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Review

Outbreaks Where Food Workers Have Been Implicated in the Spread of Foodborne Disease. Part 7. Barriers To Reduce Contamination of Food by Workers

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ABSTRACT

Contamination of food and individuals by food workers has been identified as an important contributing factor during foodborne illness investigations. Physical and chemical barriers to prevent microbial contamination of food are hurdles that block or reduce the transfer of pathogens to the food surface from the hands of a food worker, from other foods, or from the environment. In food service operations, direct contact of food by hands should be prevented by the use of barriers, especially when gloves are not worn. Although these barriers have been used for decades in food processing and food service operations, their effectiveness is sometimes questioned or their use may be ignored. Physical barriers include properly engineered building walls and doors to minimize the flow of outside particles and pests to food storage and food preparation areas; food shields to prevent aerosol contamination of displayed food by customers and workers; work clothing designated strictly for work (clothing worn outdoors can carry undesirable microorganisms, including pathogens from infected family members, into the work environment); and utensils such as spoons, tongs, and deli papers to prevent direct contact between hands and the food being prepared or served. Money and ready-to-eat foods should be handled as two separate operations, preferably by two workers. Chemical barriers include sanitizing solutions used to remove microorganisms (including pathogens) from objects or materials used during food production and preparation and to launder uniforms, work clothes, and soiled linens. However, laundering as normally practiced may not effectively eliminate viral pathogens.

In this article, the seventh in a series on food worker–associated outbreaks, the discussion focuses on physical barriers to prevent food from being contaminated. Previous articles in this series reviewed the numerous foodborne outbreaks linked to food workers, and lack of hand hygiene, including lack of or improper use of gloves, was listed among the risk factors *(37, 95, 96)*. Other articles documented how easily hands can be contaminated in food preparation environments from contact with raw foods and from infected coworkers. Pathogens with low infective doses may be present on hands in high numbers and can be easily transferred to foods and/or food contact surfaces and can survive for long periods *(97–99)*. Barriers, including protective clothing, hand utensils, and food shields or sneeze guards, are widely used in food operations, particularly in retail food and food service environments, although the value of these barriers has not been thoroughly researched. No risk assessment has evaluated the degree to which these barriers reduce foodborne illness or which barrier is most effective. However, it is generally agreed that multiple barriers (hurdles) are better than one or two when producing, preparing, and serving food. The present article is a review of the use of various barriers, excluding gloves, for preventing food contamination. The use and effectiveness of gloves as barriers is addressed in the next article in this series *(100)*.

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PHYSICAL BARRIERS TO REDUCE CONTAMINATION

Building structure and design. Buildings for food processing operations should be constructed to limit the spread of pathogenic and spoilage organisms, especially where there are potential multiple sources of contamination, e.g., raw ingredients, workers' clothing and footwear, dust, and pests. Other sources may be the processing environment, e.g., air ducts, fans, eroded flooring, leaky roofs or drains, difficult-to-clean equipment, conveyor belts, and cleaning and maintenance tools such as mops. It is hard to know how much contamination within a facility is directly spread by workers and how much is associated with environmental conditions such as airflow and drains, but workers are instrumental in activities that influence all of these factors.

Buildings must be sufficiently secure to reduce any opportunity of external penetration that may cause damage to the operation. Many industries have established zones for different risks for contamination that require different monitoring and cleaning regimens. Depending on the type of operation, e.g., whether it has a total pathogen inactivation step, a facility may generally be divided into four zones (one, two, or three processing areas in addition to the nonprocessing areas) or two zones (high- and low-risk areas, more frequently used in Europe). These areas can include those for raw materials and receiving, mixing, and other precooking steps, where general good manufacturing practices apply, and cooking areas *(38)*.

The most critical area is called a primary pathogen control area (PPCA) or a high-risk area, where the food is subjected to no further microbial reduction or elimination steps. If the food were to be contaminated by pathogens at this point, a recall or a foodborne outbreak could result after the product reached the market. PPCAs include filling, packaging, and other postcooking areas where the food is at risk of exposure to the environment. The zone of least concern, e.g., zone 4, includes nonprocess areas, such as warehousing, loading docks, shipping, employee entrances, and offices, where the risk of food contamination is very low unless the packaging is damaged.

Movement of personnel and materials into PPCAs is controlled to various degrees depending on the type of operation. The more at-risk the product is for pathogen contamination, survival, and subsequent growth, the greater the need for physical separation. Physical barriers are essential to limit the entrance of pathogens such as *Salmonella* and *Listeria* to the PPCA from the areas where raw ingredients arrive and are stored. A PPCA would also reduce the risk of any potential tampering activity. Entry and exit doors of the buffer area to the PPCA are tightly fitted, internal cores are filled, and if necessary doors are equipped with self-closing devices to minimize movement of personnel and materials between zones. Strict control of the transport of cleaning tools into the PPCA should be maintained, for instance by using separate, color-coded equipment for each of the zones or areas.

Before entering the PPCA, personnel should follow established hygiene procedures in a buffer area or vestibule. These procedures should include replacement of clothing and/or shoes worn on the raw side of the processing area with clothing and/or shoes and protective garments designated for use in the PPCA. In large operations, dedicated workers, equipment, pallets, and utensils may be assigned to hygienic areas at the facility.

