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Review

Outbreaks Where Food Workers Have Been Implicated in the Spread of Foodborne Disease. Part 8. Gloves as Barriers To Prevent Contamination of Food by Workers

EWEN C. D. TODD,[1]* BARRY S. MICHAELS,[2] JUDY D. GREIG,[3] DEBRA SMITH,[4] AND CHARLES A. BARTLESON[5]

[1]*Department of Advertising Public Relations and Retailing, Michigan State University, East Lansing, Michigan 48824, USA;* [2]*The B. Michaels Group Inc., 487 West River Road, Palatka, Florida 32177, USA;* [3]*Public Health Agency of Canada, Laboratory for Foodborne Zoonoses, 160 Research Lane, Unit 206, Guelph, Ontario, Canada N1G 5B2;* [4]*Campden BRI, Chipping Campden, Gloucestershire GL55 6LD, UK; and* [5]*6110 Troon Lane S.E., Olympia, Washington 98501, USA*

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ABSTRACT

The role played by food workers and other individuals in the contamination of food has been identified as an important contributing factor leading to foodborne outbreaks. To prevent direct bare hand contact with food and food surfaces, many jurisdictions have made glove use compulsory for food production and preparation. When properly used, gloves can substantially reduce opportunities for food contamination. However, gloves have limitations and may become a source of contamination if they are punctured or improperly used. Experiments conducted in clinical and dental settings have revealed pinhole leaks in gloves. Although such loss of glove integrity can lead to contamination of foods and surfaces, in the food industry improper use of gloves is more likely than leakage to lead to food contamination and outbreaks. Wearing jewelry (e.g., rings) and artificial nails is discouraged because these items can puncture gloves and allow accumulation of microbial populations under them. Occlusion of the skin during long-term glove use in food operations creates the warm, moist conditions necessary for microbial proliferation and can increase pathogen transfer onto foods through leaks or exposed skin or during glove removal. The most important issue is that glove use can create a false sense of security, resulting in more high-risk behaviors that can lead to cross-contamination when employees are not adequately trained.

Hand hygiene is critical during preparation of any food, whether in the home or in the food processing or food service environment, and proper hand washing and drying is a proven, effective method of hand sanitation *(77)*. In this article, the eighth in a series on food worker–associated outbreaks, the discussion focuses on hand hygiene through glove use to prevent food from becoming contaminated. Other articles in this series have included discussions of numerous outbreaks linked to food workers, and poor hand hygiene, including lack of or improper use of gloves, was listed among the risk factors *(42, 119, 120)*. Contamination of foods via the hands is ranked highly among risk factors identified during outbreak investigations *(20)* and is discussed more fully below. Other articles revealed how easily hands can be contaminated in food preparation environments from contact with raw foods and infected coworkers. Pathogens with low infective doses may be present on hands in high numbers, can be easily transferred to foods and/or food contact surfaces, and can survive for long periods *(121–123)*. Barriers to worker and customer contamination of food, such as utensils, deli papers, food shields, and appropriate clothing, have been long in use, but their effectiveness is sometimes questioned, and multiple barriers (hurdles) are recommended. Glove use is one of these recommended hurdles *(126)*. The use and effectiveness of soaps and alcohol-based gels and other products for hand sanitizing are addressed in subsequent articles in this series *(124, 125, 127)*.

HAND HYGIENE

Hand contamination. In 1938, Price *(103)* examined hand and arm skin microflora and decontamination practices and found that from the finger tip to 2 in. (5.1 cm) above the elbow the arm and hands, including fingernails, have between 2×10^6 and 1×10^7 CFU of total aerobic bacteria, and 90% of these organisms reside on the hands. Even when these areas are effectively cleansed by disinfection techniques, under normal circumstances full regrowth of these bacteria will occur within 5 to 7 days. Price also found that after more than 2 h of glove wear, total bacterial counts on the hand increased by about one order of magnitude, and the bacterial population comprised both normal resident and transient flora in a nonfood environment. By using marker bacteria, Price was able to demonstrate that recommended washing procedures could almost totally remove transient microorganisms from the hands. He deduced from this that no appreciable increase in food pathogens would occur because these bacteria typically

* Author for correspondence. Tel: 517-355-8371; Fax: 517-432-2589; E-mail: todde@msu.edu.

survive poorly on hands (compared with resident flora) and they would be suppressed by antibacterial substances secreted by the resident flora and the skin itself. However, Price also stated that continual exposure of skin to pathogens may make these bacteria part of the resident flora, with the potential for the individual to become a chronic carrier.

Since Price's work, extensive research has demonstrated the resistance of microorganisms on the skin to removal by washing and disinfection. Larson et al. *(65)* evaluated the normal microbial flora on the hands of 224 homemakers both before and after hand washing with soap or with antimicrobial hand care products. Levels were 5.72 log CFU before washing and 5.69 log CFU after washing, and an average of 3.6 species were identified before washing and 3.3 species were identified after washing. Little difference was noted in the level or number of species between those homemakers who washed with plain soap and those who used a commercial antimicrobial product. After hand washing, 75% of the participants had gram-negative bacteria, 33% had yeast, and 19% had *Staphylococcus aureus*. This study revealed that hand washing has its limitations but tends to remove transient microorganisms (e.g., enteric pathogens) more easily than resident microorganisms. Thus, the hands of healthy individuals may be colonized with microorganisms with the potential to cause foodborne illness even after washing. In another study, Larson et al. *(62)* confirmed that a single episode of hand washing had minimal effect on the quantity of the hand flora, but there were significant effects over time, regardless of whether an antimicrobial (containing 0.2% triclosan) or plain soap was used.

