Eliminated <3 logs of *S. aureus, S. choleraesuis, E. coli*O157:H7, *P. aeruginosa*[46]
Bleach	Effective against *S. aureus, S. typhi, E. coli,*[47] *Pseudomonas,*[80] *Enterococcus,*[81] *Klebseilla,*[82] *Enterobacter,*[82] *Legionella,*[83] *Salmonella, Campylobacter* and other coliforms[21, 50]
	Effective against *Mycobacterium tuberculosis*[83]
	Effective against Human Coronavirus, Parainfluenza virus, and Cosackie B virus;[84] Parvovirus;[85] Foot and Mouth Disease;[86] Hantavirus;[87] Rubella virus;[88] Adenovirus Type 5;[84] Hepatitis A virus;[89] Hepatitis B virus, Hepatitis C virus and HIV;[90] HSV-1 and HSV-2;[90] Rotavirus;[82] and Polio virus[90]
	Effective against *Giardia lamblia*[73]
	Effective against *Aspergillus niger,*[91] *Trichophyton mentagrophytes,*[92] *Streptomyces* spores and mycelia[93]
	Effective against Rhinovirus[83]
Phenolic	Reduction of ~95% of rotavirus and >60% of rhinovirus type 14[23, 48]
Lysol brand disinfectant spray	Spraying on surfaces reduced culture adapted human rotavirus greater than 5 $\log_{10}$[49]

an antiseptic. Generally, plain soaps do not kill microorganisms but rather wash them off with friction and rubbing, removing the majority of micro-organisms. For general home use when household members are healthy, plain soaps are often considered to be sufficient.[69]

Many antiseptic products are available over-the-counter, and are often labeled "antibacterial." These are detergent-based, requiring a traditional handwash with water. Non detergent-based antiseptic products are waterless hand rinses, gels or wipes, which usually contain alcohol. They are also readily available to the public over the counter, can be used when no running water or towels are available, and, similar to antiseptic hand washes, have rapid and broad spectrum activity and excellent microbicidal characteristics. Such products, however, are not a substitute for handwashing when the hands are physically soiled, since they are not good cleaning agents.[70,71] Alcohol-based products may be most beneficial in circumstances where immediate antimicrobial activity is needed after encounters that result in a high probability of contamination and where soap, running water, and/or clean towels are not readily available.

Because the skin is the most important and first-line barrier to infections, it is vital that the skin of the hands be kept as intact and healthy as possible. The skin's water content, humidity, pH, intracellular lipids, and rates of shedding each play a role in retaining the protective barrier properties of the skin, and these factors are affected by hand hygiene. For example, changes in skin pH associated with handwashing may pose a concern since some of the antibacterial characteristics of the skin are associated with its normally acidic pH. Some soaps can result in longstanding changes in skin pH, reduction in fatty acids, and, subsequently, changes in the microbial flora.[72,73] Hence, some hand hygiene practices such as frequent washing with detergents can result in skin dryness, irritation, cracking and other problems.

Moisturizers prevent dehydration, damage to barrier properties, desquamation, and loss of skin lipids, restore the water-holding capacity of the keratin layer, and increase the width of corneocytes.[74,75] They may even help to prevent the transmission of microorganisms from the hands.[76,77] For those individuals with dry or damaged skin on the hands, it is important to use emollients or lotions to replace lost fatty acids and keep the hands hydrated.

Several recent reviews regarding hand and skin hygiene have been published. For additional information, the reader is referred to references.[78,79]

Since hands serve as one primary mode of fecal-oral and respiratory transmission, specific indications for use of antiseptic hand products in the general public occur when:

- There is close physical contact with individuals at high risk for infection (e.g., neonates, the very old, or immunosuppressed);
- An individual is infected with an organism and may potentially transmit the agent by the direct contact route (diarrhea, upper respiratory infection, skin infections) or in close physical contact (touching) with infected individuals;
- An individual is working in a setting in which infectious disease transmission is likely (food preparation, crowded living quarters such as chronic care residences, prisons, child care centers, and preschools).

SUMMARY

The purpose of this paper was to examine research literature from the last twenty years to determine the potential role of the home environment in the transmission of infectious disease. Kitchens, bathrooms, and washing machines harbor a wide range of potential pathogens, and routine practices within these areas of the home can either prevent or facilitate cross-contamination within the home. The potential for transmission of microbes in the home exists, and several studies have demonstrated that transmission does occur. Hence, even though infectious risks in the home may be less than in healthcare settings such as the hospital or nursing home, they are certainly present. Commercial disinfectants and cleaning products vary in their ability to remove microbes from household surfaces, but successful strategies for reducing microbial risks in the home include both adequate cleaning practices and appropriate use of cleaning and disinfection products. Care should be taken to use these products according to instructions in order to maximize removal. In general, these products clearly have a role as part of an overall hygiene strategy within the home. Lastly, the behavioral aspects of infection prevention in the home such as food handling practices, warrant increased public attention and education.

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