Hands should be washed and dried before entering the PPCA. A hands-free hand washing sink should be located at the noncritical end of the buffer area or just outside the buffer area on the noncritical side. At any hand washing station, the surrounding floor may become wet, and moisture should not be brought into the PPCA, especially if low-moisture foods are being processed. Wet environments and those containing raw products are prime areas where footwear can become contaminated, making it more likely that these contaminants, including pathogens, will be tracked into the food production and preparation zones. Contaminated footwear can spread these organisms over long distances, especially on wet floors. Boots artificially contaminated with a suspension of indicator organisms spread the organisms on a facility floor for up to 15 steps *(91)*. In a separate experiment, boots contaminated with a powdered soil were able to transfer the powder for up to 47 m on wet floors *(91)*.

Operators must ensure that protective clothing, including overboots, do not become contaminated during work. If contamination occurs, the clothing should be changed immediately, before moving to a different operation area. Although there should be no personnel moving between these zones, such movement can occur during plant tours or maintenance of equipment or when laboratory technologists collect environmental samples from different areas throughout the facility and machinery engineers carry out repairs. These individuals must follow the procedures outlined above.

Unfortunately, in food service facilities, multiple barriers against pathogen entrance and spread are more difficult to create because of the smaller size of these operations and the many food items being prepared by the same personnel. As indicated in previous articles *(96, 98, 99)*, the two main sources of pathogens for restaurants, catering companies, and institutions that lead to outbreaks are sick and asymptomatic infected employees and raw meat ingredients. Although building design may not be a priority during the inspection of food premises or the investigation of an outbreak, building structure can influence the risk posed from the transfer of pathogens by workers, including the location of toilet and hand washing facilities. Many of these operation zones are completely open, from food preparation to customer service. Improper design also influences traffic flow and may inhibit workers from washing their hands on a regular basis, not just after visiting the restroom.

Proper design of food service facilities was discussed by Giambrone *(33)*, with an example given of a food service operation at a medical center in Hawaii. The four different zones mentioned in the U.S. Food and Drug Administration (FDA) Food Code *(104)* were discussed, similar to those zones in food processing plants. The food service operation had good traffic flow off central hallways that avoided critical areas and minimized opportunities for cross-contamination during food preparation and handling. The author stated that tray assembly for hospital meals can be a critical control point for preventing food contamination for vulnerable patients.

The FDA Food Code indicates that all equipment, including washing machines used to clean dishware, glassware, and utensils, should be constructed to minimize niches where microorganisms can grow and to simplify cleaning *(104)*. The Code permits wet cleaning with detergents, acids, alkalis, hot water brushes, and high-pressure sprays, but unless these operations are effectively implemented, the environment may become contaminated, e.g., food particles and aerosols can be released when high-pressure hoses are utilized.

Utensils, linen, and single-use items should not be stored in locker rooms, toilets, or garbage rooms, under open stairwells, or where water or sewage may drip onto them. Although these recommendations may seem to be common sense, limited space in many operations has caused managers to be creative concerning storage of materials and equipment. Flooring should be nonabsorbent, especially in high-moisture areas. Toilets should be completely enclosed with a self-closing door. Exterior doors and openings should be designed to prevent entrance of insects and rodents. Air curtains are found mainly in processing plants, but some are designed for food service facilities to provide environmental separation and temperature and pest control. These curtains consist of an invisible air barrier created by a powerful fan. Typically positioned at doorways, air curtains and doors pull in conditioned air, accelerate it, and force it through an air curtain. These curtains can minimize transfer of food particles, dust, odors, and microorganisms between zones. Locations for air curtains include entrances, delivery doors, drive-through windows, patios, and dumpster areas.

For workers who harvest, sort, and package fruits or vegetables in the field, either no buildings or those of simple design are present, particularly in developing countries. Thus, the opportunities for worker contamination to and from the product are greater than in processed food facilities. Some of these field issues include portable (or no) toilet systems, limited access to potable water for hygienic purposes, and contamination from dust, irrigation water, and animal sources. Hygienic issues for farm workers were further discussed by Michaels and Todd *(59)*.

Barriers against aerosol contamination. Airborne microorganisms, including yeasts, molds, and members of the *Enterobacteriaceae,* are a major product spoilage concern in some food processing plants, and *Listeria monocytogenes* is the major pathogen of concern because it can be distributed though aerosols to ready-to-eat (RTE) food *(116)*. Aerosols generated by the high-pressure washing of floors can transfer bacterial cells away from the drain as intended but also onto surfaces where food is being processed a few feet above the floor *(39)*. Holah *(41)* at Campden BRI found that water droplets from high-pressure (pumped) spray jets on floor surfaces traveled 3 m in height and 7 m in distance, and aerosols from low-pressure hoses (those connected to city water lines) traveled 2 m in height and 3.5 m in distance.

The potential for infections of workers and patrons through aerosols at food service establishments is well established *(98)*. Fork lift vehicles and other moving machinery can create aerosols from floor dust or puddles in the food processing environment, but dollies and catering carts for moving cartons of supplies and food items have not been studied well enough to determine whether these vehicles pose a major concern for pathogen transmission in food service scenarios. Zorman and Jeršek *(117)* assessed levels of bioaerosols in different indoor environments, some of which reflected activities in food preparation areas. The areas they studied included a food service kitchen, cold and frozen storage areas, a restaurant, a meat processing facility, hospital wards and waiting rooms, an office, and a toilet. These authors found that 60.9% of air samples from public places and all air samples collected in food processing plants had higher concentrations of viable microorganisms than the suggested standard of <300 CFU/m^3. Because areas in meat processing facilities had the highest aerosol levels, handling of raw poultry and meat in food service establishments poses a risk of zoonotic infections by the aerosol route. Analysis of aerosol samples from eight types of food production facilities in the United Kingdom yielded total viable counts of up to 10^3 CFU/m^3 (range, 85 to 987 CFU/m^3); vegetable and meat operations had the highest counts, and dry goods and confectionery areas had the lowest *(42)*. The highest counts were associated with floor and equipment cleaning, walk-in freezers, and weighing areas. However, Helm-Archer et al. *(40)* found no direct relationship between microbial air quality and product contamination. The microbial counts in the products suggested that other sources of contamination were present, such as augers, conveyors, or sorting equipment. Periodic sanitation of the cooking area and an emphasis on the need to limit hand contact with potentially contaminated foods or food contact surfaces are necessary to keep microbial counts low.