Horwood and Minch *(52)* recovered 1.5×10^4 to 9.5×10^7 organisms from each hand before washing. Taylor et al. *(113)* found 10^2 to 10^6 CFU per hand from finger rinses of 15 individuals before and after washing. The counts were similar for the left and right hands, and day-to-day variation for each person was small. de Wit and Kampelmacher *(26)* reported that 50% of food industry workers had similar total viable counts on the left and right hands, and 60% of workers had similar numbers of *S. aureus* on both hands. However, Fierer et al. *(35)*, in a more recent study involving a pyrosequencing-based method, found that the diversity of skin-associated bacterial communities was high; a typical hand surface harbored >150 unique species-level bacterial phylotypes (a species is defined as an organism sharing ≥97% identity based on its 16S rRNA gene sequences). This level of diversity is at least 10 times higher than that obtained by culture methods. The bacterial families included *Staphylococcaceae, Streptococcaceae, Enterobacteriaceae,* and *Pseudomonadaceae,* with a total of 4,742 unique phylotypes across all of the 51 hands examined. *Streptococcus* and *Staphylococcus* were among the dominant bacterial genera. Fierer et al. also observed pronounced intra- and interpersonal variation in bacterial community composition. Hands from the same individual shared only 17% of their phylotypes, and different individuals shared only 13%. Women had significantly higher bacterial diversity than men, and bacterial community composition was significantly affected by handedness (dominant versus nondominant hands) and the amount of time since the last hand washing.

The surface of the skin is continually replaced by the process of desquamation, and cells at the surface are sloughed off and replaced with cells from lower layers. Squamous cells also carry attached microorganisms that can be dispersed into the air to form aerosols and can settle on surfaces. Because the human body sheds viable microorganisms at a rate of 1×10^3 to 1×10^4 CFU/min, according to Frazier and Westoff *(38)*, the likelihood is very high that hands will frequently contaminate surfaces through touching and holding. The fact that women have a higher diversity of bacterial species on their hands than do men may have consequences for hand hygiene and food safety training that should be explored further.

Hand contamination in food operations. Even in the controlled environments of food processing and food service operations, exposed areas of the body such as the hands, arms, and face will inevitably come in contact with human secretions or animal or plant material contaminated with fecal or oral organisms *(77)*. McGinley et al. *(73)* commonly isolated staphylococci, *Pseudomonas, Enterobacter, Serratia,* yeasts, and molds from the subungual region of fingernails. Because an estimated 1 in every 50 asymptomatic food workers sheds pathogens at 10^9 CFU/g of feces *(37)*, a lack of proper hand and nail hygiene by workers may allow fecal pathogens, including *Salmonella, Shigella, Escherichia coli, S. aureus,* and norovirus, to accumulate in the subungual area.

In the United States, from 1973 to 1997 poor personal hygiene of food workers was the second most frequently cited contributory factor (25% of all outbreaks) in foodborne illness outbreaks *(9, 10, 89)*. The general term ''poor personal hygiene'' as used by the Centers for Disease Control and Prevention includes many factors relating to employees, such as failure to properly wash hands, failure to wear hair nets, chewing tobacco, and wearing dirty work clothes. In a national survey of approximately 1,000 U.S. food establishments, the percentage of people with poor personal hygiene practices varied across facility types such as institutional food service facilities (nursing homes, 20.2%; hospitals, 17.5%; elementary schools, 16.3%), restaurants (full service, 41.7%; fast food, 31.2%), and retail food establishments (meat and poultry departments and markets, 21.4%; produce departments and markets, 22.3%; seafood departments and markets, 16.8%) *(130)*.

In a report of the factors contributing to foodborne disease outbreaks from 1998 to 2002 *(20)*, bare-hand contact, inadequate cleaning of processing or preparation equipment or utensils, and handling of food by an infected person or an asymptomatic carrier were among the most important factors (associated with 26, 25, and 22% of disease outbreaks, respectively), indicating the importance of the human element. The only factor more important than bare-hand contact was allowing foods to remain at room or warm outdoor temperatures for several hours (29% of outbreaks). Gloved-hand contact by a food worker leading to an outbreak was much less common (6% of outbreaks), indicting that usually gloves offer some degree of protection, although not in every situation *(20)*. This protection cannot be guaranteed because of a number of variables, including (i) the initial hand contamination level, (ii) worker compliance with directives for frequent hand washing, and (iii) the effectiveness of the hand washing procedure. In a European study on hygienic practices at processing plants, food worker contact was the greatest cause of food contamination (9.2%), followed by cross-contamination from dirty equipment (5.7%) and contaminated food ingredients (3.4%) *(107)*.

The importance of infected food workers and hand hygiene is illustrated by an EHS-Net study in 2002 and 2003 *(47)*. Systematic environmental evaluations were conducted in 22 restaurants in which outbreaks had occurred and in 347 restaurants in which outbreaks had not occurred. Handling of food by an infected person or carrier (65%) and bare-hand contact with food (35%) were the most commonly identified practices that could contribute to spread of pathogens. The majority of outbreaks associated with food worker activities (42% of all confirmed cases in the study period) involved norovirus for several reasons: (i) norovirus is excreted in large numbers in feces of asymptomatic and symptomatic infected persons, (ii) norovirus survives well in vomitus and the environment, (iii) the infectious dose for norovirus is very low, and (iv) norovirus is easily spread from person to person. These characteristics of norovirus indicate that proper glove use could be a factor in reducing the spread of this pathogen.

These studies indicate that hands are the most common means by which workers contaminate food products, although various barriers have been introduced to limit the direct contact between hands and foods. These barriers include work clothing and avoidance of bare-hand contact with ready-to-eat (RTE) foods through use of gloves, utensils such as spatulas and tongs, and bakery papers or deli wraps. These other barriers are discussed in a separate article *(126)*.

THE USE OF GLOVES AS BARRIERS TO CONTAMINATION

Effectiveness of gloves. When worn correctly in health care environments, gloves have consistently reduced hospital-acquired infection rates *(11, 49, 114)*. However, considerable time passed between implementation of glove use in health care settings and the recognition of their value in food environments to reduce disease transmission *(78, 79)*, and glove use still is not mandatory in many jurisdictions. Eventually, glove use was proposed as a risk reduction strategy by most public health authorities because compliance can be monitored by management and food control agencies. For instance, inspectors can walk into a facility and determine compliance immediately by observing the gloves on workers and can determine the extent of change by monitoring discards in trash receptacles *(45, 129)*. Inspectors also can look at glove purchase invoices and compare invoiced to inventoried glove boxes and determine the glove use per hour by dividing the number of gloves in boxes by the number of workers and the hours they worked, averaged over several weeks. However, inspectors have more difficulty determining how often gloves become contaminated and whether gloves are used properly.

Glove use has been emphasized through the widespread distribution of the U.S. Food and Drug Administration (FDA) Food Code *(132)*, and their use has increased in hospital food service facilities operated under hazard analysis critical control point (HACCP) systems *(5, 6)* designed to protect susceptible populations. Although utensils have hygienic value during food production and preparation, for ease of working, hands need to be in regular contact with food much of the time, and glove use has been advocated to prevent transfer of pathogens. In food service operations, slash-resistant gloves can be used for RTE foods only if these gloves have a smooth, durable, nonabsorbent outer surface. Cloth gloves are permitted for direct contact only with foods that are to be subsequently cooked *(130)*.

Generally workers are well informed about personal protective equipment and the need to wear gloves when handling hazardous chemicals or agents to protect their hands, but they may not be so well informed about the issues concerning glove use to avoid cross-contamination. Gloves differ in their material, quality, and resistance to leaking. Common glove materials used in both the food and health care industries are latex, rubber, or nonlatex materials such as nitrile or vinyl *(66, 68, 78–80)*. Such gloves are now used in the food industry, both to protect the food worker from occupational exposures and to prevent pathogen transmission from the worker to the food product *(66, 68, 76)*. The results of several studies have confirmed the effectiveness of gloves for preventing contamination of hands *(46, 84, 88, 114)*. To optimize glove performance and prevent loss of integrity, wearers should (i) maintain short fingernails, (ii) minimize or eliminate hand jewelry, and (iii) use work practices that avoid punctures from bone fragments, sharp tools, and equipment.

When gloves are worn properly, the risk of pathogen transmission can be reduced considerably, but glove use must be monitored carefully to ensure that it is appropriate for the required tasks. Contrary to popular belief, new nonsurgical gloves are not completely sterile, although no study has shown them to carry pathogens. Another major issue to consider in the food industry is that broken pieces from gloves may find their way into food during production; therefore, gloves are usually colored blue for easy detection. Most pieces are finger size fragments that are torn off during operations and are easily visible; however, minute pieces could pass through the food undetected. This problem is prevalent enough within the food industry that gloves are now being manufactured so that pieces can be located by an automatic detection system.

For safety reasons, some companies use different kinds of gloves for different parts of an operation, e.g., colored disposable gloves for handling raw meat ingredients, high-density melt-resistant reusable gloves for cooking on a grill, and clear or white disposable gloves for handling RTE products. Reusable gloves are used in many types of food processing plants, including meat fabrication plants and other places in which raw food is prepared but will eventually be cooked, because these gloves protect the hands of the worker from sharp objects such as bone and wood fragments and limit worker contamination of food. RTE or minimally processed foods may also be prepared using combinations of disposable and reusable gloves. Other reasons exist for wearing reusable gloves: (i) food grade gloves allow direct food contact without affecting quality, (ii) gloves can be approved by regulatory authorities or inspectors for specified use within HACCP plans, and (iii) reusable gloves are sturdier and less likely to fail than disposable gloves, and cleaning and sanitizing of gloves can be effectively accomplished without affecting their quality. Under certain conditions with some food products, limited puncturing may be allowed providing the gloves remain intact and continue to reduce the risk for which their use was intended.

Limitations on the effectiveness of glove use. Although gloving has been recommended for and used in food operations for many years, its benefits are still questioned for two reasons: the on-going potential for cross-contamination with improper use and the likelihood of contact dermatitis with continued use. In a study of nurses' hands in four hospitals, skin damage was significantly correlated with, among other things, the number of times gloves were worn ($P = 0.008$) *(63)*. Wearers of latex gloves can develop skin redness, itching, rash, or hives, and in the United States 22% of health care workers are reportedly sensitive to traditional latex. Newer glove materials seem to be less allergenic. A glove made of natural rubber latex (guayule latex) from a desert plant lacking the protein associated with latex allergies produced no reaction when worn by persons who were highly allergic to latex and was approved by the FDA in 2008 *(129)*.