The greatest risk for outbreaks of norovirus infection via aerosols occurs when an infected individual vomits within the food preparation area or the environment of the food service establishment. Aerosols are produced during expulsive vomiting or later cleanup of contaminated surfaces such as sinks, carpets, and washrooms with dry vacuum cleaners or cloths *(96)*. Aerosols also may be generated from contaminated clothing when the agitation speed in laundry operations is set too high *(113)*. A well-established risk for slaughterhouse employees is that of developing campylobacteriosis via aerosols of *Campylobacter* from handling and slaughtering contaminated birds *(72, 109)*.

Food operations should protect food and workers from contaminants such as dust, dirt, pests, and aerosols. As indicated in earlier articles on food worker–associated outbreaks *(37, 95, 96),* pathogens can arise from various sources to contaminate food and infect food workers. Consideration should be given to optimizing the operation of machines and equipment to minimize the movement of microorganisms through the air and to avoid high-pressure hosing of floors, drains, and equipment.

Food shields or sneeze guards as barriers. Despite a lack of scientific data that sneeze guards are effective for protecting food from airborne contaminants, most food businesses with a buffet, salad bar, or display of saleable RTE food use these guards. Sneeze guards, more often referred to as food shields or food protective devices, consist of a transparent barrier, usually glass or plastic, that is placed in front of and well above the displayed food to block contaminants expelled from a customer's mouth or nose. These guards may be as much for esthetic value as for real protection when customers with coughs and colds want to purchase unpackaged RTE food. In some circumstances, the properly positioned cover of a serving dish may be an acceptable alternative to a shield.

NSF International *(65)* has published a recent standard that includes food shields. This standard states that food shields shall be ''designed and manufactured to provide a barrier between the mouth of a customer and unpackaged food to minimize the potential of contamination of the food by a customer . . . but designed to minimize obstruction of a customer's view of the food.'' Specific information is given on the distances between vertical, horizontal, and angled panels. The zone of potential droplet contamination can be calculated by assuming an average mouth height of 4.5 ft (1.4 m) and 5 ft (1.5 m) and a service line height of 2.5 ft (0.8 m). The zone of potential droplet contamination is an area extending 2.5 by 2.5 ft from a point 2.5 ft directly above the customer edge of the service line to a point 2.5 ft directly in from the customer edge of the service line.

The food shield design is different when the food is for display only, the food is served by an employee, or the food is obtained through self-service, as in a buffet line. Illustrations of different types of guards are available in the Sonoma County buffet service guidelines *(84)*. Accessibility to food is important for sales, but a customer leaning over a food shield or a child reaching in from underneath negates the effectiveness of such a shield. Unfortunately, food shields probably cannot protect food from highly aerosolized particles such as viruses. This problem is particularly acute following projectile vomiting, by either a customer or an employee, when aerosols can be widely dispersed throughout the entire facility. Shields would likely prevent direct contamination of food with the vomitus but not indirect contamination by the aerosols generated and may give the management a false sense of security that the food in the immediate area can remain on display. When such vomiting events occur, all food being displayed and served should be discarded, and the facility should be completely cleaned with a chlorine compound before the display areas are restocked. Although such a vomiting episode probably is a rare event, outbreak investigators have identified a high number of cases associated with one or two vomiting occasions, illustrating the extent of virus spread and the fact that noroviruses can remain viable on surfaces for long periods *(37, 98)*.

Utensils. In food service settings, the FDA Food Code recommends that bare-hand contact with RTE food should be discouraged to prevent worker contamination of RTE foods and suggests that suitable utensils be used to work with food items *(104)*. Utensils adequate for dispensing foods include spatulas, tongs, scoops, spoons, ladles, single-use dispensers, and thin papers for grasping and weighing deli meats and serving bakery items. Some of these utensils also should be used for mixing foods and handling potentially contaminated foods such as raw meat, so that the hands of food workers are less likely to become contaminated.

A single-use item is an instrument, apparatus, utensil, or other object intended by the manufacturer to be used only once in connection with food. One example is disposable gloves (discussed further by Todd et al. *(100)*). Other such items are drinking straws, cutlery, disposable eating and drinking utensils, plastic containers for selling take-out food, cardboard boxes for pizzas, napkins, table covers, and other disposable wrappers or packaging materials used in contact with food. These items are typically made of paper, plastic, or polystyrene foam. However, some environmentally concerned operators want to limit the landfill waste and use ''green'' disposable, readily compostable products that decay rapidly. When food operations adopt a policy that includes single-use items to avoid risks of contamination, these items must never be reused. These items also must be protected from contamination until their use; specifically, they must not come into contact with food or the skin or mouth of a person.

Utensils that are not single use should be thoroughly washed and sanitized before reuse. However, in some operations utensils and papers tend to be used inconsistently or not at all. Some authors have described outbreaks in which utensils were used but were evidently contaminated by a food worker, e.g., a beverage mixture prepared with tap water from a bathroom sink using utensils stored beside a toilet *(20)*, tables and utensils used for both raw and cooked food preparation without appropriate cleaning *(112)*, or hands that touched food despite the use of utensils *(10, 11, 16, 17, 67)*.

Lack of proper utensil use was linked in the United Kingdom to *Salmonella* contamination in 934 catering premises that handled raw shell egg mixes *(36)*. *Salmonella* was detected in 0.13% of the egg mixes, 0.3% of environmental swabs, and 1.3% of cleaning cloths. The study revealed that on 40% of premises workers failed to use designated utensils when a prepared mix was added to other ingredients during food preparation; on 17%, workers did not clean surfaces and utensils thoroughly after use and before preparing other foods; and on 43%, staff did not wash and dry hands after handling eggs or a pooled egg mix.

The U.S. Foodservice and Packaging Institute conducted a survey of reusable versus single-use items with the help of the Clark County (Las Vegas), Nevada Health Department. Investigators visited 24 food service establishments, including coffee bars, restaurants, delicatessens, and nine child care centers *(4)*, and found that reusable items had higher total microbial levels than did single-use items. However, enterococci, coagulase-positive staphylococci, and coliforms were not recovered from any of the items tested. Thus, it probably is not the utensils themselves but rather hand contact that leads to contamination, and the use of such utensils can contribute to risky behaviors. Specialty cooks tend to be jealous of their equipment (i.e., wipes and knives) and may hide them between use to prevent other employees from using them. However, this behavior prevents inspection of this equipment by management *(87)*. NSF International *(65)* has provided specific standards for reusable utensils, including pots and pans, to minimize dead spots and encourage ease of cleaning, e.g., handles and handle assembly parts shall be closed at the point of attachment to the pot, pan, or utensil, and rims of pots and pans shall be easily cleaned.

Food preparation in developing countries may present other problems. Taulo et al. *(90)* investigated bacterial transfer to cooked thick porridge via wooden ladles and hands during serving in 29 households in rural Malawi. Stored household water used for hand and ladle washing was contaminated with *Escherichia coli* and *Staphylococcus aureus* from the hands of household members or from contaminated ladles used in food preparation. Hands became contaminated with *E. coli* and *S. aureus* at levels of 0.6 to3.7 and 2.2 to 4.3 log CFU/cm^2, respectively, after washing with contaminated water. Ladles were contaminated with *E. coli* at 0.9 to 3.2 log CFU/cm^2, and *S. aureus* contamination on ladles ranged from 1.9 to 4.6 log CFU/cm^2. Bacterial transfer from hands to food ranged from <1 to 3.6 log CFU/g for *E. coli* and 2.1 to 4.2 log CFU/g for *S. aureus*. Ladle surfaces transferred *E. coli* and *S. aureus* at 1.3 to 3.1 and 1.2 to 4.3 log CFU/g, respectively, to the food. Contamination of food by hands was significantly higher ($P < 0.05$) than that of ladles, and transfer of *S. aureus* was significantly higher ($P < 0.05$) than that of *E. coli*. Thus, although the traditional cooking of thick porridge inactivated *S. aureus* and *E. coli,* the porridge could become contaminated with bacteria during consumption using hands or when served onto plates with contaminated wooden ladles. Although these activities occurred in homes, food service establishments probably used the same procedures in similar scenarios, resulting in a risk of illness to patrons.

Bakery and deli papers. For decades, bakery and deli papers have been used as a barrier to bare hand touching when picking up food items or to avoid sticky or powdery food ingredients from soiling bare hands. These papers are single-use items and should be discarded or transported with food in the package and then discarded after transfer from the packaging. Although contaminated utensils and inappropriate utensil storage have been linked to contaminated food (especially street-vended foods) in a few foodborne outbreaks *(11, 20, 29, 67, 88),* or despite the use of such utensils hands touched food *(46),* no known outbreaks have been associated with improper use of disposable bakery or deli papers, paper towels, or napkins or use of any contaminated paper products *(5, 55).*

Microbial specifications for paper products include the so called ''dairymen's standard,'' a sanitation standard for milk carton material established more than 50 years ago that calls for paper products in contact with food to have microbial counts of $<$250 CFU/g *(51).* Paperboard products usually contain a variety of microorganisms originating from the process water or paper mill systems where they were manufactured or from the use of recycled materials *(81, 105).* Extensive testing and published reports, however, have revealed that new tissue paper products of the type used in bakery or deli papers are virtually free from bacterial contamination *(5, 55)* because the drying process used to obtain the thin paper substrate kills the vast majority of microorganisms found in paperboard pulp, leaving only spore-forming *Bacillus* spp. *(81, 89, 106).*

In some experiments, the die-off of food pathogens and their indicator bacteria (*E. coli, L. monocytogenes, Pseudomonas aeruginosa, Salmonella* Typhimurium, *Serratia marcescens,* and *S. aureus*) on paper products took place more rapidly than on other common food contact surfaces, such as stainless steel, enameled steel, ceramic tile, wood, glass, polyethylene, acrylic, sponge, and cloth *(57).* This survival difference helps explain the lack of reports of abuse of this paper barrier to transmission and the general acceptance of bakery and deli paper as a safe means for storing, holding, and transferring food items.

Pathogen growth and release to the environment occurs only when the paper is exposed to moisture *(5).* Therefore, paper products and cardboard packaging in food service environments must be maintained in appropriate clean, dry locations so that sanitary integrity can be maintained *(45).* Unapproved chemicals, such as those from pulp derived from reclaimed fiber extracted from industrial waste or from products used for shipping chemicals, are not allowed in paper products that contact food.