Gill and Jones *(40)* found that the transfer of *E. coli* from contaminated gloves in meat production plants is much lower than that from contaminated hands, possibly because gloves have a more easily cleaned, consistent surface. Volunteers inoculated their hands with a strain of *E. coli* and then wore knitted open mesh polyester or cotton (PC) gloves, as typically used in meat plants, or thick reusable rubber gloves. The numbers of *E. coli* recovered from the PC gloves were 1 to 10% of the numbers recovered from meat handled with contaminated bare hands. The data for wet PC gloves suggest that most of the *E. coli* on the hands was transferred to the inside of the gloves, but a relatively small consistent amount was then transferred from the gloves to other portions of meat. The data for dry PC gloves indicated that the transfer of *E. coli* from hands to gloves was delayed compared with the transfer to wet gloves, but *E. coli* numbers were similar after the formerly dry gloves had absorbed the meat juices. Wearing thick rubber gloves prevented the transfer of *E. coli* from contaminated hands to meat, but these gloves are not comfortable to wear for long periods and do not allow the same dexterity as do the thinner gloves. In a meat fabrication operation, the open mesh gloves quickly became wet and contaminated, whereas the rubber gloves remained dry and restricted the transfer of *E. coli*. The cloth gloves had no integrity. The gloves were changed after normal operations, presumably at each shift. All meat handled was raw, which would be later cooked, but transferring *E. coli* around more meat pieces is not desirable. Gill and Jones concluded that although the PC gloves could reduce the transfer of *E. coli* and other bacteria from hands to meat compared with bare hands, these gloves could increase the transfer of bacteria between meat pieces, whereas rubber gloves could largely prevent the first type and greatly reduce the second type of transfer.

Gloves can sometimes, but not always, reduce the transfer of microorganisms to food surfaces, as indicated by the results of the study in meat plants. However, the concern is greater in RTE operations. As part of a 3-year Campden BRI research project, more than 100 swab samples were taken from bare hands and gloved hands in three different RTE food factories (25-cm^2 area swabbed per sample). Rather than take samples directly after hand washing or from freshly gloved hands, samples were taken at approximately hourly intervals throughout the production period. The bare hands and gloved hands (three types of gloves: nitrile, latex, and rubber) of process workers in various RTE food factories became contaminated with high numbers of microorganisms, and some gloves were more highly contaminated than were bare hands *(112)*. Of 48 hands tested, the mean and maximum observed aerobic colony counts were 3.8×10^3 and 3.8×10^4 CFU/25 cm^2, respectively. When compared with similar counts from gloved hands (53 glove samples with a mean of 4.0×10^4 CFU/25 cm^2 and a maximum of 1.2×10^6 CFU/cm^2), it is clear that the gloves were more contaminated than were bare fingers and palms.

Although the microorganisms found were of undetermined origin, the potential for gloves to transfer contamination, including pathogens, to RTE foods is very high. This observation is substantiated by the results of work undertaken as part of the Campden BRI project using pathogen indicators *(111)*. Washed and alcohol-disinfected hands or pieces of three brands of two types of glove (nitrile and latex, as used and supplied by two of the RTE food factories studied) were inoculated with 0.1 ml of a 10^3-CFU/ml suspension of each test organism: *E. coli* K-12, *Staphylococcus* spp., and *Listeria innocua,* which are indicators of pathogens encountered in RTE food settings. This inoculum was spread over a 25-cm^2 area on the palm of the hand or the surface of the glove material and then ''blotted'' with a nutrient agar contact plate with slight pressure for 2 s. Following incubation of the contact plate, the percentage of organisms transferred from the hands or glove material to the contact plate was calculated using the following formula:

$$\frac{\text{number of organisms transferred from surface to agar}}{\text{number of organisms in original inoculation volume}} \times 100$$

The results were variable both within experiments and among organisms (Fig. 1), but the mean transfer of

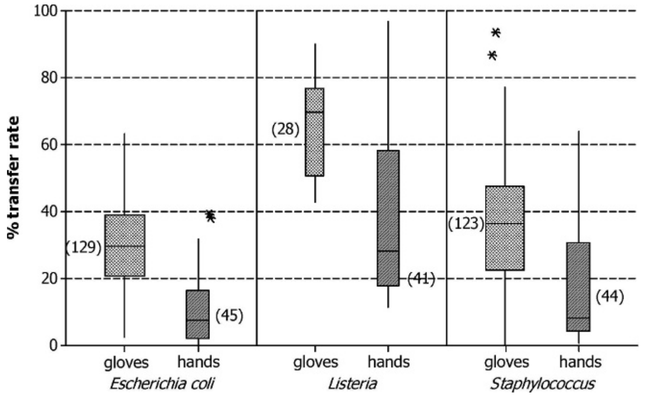

FIGURE 1. *Percent transfer of individual test microorganisms from bare hands and gloved hands to contact plates (111). Box widths are proportional to the number of observations in each study (in parentheses). Asterisks represent outliers.*

microbial contamination from bare hands and gloved hands to an agar food model was approximately 11 and 39%, respectively, for the three test organisms. Based on the microbial load data collected from the three RTE food factory studies and the transfer rates determined by the initial laboratory investigations, it appears that gloves have a higher level of contamination than bare hands and may transfer more of this contamination than would bare hands.

In a Campden BRI study of production areas for salads, pastas, and ham, the vectors most likely to contribute to product contamination in each case were food contact surfaces *(111)*. The results indicate that gloved and bare hands were equally implicated in product contamination. For mixed salad leaves, gloves ranked third and bare hands ranked fourth, for a slice of a sheet of fresh pasta, gloves ranked second and bare hands ranked third; and for a ham slice, gloves ranked second (no bare hands were used with ham). The transfers via gloved hands were 17, 1,400, and 2,900 CFU/cm^2 to salad leaves, a slice of pasta, and a slice of ham, respectively, and transfers via bare hands were 11 and 21 CFU/cm^2 to salad leaves and a slice of pasta *(111)*.