Packaging as protection. Packaging of food products is designed to protect the contents from physical damage and environmental contamination. Packaging is the last step in the process of delivering the product to the consumer at retail. Food packages have become much more robust, with plastic covers replacing cardboard boxes and brown paper wraps that will virtually eliminate penetration by both moisture and microorganisms and sometimes gases. However, food workers and purchasers must open packages to remove the desired products, thereby creating a potential for contamination and possible bacterial growth when there is no antimicrobial compound present. Consumers often forget this point, and the domestic refrigerator is a potential source of pathogen contamination.

Work clothing. Protective clothing, overalls, and equipment (e.g., gowns, laboratory coats, masks, and protective eyewear or face shields) used in medical and dental practices are rarely used in the food industry. In medical settings, the objective is to keep the patients' bodily fluids from infecting the wearer or to keep these fluids from being transferred to other patients. In food service establishments, the purpose of clothing is to act as a barrier to prevent the transfer of microbial contaminants from workers to the food supply. However, the effectiveness of clothing as a barrier has been mainly evaluated in health care environments.

Clothing becomes easily contaminated during work with unprocessed food ingredients such as raw meat and should be changed at appropriate intervals because pathogens are easily transferred from clothing to foods. Contamination transfer from clothing was demonstrated in a simulated hospital setting by Casanova et al. *(19),* who found that when surgical gowns were deliberately contaminated with both a nonpathogenic virus and GloGerm beads that fluoresce under UV light, removal of the gowns caused the gloved hands to become contaminated. Transfer of virus to both hands, the initially uncontaminated glove on the nondominant hand, and the scrub shirt and pants worn underneath the protective clothing was observed in most volunteers. Therefore, protective clothing, including eye shields when necessary, provide hazard barriers between workers and food but must be designed to be appropriate for the specific task and must be worn correctly. Clothing also may act as a source of contamination, e.g., buttons and other loosely attached parts on work clothing can fall into the food, or pockets may contain food particles from various operations, and these particles can later contaminate other food preparation operations.

Items in addition to clothing that totally covers the body are aprons, hair nets, snoods for facial hair, boots, and shoe covers. Employees are required to wear hair restraints such as hair nets, hats, scarves, or beard nets that are effective for hair control. For personal safety, hard hats are frequently mandated to be worn over hair nets in designated areas of most food manufacturing plants. Balaclavas, which cover the mouth, are frequently used in food processing environments to prevent contamination of product while workers speak. The New Zealand Food Safety Authority *(64)* Draft Poultry Code of Practice states that body hair must be managed to minimize contamination of product; hats (paper, cloth, and plastic), hair nets, beard nets, food industry balaclavas, or other items must be worn to contain hair on the head and face. However, protective clothing is not always worn or worn properly; some caps are more decorative than protective. A comprehensive review of head coverings and guidance on their use has been produced by Campden BRI *(15)*. A more detailed discussion of the need for and use of hair nets and head gear was given by Michaels and Todd *(59)*. Caps or hats may cover the head hair completely but do not address facial hair, which may be covered by snoods or nets. If hair nets are used, they must have a mesh size sufficiently small to prevent loose hair from escaping and falling onto food or food contact surfaces.

Outer protective garments that are disposable must be changed at appropriate intervals. Outer garments that are reusable must be laundered or cleaned using effective methods. Recently, concern has been expressed about ''lab coats'' worn by health care workers both inside hospitals and outdoors, and there has been some confusion about the health risks that these garments may pose. Loveday et al. *(48)* found that there was significant public concern in England about health care workers wearing uniforms in public places and that contaminated uniforms might contribute to the spread of health care–associated infections. The authors stated that small scale studies indicate that uniforms and white coats become progressively contaminated during clinical care, and the majority of microbial contaminants arose from the uniform or coat wearer, but there was no evidence that diseases in health care settings were transmitted via this type of clothing. Nurses' uniforms also have been implicated in the spread of microorganisms, leading to the widespread use of disposable white plastic aprons. One problem with these aprons is that the plastic attracts microorganisms through static electrical charges, posing a risk of infection to those in contact with these aprons. However, Allen and Henshaw *(3)* found that aprons made with antistatic materials had 38% fewer bacteria adhering to the surface compared with the other white plastic aprons.

Infrequent changing of lab coats is a contributing factor to the contamination problem in health care settings. At the University of Maryland, 65% of medical personnel confessed that they changed their lab coats less than once per week, although they knew these coats were contaminated, and 15% admitted that they changed them less than once per month *(52)*. In a 2004 study, 48% of neckties worn by a sample of New York City doctors and clinical workers carried at least one species of infectious microbe *(107)*. The American Medical Association (AMA) voted in June 2009 on a resolution that would recommend that hospitals ban doctors' white lab coats, citing evidence that such garments contribute to the spread of infection *(22, 107)*. If hospitals followed the AMA resolution and banned the white coat, what would doctors wear? The Scottish National Health Service outlawed white coats in 2008 and instituted a uniform of color-coded scrubs for all medical staff (doctors, nurses, and other employees) with a ''bare below the elbow'' hospital dress policy that bans long fingernails, ties, hand and wrist jewelry, and lab coats. In the United States, the Mayo Clinic does not allow white coats, and the doctors wear business attire *(22)*.

Although work clothing in many food operations has not received the same scrutiny as that used by workers in health care settings, food manufacturing audit bodies, e.g., the British Retail Consortium, require that fresh clothing be worn each day and that laundry from high- and low-risk areas be segregated. Regular laundering of garments or disposable overalls is necessary to prevent potential contamination of food.