Rubber gloves are too expensive to be used only once and must therefore be effectively washed and sanitized for multiple use (see ‘‘Glove use and hand washing’’). Rediers et al. *(106)* reviewed transfer data for *Enterobacter* and *E. coli (21, 32, 33, 84)* and found that for transfer from contaminated surfaces to hands, the transfer with no glove use was 1% compared with 0.01 to 1% for gloved hands. The transfer from contaminated hands to other surfaces (e.g., salads or faucets) was highly variable at 0.01 to 10% for no gloves and 0.1% for gloves.

The complexity of cross-contamination among hands, gloves, and food is illustrated by a number of studies. Fendler et al. *(32)* asked volunteers to handle ground beef containing *E. coli* and found that the outside of the glove was highly contaminated at the end of a 3-h period regardless of whether gloves had been changed or hands had been washed. In a second study, Fendler et al. *(33)* found that bare hands with a regimen of hourly washing and sanitizing provided a higher level of hand sanitization than did gloved hands with and without washing. Lynch et al. *(69)* also found that gloved hands do not necessarily reduce bacterial contamination at fast food restaurants. Coliform bacteria were present in 9.6% of tortilla samples handled by gloved workers compared with 4.4% of samples handled by workers with bare hands, although this difference was not statistically significant. The numbers of mesophilic aerobic bacteria, a general measure of hygiene, also were higher in samples handled by gloved workers in one restaurant chain.

Although gloves give some benefit, they do not completely prevent pathogen transfer. The experimental and observational data clearly indicate that variable results can be obtained when food is handled by bare and gloved hands. Therefore, gloves should be considered an adjunct to and not a replacement for hand washing for food production and preparation operations *(32, 33)*.

Complacency with glove use gives a false sense of security. The number of glove changes needed differs by operation. For a task that involves touching raw product and then touching a cooked or RTE product, glove changes should occur between each type of food. For a single operation where the risk of transfer of a pathogen is low, e.g., mixing chopped vegetables or cooked meat, glove change could take place at a convenient break time. When a hamburger is being prepared by one person and the raw patties must be formed and cooked, many glove changes would be expected in a short time. However, the observed tendency of food workers to wear the same pair of gloves for extended periods and the observed complacency concerning hand hygiene might account for the apparent failure of gloves to reduce or prevent bacterial contamination. The false sense of security associated with gloves may cause users to engage in risky food handling practices or activities that result in cross-contamination and possible contamination of food or food contact surfaces, e.g., workers may wash their hands less frequently when gloved.

McCarthy et al. *(72)* reviewed factors contributing to foodborne disease outbreaks from 1999 to 2002 and noted that contaminated gloves and glove cross-contamination were a contributing factor in 1.6% of these outbreaks compared with 8.8% of the outbreaks associated with bare-hand contact. In a multistate study, workers in restaurants were observed performing a variety of tasks (median of 8.6 tasks per h) for which hand washing is recommended *(41)*. These tasks included, in order of frequency, (i) handling dirty equipment and then preparing food, (ii) preparing raw animal products, (iii) putting on gloves for food preparation, (iv) touching the body, (v) eating, drinking, or using tobacco, (vi) coughing, or (vii) using hand tissues. The results of the study indicated that hand washing and glove use were more likely to occur in conjunction with food preparation than with other activities (e.g., handling dirty equipment, which could harbor pathogens) and when workers were not busy. Hand washing was also more likely to occur where food workers received food safety training, when more than one hand sink was available, and when a hand sink was within the worker’s sight. Glove use was more likely to occur in chain restaurants and in restaurants with glove supplies in food preparation areas. Hand washing and glove use were also related to each other; hand washing was less likely to be associated with activities in which gloves were worn. These results suggest that workers who wear gloves do not remove them and wash their hands as often as they should. These observations support the conclusions of Fendler et al. *(32)*, Guzewich and Ross *(44)*, and Lynch et al. *(69)*, but Green et al. *(41)* cautioned that more research is needed to understand the relationship between glove use and hand washing.

Glove use and outbreaks. Guzewich and Ross *(44)* noted that in some outbreaks food workers wore gloves. In the reviews by Greig et al. *(42)* and Todd et al. *(119, 120)*, glove use was documented in 9 of 816 outbreaks where a food worker was implicated; however, in all cases, the gloves were worn improperly (i.e., not worn consistently or not worn to cover skin lesions) or were not worn during food preparation and handling of implicated food *(24, 75)*. Outbreaks have occurred because of small lapses in food preparation practices where there is extensive handling. In one instance, gloves were worn for all activities except for preparation of romaine lettuce *(23)*. In another, basil leaves were picked by gloved hands but then processed bare handed *(18)*. In a New York bakery, workers were legally required to wear gloves when handling RTE food but wore them inconsistently when applying sugar glazes *(133)*. A cafeteria worker made sandwiches wearing gloves but used bare hands to prepare salad bar vegetables, resulting in an outbreak of 26 cases of *Giardia* infection *(82)*.

Claims of proper glove use just before an outbreak has occurred are often suspect, even if not proven, as shown in the following example. A food worker admitted having a sick infant with watery diarrhea at home but denied having any gastrointestinal illness. Although the worker claimed to have worn gloves while slicing ham, 125 students at a Texas university became ill with a norovirus infection *(24)*. The documented instances of cross-contamination associated with gloves *(19, 70, 87, 94, 98)* tend to illustrate cases of risk amplification when gloves are not worn properly. Chain mesh gloves have been identified as a potential cause of cross-contamination in the processing of meat and poultry products, leading to illnesses from infection with *S. aureus* *(96)* and *Yersinia enterocolitica* *(39)*. Slash-resistant gloves are not permitted in food service operations for cutting frozen or fresh meat unless the meat is to be subsequently cooked *(131)*. Elastomeric glove failures have been identified as a potential cause of foodborne outbreaks due to glove cross-contamination in food service operations *(16, 69)* and in processing of produce *(54)*, poultry *(51)*, and seafood *(116)*. Pérez-Rodríguez et al. *(97)* found a higher risk of transfer when the same gloves were used to handle contaminated chicken meat and then sliced ham than when the safer method was used of different gloves for handling each product. A combination of gloves and proper hand washing was the least risky procedure for transferring a pathogen. Although the above work was laboratory based, in principle gloves should always be changed (and hands washed) between handling a raw product (e.g., chicken meat) and a cooked product (e.g., sliced ham).

Breach of glove integrity through pinholes and punctures. Glove integrity is another important issue, and failure to change gloves when contaminated or punctured is at least as common a problem as lack of hand washing *(101)*. Gloves can have small, inapparent defects or can be torn during use, and hands can become contaminated during glove use or removal *(15, 57, 64, 88)*. In a hospital study of vinyl and latex gloves, leaks occurred more frequently at the tip of the forefinger and middle finger, and vinyl gloves were more likely than latex gloves to have multiple leaks *(60)*. Leakage may occur because less care is taken in the molding of gloves for nonsterile use or because such gloves are not adequately tested for leakage *(25)*. Leakage rates differ by glove material (e.g., latex, vinyl, and nitrile), duration of use, type of procedure performed, and manufacturer *(15, 56, 60, 90)*. Gloves can develop defects in 30 min to 3 h, depending on type of glove and procedure. Glove leaks also have been demonstrated in 1.9 to 5.5% of unused gloves *(4, 90)*.

The risk for smaller viral particles penetrating gloves is even greater than that for bacteria. If bacteria can breach glove integrity though pinholes, then viruses can do so even more easily. Gloves are not always checked for pinholes during food operations, and the risk of a few infectious agents penetrating is low but real, which is one reason why workers should change their gloves frequently. Vinyl and latex gloves allowed passage of 1.4 and 1.5%, respectively, of poliovirus *(59)*, and 63% of vinyl gloves and 7% of latex gloves leaked a bacteriophage (27 nm in diameter) during experimental clinical procedures *(58)*. Although viral penetration is less of a concern in the food industry than in health care settings, gloves should be durable enough to withstand the rigors of specific food handling operations.

Gloves that have limited strength or are prone to allowing sweat buildup should be changed often, and hands should be washed between changes to prevent contamination of the glove's outer surface *(79)*. When a glove break occurs, a liquid bridge of microbial contamination can flow to the hands, contact surfaces, and food. The extent of this flow can de deduced from the fact that sweat accumulated inside a glove can allow up to 1.8×10^4 CFU of *S. aureus* to pass through a single hole a little larger than 1 μm during a 20-min period *(22, 44)*. If a glove puncture is known or suspected, both gloves should be changed as soon as possible *(27, 135)*.

Numerous instances of glove puncture during surgical operations have been documented. The puncture incidence for unused surgical gloves is 1.4 to 5.5% *(30)*, but the frequency of glove perforation during surgery is much higher (8 to 51%) *(83)*. The risk of perforation increases over the duration of the surgery, especially after 2 h, and perforation occurs more often when gloves do not fit properly. Factors favoring glove perforation include puncture by needles, scalpels, spiked bone fragments, or sharp surfaces on complex instruments. Driever et al. *(29)* found that the most frequent sites of scalpel and suture needle injuries were the thumb (27.3%) and forefinger (42.1%) of the nondominant hand followed by the middle finger

(10.2%), other fingers (15.7%), palm (3.8%), and back of the hand (0.9%).

Mistelli et al. *(83)* found a higher likelihood of surgical site infection when gloves were perforated and recommended antimicrobial prophylaxis for patients. Latex gloves are more resistant than vinyl gloves to perforation, and Mistelli et al. recommended that latex gloves be changed every 2 h. These authors also noted that the most effective method for decreasing the risk of contamination is double gloving, which reduced the glove failure rate from as high as 51% for single gloves to as low as 7% when two pairs are used. Double gloving is accepted by the majority of surgeons but used much less often in the food industry. During a randomized study designed to assess the effectiveness of double gloving versus single gloving for decreasing finger contamination during surgery, an overwhelming majority of glove perforations (83.3%) went unnoticed *(117)*. Therefore, researchers agree that gloving, including double gloving, is not a substitute for hand washing. Gown contamination can be transferred to hands during surgery or during changes of surgical gowns and other personal protective equipment such as goggles, hair nets, overalls, or masks *(17)*. The removal sequence practiced in hospitals begins with peeling of the outer glove, which is followed by removal of any other personal protective equipment. The final stage is removal of the second glove, which should always be followed by hand washing. The purpose of this sequence is to reduce the risk of contamination after glove removal.

Although these scenarios differ from those in the majority of food operations, bone fragments and sharp surfaces, including knives, are potential sources of puncture, and frequent glove changes, double gloving, and use of mesh gloves should be considered for specific operations. Similar experiments to determine the frequency and site of glove punctures during certain food operations where sharp objects are encountered are needed. In laboratory-controlled studies, Montville et al. *(84)* demonstrated the benefits of glove use for handling food items. These authors found 10% transfer of bacteria from food to hands or hands to food, but transfer decreased to 0.01% when gloves were used (i.e., a difference of four orders of magnitude). Although glove use was a significant hurdle, these observations and other experimental results indicate that bacteria can breach the glove barrier through pinholes or because of permeability of the glove material or can escape through the open end of loose-fitting gloves, as indicated by the work of Gill and Jones *(40)*. The double gloving procedure is more common in hospital settings than in the food industry but certainly should be considered for other high-risk food operations such as preparing RTE foods in elder care facilities. Double gloving is discussed further in a subsequent article *(127)*.