In a South Wales *E. coli* O157:H7 infection outbreak, 157 persons became ill, and 1 child died. Butcher workers in that area wore the same clothes for handling cooked and raw meat and did not display appropriate concern for hygienic practices *(68)*. Clothing worn in the meat product factory consisted of white steel-toe Wellington boots (''wellies''), white trousers, jacket or coat, and apron. The steam-generated wellie washer did not work. Different color-coded uniforms were supplied for workers handling raw or cooked meat, but these uniforms were not always worn as directed. Although a laundry supply service was available, it was not always used. One employee stated that he kept his own set of clothing and took it home and washed it a couple of times a week because he did not think he would get the right size clothes back from the laundry. He also wore the same clothing when undertaking tasks in both the raw and cooked meat sections. Another employee said that when his clothes were not dirty, he would not need a clean set every day. Video evidence showed the storage of clean and dirty clothing together. Waterproof wellies, some with blood on them, were stored on top of clothing.

Although these scenarios may seem to be extreme examples of poor hygienic practices with clothing, they probably occur more often than can be identified during irregular inspections. This information indicates that clothing should be considered a potential source of contamination in food settings, with the additional risk of extraneous matter such as coins, buttons, and tissue paper entering the food supply. Clothing for workers, particularly those harvesting fruits and vegetables in fields, was further discussed by Michaels and Todd *(59)*. Outer clothing and footwear may need to be designed especially for operating under different environmental conditions. Goggles and masks should be used to prevent dust inhalation and eye damage.

Avoiding cross-contamination between food and money. Food and money are both handled at food service establishments when customers exchange coins and notes for food. At larger fast food locations, these operations are usually conducted by separate employees. However, on some occasions (e.g., rushed orders, staff shortages, and forgetful staff) bare or gloved hands touch coins or notes and then touch food items. In small local stores, especially those with extended hours or 24-h service, when only one or two employees are available to handle all the store activities, the likelihood for cross-contamination is much greater.

The possibility of money as a vehicle for transmitting enteric disease was first raised in the 1970s by Abrams and Waterman *(1)*, who found that 13% of coins and 42% of paper money were contaminated with potential pathogens (e.g., *E. coli, Pseudomonas,* and *Staphylococcus*). Michaels *(56)* reviewed studies of currency contamination in both the United States and other countries and found that handling money and RTE food with the same gloved hands without hand washing or another hygienic intervention between the two activities could result in cross-contamination, potentially spreading disease to customers.

Jiang and Doyle *(44)* showed experimentally that pathogens could survive on coins for many days. At room temperature, *E. coli* O157:H7 survived for 7, 9, and 11 days on the surfaces of pennies, nickels, and dimes or quarters, respectively, and *Salmonella* Enteritidis survived for 1, 2, 4, and 9 days on the surfaces of pennies, nickels, quarters, and dimes, respectively. The differential survival times, e.g., pennies versus quarters or dimes, may reflect the inactivation properties of copper. However, because the minimum infectious dose of *E. coli* O157:H7 is very low, Jiang and Doyle recommended that food workers use an intervention treatment such as washing hands after handling coins and before handling food.

In a more recent study of notes in Nigeria, heavy contamination with parasites and bacteria was found *(102)*. Of the 250 currency notes examined, 53.2% were contaminated with bacteria, i.e., *Streptococcus, Staphylococcus* spp., *E. coli,* and *Bacillus* spp., and 21.6% were contaminated with enteric parasite ova, i.e., *Ascaris, Enterobius, Taenia,* and *Trichuris*. Contamination frequency was related to the denomination level, physical condition (e.g., parasite contamination was most prevalent among dirty or mutilated notes), and place of transaction (e.g., highest contamination on notes from butchers, farmers, and beggars and lowest contamination on notes obtained from banks).

Pope et al. *(71)* confirmed that bills in common usage in the United States can be highly contaminated; 94% of 68 $1 bills carried bacteria, including *S. aureus* (3%). Despite increased public health agency awareness of global viral infections (e.g., avian influenza virus, severe acute respiratory syndrome, H1N1 virus, rotavirus, and norovirus), currency could be a harborage for these viruses; enteric viruses are known to survive well in the environment *(99)*. Unfortunately, no surveys of notes or coins for these pathogens have been completed, although the concern was raised by Michaels *(56)*.

The FDA Food Code *(104)* does not specifically provide a recommendation for handling currency in food service establishments. Although specific advice is not possible for all food service operations, general principles of good hygienic practices should apply. Employees should recognize that currency has the potential to spread disease, and the public should recognize that the handling of money and food by the same person is unhygienic and inappropriate in food service settings. Ideally, a worker should be assigned specifically to conduct all the financial transactions and must avoid touching fingers to mouth, face, and clothing before, during, and after counting bills or coins. When it is not possible to provide such a specialized employee, all employees should wash and dry hands after handling bills and coins and before touching food. When gloves are worn, they should be removed and hands should be washed before money is handled, and after money is handled hands should be rewashed before new gloves are donned. In general, when gloves are used, they should be changed frequently between tasks to avoid cross-contamination, and hands should be washed between glove changes.

CHEMICAL BARRIERS TO REDUCE CONTAMINATION

Laundering of clothing. Although contaminated clothing was not a major factor identified in outbreak investigations, such clothing probably exacerbates the risks if hands are contaminated with fecal matter or raw foods of animal origin and then outer clothing is touched, as described above. In another scenario, a food preparer changed a child's diaper and went to work without changing her clothing; this resulted in foodborne infections in 81 patients and 114 staff in four hospitals served by one central hospital kitchen *(47)*. A food handler who prepared the salads and became ill the day following food preparation had a young child at home who had been ill with a gastrointestinal illness during the previous 2 days. Contamination of food by mechanical transmission of the virus from the child via the clothes and hands of the mother is a likely explanation for virus transmission to the food. All four hospitals ceased to take new admissions for 10 days because of the outbreak.