Breach of glove integrity through damage by rings and fingernails. Fingernails, rings, and watches may cause glove punctures *(64)*. Fingernail length and glove durability are important determinants of the effectiveness of gloves for mitigating risk. Sharp nail edges or broken nails are likely to increase glove failure. Studies have revealed that the areas under wedding and other rings and under watches are more heavily colonized by microorganisms than are other parts of the hand, although this finding has not always been conclusive *(3, 34, 50, 53)*. In a study of intensive care nurses, multivariate analysis revealed that rings were the only substantial risk factor for carriage of gram-negative bacilli and *S. aureus*, and the number of organisms was correlated with the number of rings worn *(128)*. Other research indicated that plain wedding bands harbor fewer bacteria than do more ornate rings *(31, 110)*. This finding was challenged by more recent studies by Yildirim et al. *(137)*, who found that ring wearing increased the bacterial colonization of hands but that the type of ring did not significantly affect the bacterial load ($P > 0.05$). Most of the bacteria cultured were *Micrococcus* and *Staphylococcus* species but not *S. aureus*. Yildirim et al. also found that nurses who wore rings had more gram-positive, gram-negative, and total bacteria on their hands than did nurses without rings, despite the use of an alcohol-based rub ($P = 0.001$).

Most of these studies were carried out in health care settings where human pathogens are more prevalent. In the food industry, hands also become contaminated with zoonotic microorganisms from handling raw materials of animal origin, and hand hygiene procedures are not always effective for removing the organisms from under rings and watches, as indicated in the study by Field et al. *(34)*. Rings, watches, and other pieces of jewelry should be removed before hand washing and should not be worn during food production for both foreign body and hygiene reasons. However, the wearing of jewelry of religious or medical significance in the food handling area should be based on a risk assessment of the hazards associated with such items. Plain jewelry items that cannot fall into food, such as a wedding band or Kara bangle, may be permitted provided that they are washed, dried, and (if required) sanitized as part of the hand hygiene procedure *(112)*.

Artificial acrylic fingernails pose a risk for glove puncture and are difficult to clean and disinfect. Long artificial or natural nails can make donning gloves more difficult and can cause gloves to tear more readily *(34, 61)*. Although guidelines include recommendations that nails, either natural or artificial, should be kept short *(13, 73, 134)*, research findings have reinforced policies that artificial nails should not be worn at all while preparing food, and the use of these nails should be discouraged in food preparation settings. Hand carriage of gram-negative organisms is greater among wearers of artificial nails than among nonwearers, both before and after hand washing *(48, 74, 102, 109)*. In addition, artificial fingernails or extenders have been epidemiologically implicated in multiple outbreaks involving fungal and bacterial infections in hospital intensive care units and operating rooms *(36, 43, 85, 92, 93)*. Freshly applied nail polish on natural nails does not increase the microbial load from periungual skin if fingernails are short. However, chipped nail polish can harbor bacteria *(8, 136)* and present a foreign body food contamination risk.

Glove use and occlusion of the skin. Occlusion of the skin by gloves (trapping of moisture with low oxygen levels causing skin maceration) results in sweating and incubation of skin flora associated with the hand and fingernail regions *(81)*. The microorganisms can multiply to sufficient numbers to cover most of the hand within the glove *(22)*. Although the palm of the hand and the finger pads are completely lacking in sebaceous glands and hair, they contain 400 to 500 sweat glands per cm^2 *(108)*. Total bacterial counts in gloves can increase from 3×10^6 to 2.6×10^7 CFU in 2.7 h if the gloves are not changed *(103)*.

S. aureus is a particular pathogen of concern in gloves; it is readily transmitted between hands, surfaces, cloths, and fabrics. If *S. aureus* is on the skin, as few as 10^2 CFU may be sufficient to colonize when the skin is occluded or traumatized, with pus formed when the levels reach 10^6 CFU *(115)*. Occlusion by gloves decreases the generation time of microorganisms, but the increased contamination is retained within the glove (unless it is punctured) and is not spread through various handling activities, as would occur with bare hands. However, removal of gloves at this stage without effective hand washing presents a significant hazard because wet hands facilitate the transfer of contamination. Gloves become contaminated inside and out during use, and without clear directives concerning frequency of change workers are apt to wear gloves for longer than acceptable periods; this problem is more of an issue in a processing plant where workers often perform the same repetitive activity.

Drying of hands after washing and before replacing gloves is also important to delay occlusion of the hands. Food service workers change activities very frequently. Workers in meat plants wear open-mesh PC gloves for convenience when handling meat, and although requirements were in place for impervious rubber gloves to be worn during certain operations, the workers found them uncomfortable due to the accumulation of sweat, even after a short time *(40)*. Unfortunately, continuous glove use creates the potential for skin irritation and damage, which then discourages glove use. Skin damage in the health care environment is correlated with frequency of glove use and hand washing *(63)*. Glove occlusion may produce skin fissures and bacterial colonization as a result of hyperhydration, and the condition can be aggravated by allergic contact dermatitis *(104, 105)*. Although the lipid barrier can be completely destroyed by overwashing, it can be repaired by application of lipid compounds found in hand lotions *(55)*.