Proper laundering of clothes will keep the pathogen populations low, even if the bacteria are not totally eliminated every time. Work clothing can easily become contaminated by microorganisms from environmental or personnel sources, and scrubs and other garments need to be replaced frequently or laundered. However, the efficacy of laundering for removing pathogens from soiled clothing and gloves has come under scrutiny. Early research showed that the laundering process relies on disinfection through washing, physical removal, dilution *(80, 83, 86, 111),* and the effects of soap and/or sanitizer and temperatures achieved during washing, rinsing, and drying *(6, 83)*. Hot water and dryer temperatures increase the overall sanitary quality of laundered fabrics *(83)*. However, aerosols from contaminated clothing may be created if the agitation speed in laundry operations is set too high *(113)*. In restaurants and other food service operations, clean and soiled linens should be kept apart, with soiled linens stored in nonabsorbent receptacles before transportation to a laundry *(103)*.

Cloth gloves are permitted only in food service establishments that handle food such as primal cuts, which are then subsequently cooked. These gloves can be worn under open mesh or Kevlar gloves if cutting is required to keep the hands warm because the metal conducts the cold, e.g., in carcass fabrication or meat cut trimming rooms. An example of cloth glove composition is a string knit blend of 35% cotton, 55% polyester, and 10% rayon for durability. These gloves are preshrunk and are washable up to 10 times. Cloth gloves also should be laundered between handling of different animal products, e.g., a worker cannot start work on beef after working with lamb or fish without donning newly laundered gloves *(104)*. Cloth napkins should be laundered between each use, and dry wiping cloths should be laundered as necessary to prevent contamination of food and clean serving utensils, but wet wiping cloths need to be laundered daily.

Although some institutions supply scrub apparel to staff, typically health care workers are responsible for laundering their own uniforms or scrubs at home. Home laundering is even more likely to be necessary in food service establishments where there are no laundry facilities on the premises. Laundering at home seems to provide effective decontamination of lab coats and uniforms and does not present a hazard in terms of cross-contamination of other items in the wash load with hospital pathogens even at the lower temperatures more commonly associated with domestic washing machines, e.g., 40°C *(48)*. However, home laundering may not be sufficient for heavily soiled work clothes or clothes with viral contamination, which was not examined.

The ownership of scrub apparel, the responsibility for laundering them regularly, and the oversight of their use solely at work requires an institutional policy decision because there are no standards for health care operations *(12)* or food processing or preparation establishments. In food operations, a 1.5-log reduction of microorganisms can be achieved by cleaning very dirty fabrics in heavily loaded washers with bleach. If automatic home washers are used to clean heavily soiled bed linen and clothes, a 2-log (99%) reduction can be obtained with water at 63°C and a 10- to 20-min wash cycle with a germicide added to the rinse *(31)*. Washing standard-sized loads should consistently reduce bacterial counts on fabrics by 3 log units from an initial load with an average of 10^8 CFU/100 cm^2. Under normal contamination conditions, washing soiled fabrics routinely produced fabric containing less than 1 CFU/cm^2 (6.5 CFU/in^2). Cleaning effectiveness is optimized with 20 min of presoaking and washer cycles using 40°C water and 0.3% detergent as a precursor to steam sterilization *(108)*. Even though in home laundering lower temperatures are more commonly used, a significant reduction of the microbial load can still be achieved *(12)*.

This research on laundering has been conducted for bacteria. Viruses are more difficult to destroy through laundering. Sidwell et al. *(80)* found that hot wash water was more important for reducing the polio virus titer than was the type of detergent used. Fabric type was not a major factor in the majority of the experiments, although virus tended to be eliminated more readily from nylon, and in warm water the virus persisted longer on wool blanket material laundered in anionic detergent. When the fabrics were dried 20 h after laundering, an additional decline in virus titers occurred, often to below detectable levels. Virus titers ranging from undetectable to $10^{3.9}$ cell culture 50% infectious doses per ml were obtained from samples of the rinse water after warm-water and cold-water laundering. However, this research was done with polio virus, a pathogen not likely to be encountered in food establishments.

Gerba and Kennedy *(32)* examined the effectiveness of home laundering of cotton cloths to eliminate enteric viruses that can have peak concentrations in feces of 10^{10} to 10^{11} particles per g. These authors found that washing cotton with detergent alone led to virus reductions of only 92 to 99% and that viruses are readily transferred from contaminated cloths to uncontaminated clothes. The most important factors for the reduction of virus in laundry were passage through the drying cycle and the addition of sodium hypochlorite. The use of sodium hypochlorite reduced the number of infectious virus particles on the cotton after washing and drying by at least 99.99%.

In summary, laundering practices commonly used in the United States do not eliminate enteric and respiratory viruses from clothes, and the use of bleach is recommended to reduce the numbers of enteric viruses. In an outbreak of methicillin-resistant *S. aureus* (MRSA) infection in prison inmates, an identified risk factor was the laundry *(101)*. Inmates who used the prison laundry to wash their personal items (odds ratio 23.89) or bed linens (odds ratio 3.9) were more likely to have an MRSA infection than were inmates who washed those items themselves, indicating that the laundry process was not sufficient to destroy the pathogen and allowed contamination of other clothing during washing.