Glove use and hand washing. In food processing and preparation environments, gloves should be changed at least every shift or break, e.g., every 2 h, and whenever their integrity has been breached. The number of times gloves should be changed depends on the type of food being handled and the activity or work area. Operators in high-risk food production areas, e.g., zone 1 where there is primary pathogen control, should change their gloves more often than those operators in low-risk areas, e.g., zones 2 through 4, as determined by HACCP plans. Zone 1 is the most vulnerable to contamination and lacks a decontamination step for products such as RTE foods; the remaining zones are of decreasing concern *(125)*. Because contamination of the hands while wearing gloves is a possibility, hands also should be cleaned after gloves are removed *(28, 44, 61, 114)*. Paulson *(95)* found that when the hands were not washed before donning gloves, *E. coli* numbers increased (as determined after 1 and 3 h), but when hands were washed before gloving, no significant growth of contaminating microorganisms occurred after 3 h of consecutive glove wearing. Therefore, gloving does not replace hand washing, which should be done after removing gloves and before donning gloves at every glove change.

Reusable gloves can be washed and disinfected: (i) immerse the gloved hands in a 0.5% sodium hypochlorite solution, (ii) remove gloves by turning them inside out and soak them in the same solution for 10 min, (iii) wash gloves by hand, inside and out, in soapy water, (iv) rinse thoroughly, and (v) air test for leaks by inflating by hand and holding under water *(118)*. For the inflation step, gloves can be inflated by hand simply by shaking the glove open to contain the greatest amount of air possible, twisting the wrist area to effect a seal, and quickly squeezing the wrist and palm area. This causes fingers to inflate; the thumb and forefinger are most important. This test does not compromise the integrity of the glove interior. The air leak test is not necessarily done for every glove use. Decontamination of gloves, however, can never be absolute even when sanitizers are used. Doebbeling et al. *(28)* found that washing gloves does not completely remove microorganisms and recommended that disposable gloves be changed regularly. These authors and Larson *(61)* also stated that thorough hand washing after glove removal is necessary because of increased bacterial counts due to occlusion.

Durability of gloves when used with sanitizers. Washing of latex gloves with plain soap, chlorhexidine, or alcohol can cause glove micropunctures *(1, 25, 71)* and subsequent hand contamination *(28)*. Because liquids can penetrate gloves through undetected holes, washing of disposable gloves is not recommended. Durability usually is not an issue with single-use gloves, as typically used in the food service industry. However, after a hand rub with alcohol, the hands should be thoroughly dried before regloving because hands still wet with an alcohol-based hand hygiene product can increase the risk of glove perforation *(99)*. Care also should be taken regarding glove contact with hand and facility sanitizers because most glove types are adversely affected by contact with these chemicals *(79)*. Gloves of sufficient durability to withstand repeated washing and sanitizing can be cleaned up to 1,000 times better than the human hand *(12, 67, 86, 100, 103)*. Therefore, a multiuse glove would be an advantage if dexterity and heat buildup issues could be overcome. One innovative way of reducing the likelihood of hand contamination is the use of gloves impregnated with microspheres *(7, 14)*. When activated by light or moisture, these microspheres produce chlorine dioxide gas, generating a disinfecting microatmosphere. Barza *(7)* demonstrated that populations of *S. aureus, E. coli, Listeria monocytogenes,* and *Salmonella* Typhimurium on inoculated gloves decreased by 1 to 3 log units within 20 min after being exposed to light both on the outside of the gloves and on the hands of the wearer. These chlorine dioxide gas–generating microspheres also have been used in thin films for food packaging *(91)*. The FDA has posed no objection to these microspheres and has granted generally recognized as safe status to such packaging materials *(2)*.

The pros and cons of glove use, the different types available, their advantages and disadvantages for food processing and food service operations, and the chain of causation of contamination of a food through glove use was fully discussed by Michaels *(78, 79)*.

CONCLUSION

Although gloves provide an important barrier against food contamination, they cannot be used as a stand-alone hygienic measure. Hand washing should always be performed before donning gloves and after their removal. Hand cleaning also should be performed before handling clothing from a high-risk area, changing into clothing for work in a high-risk area, entering a food handling area, and handling RTE food and after using the toilet, handling raw food, handling food waste, carrying out cleaning duties, touching non–food contact surfaces (e.g., machines, power switches, buttons, and cell phones), blowing noses, and touching body parts. Whether glove use will become mandatory in all sectors of the food industry is still an open question. Arguments for glove use are (i) gloves protect the worker from foods that can cause damage to the skin, e.g., acidic ingredients, (ii) gloves protect the food from direct hand contact, (iii) glove use is easily observed to verify hygiene compliance, unlike assessing hand washing frequency and thoroughness, and (iv) gloves can be used to cover skin damage or infections. Arguments against glove use are (i) gloves can reduce operational dexterity and increase the risk of injury, (ii) higher levels of food contamination are possible in the event of glove failure, (iii) a small percentage of gloves have pinhole leaks that are not possible to detect before use, (iv) gloves can be worn for longer than they should be, (v) gloves give a false sense of security as a substitute for good hand hygiene practices, and (vi) gloves increase the risk of hand irritation. Studies in the United Kingdom revealed that compared with bare hands gloved hands can contribute as much if not more bacteria to RTE food products. Fingernail length, presence of jewelry, and glove durability are important determinants regarding the effectiveness of gloves for mitigating contamination risk. Fingernails for food service workers must not extend beyond the tip of the finger and must be neatly trimmed and smooth. Food workers should not wear false fingernails, fingernail adornments, or fingernail polish because these items may fall into the food and may harbor pathogens. Because most glove studies have been done with bacteria, the utility of gloves for preventing infections with norovirus or other enteric viruses has not been well studied. Thus, proper hand hygiene is essential in addition to gloving and other barriers. The best approach is to use multiple hurdles, including gloves, other barriers, and appropriate hand washing, to prevent transfer of bacterial, parasitic, and viral pathogens to food.

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