The risk of infectious organisms reaching those doing laundry was stressed in the following recommendation. According to World Health Organization guidelines for community care facilities *(113),* two categories of used linen are recognized. When there is visible contamination by blood, feces, or other biological fluids, linen is considered ''contaminated,'' whereas other linen is considered ''soiled.'' These two categories of linen should be segregated and treated separately:

1. All linen should be handled with minimum agitation to avoid aerosolization of pathogenic microorganisms.

2. Contaminated linen may be a source of infection to patients and staff and should be placed in impervious bags for transportation.
3. Disinfection can be achieved by using hot water and/or bleach and using heavy-duty gloves, eye protection, and masks to protect against splashes.
4. Heavy-duty washers and/or dryers are recommended for hospital laundry.
5. Laundered linen should be autoclaved before being supplied to the operating rooms or theaters and high risk areas, e.g., burns units and transplant units.

No linen should leave the hospital premises unless it has been decontaminated. Service Executive Guidelines *(62)* recommend that ''soiled and foul linen'' should be subjected to water at a minimum of 65°C for 10 min or preferably 71°C for 3 min. Heat-labile clothing presents a problem because it can be washed at only 40°C (104°F) and dried with tumble driers operating at <60°C (140°F). The Guidelines also suggest that disinfection with hypochlorite is possible but not very effective when there is excessive soiling. Detergents and alkaline compounds are best added at the next-to-last step in the wash cycle, i.e., before the final rinse. Another potential disinfection process currently under investigation is the use of ozonated wash water. Preliminary investigations at Campden BRI *(82)* revealed that ozonated wash water reduced the number of *E. coli,* MRSA, and *Clostridium difficile* inoculated onto laundry swatches by about 1 log unit compared with wash water without ozone.

No experimental work has been done regarding removal of norovirus, including through the laundry process. However, because this virus is highly infectious and often present in high numbers in sticky vomitus, it is probably difficult to eliminate from clothing *(18)*. The California Department of Public Health *(48)* suggested the following precautions:

1. Put linens soiled with vomit or fecal matter in a plastic bag before sending them to the laundry.
2. Encourage staff working in the laundry to wear gloves, a mask, and a disposable gown (or to change their clothes) when physical contact with soiled linens is necessary.
3. Wash soiled clothing in hot water using any commercial laundry detergent and disinfectant.
4. Dry clothes in a dryer; the reliability of disinfectants other than those containing chlorine for killing norovirus is uncertain, and chlorine-containing (hypochlorite) solutions in a 1:100 (500 ppm) to 1:10 (5,000 ppm) dilution is recommended.
5. Clean carpets and soft furnishings with hot water and detergent or steam clean; dry vacuuming is not recommended.

In 1969, Gilbert *(34)* noted that meat cloths used for wrapping raw meats may be contaminated with *Salmonella* from slaughtered animals. We should also consider *Campylobacter* or *E. coli* O157:H7 as pathogens of concern for meat cloths today. Although such cloths are no longer permitted in most jurisdictions, Worsfield *(114)* found that some small butcher shops in the United Kingdom have used these cloths, with a lack of separation between cooked and raw meat items on display. The author recommended disposable cloths or paper for use on cooked meat surfaces or color-coded cloths for separating raw from cooked meats. Any raw meat product will have dripping blood and should be displayed and sold in a nonpermeable wrapping, as occurs in most retail stores today. However, street vendors in developing countries most likely need education in the hygienic value of the proper wrappings.

Avoidance or sanitation of cloth wipes and sponge products. Cloths and sponges have long been used in homes and food service facilities to handle hot items, wipe hands and food contact surfaces, clean food preparation areas, and absorb excess countertop water or grease. However, these cleaning items have been identified as major sources of microbial contamination because they accumulate food and soil and potentially compromise sanitary integrity. Surveys conducted over many years have revealed that pathogens such as *S. aureus, Clostridium perfringens,* and *Streptococcus faecalis* can be transmitted to hands, RTE food, or food contact surfaces from sponges, dish rags, dish cloths, towels, or meat cloths used for wrapping raw meat *(21, 27, 34, 54, 76–78)*. Through continual use, sponges and cleaning clothes or dish rags in commercial and consumer environments act as reservoirs for potentially hazardous microorganisms in the kitchen *(27, 49, 66, 110)*. Contaminated cleaning cloths and sponges also have been identified as risk factors in foodborne outbreaks and hospital-acquired infections *(43, 66)*.

Even though the use of sponges and multiuse wiping cloths is discouraged or even forbidden for food operations in many jurisdictions, these cleaning items are convenient for a quick, visible cleanup and continue to be implicated in risky practices. In 1969, Gilbert *(34)* noted that meat cloths used for wrapping raw meats may be contaminated with *Salmonella* from slaughtered animals; we should also consider *Campylobacter* and *E. coli* O157:H7 as pathogens of concern for meat cloths today. As previously discussed, in a study of small butcher shops in the United Kingdom, Worsfield *(114)* found that wiping cloths were frequently used inappropriately. A minority of these butchers (15%) did not clean the meat slicer until the end of the day, but most butchers claimed to provide periodic cleaning of the equipment as required. The cleaning procedure usually involved removal of food debris with a wet cloth and wiping or spraying of the slicer blade, guard, and base plate with sanitizer but rarely entailed the dismantling of the slicer and the sanitizing of component parts. Sanitizer was usually applied by means of a stockinette or cellulose cloth or a hand-held sprayer. Most butchers (75%) selected a cloth already in use for this cleaning task, but a minority (25%) used a new cloth or paper. Some (20%) cleaned the blade with the equipment turned on while holding a cloth to the rotating blade, claiming that this practice assisted cleaning. A minority (7%) used an alcohol-impregnated wipe for cleaning. The equipment was rarely rinsed with clean water and was generally left to air dry or was dried with a paper towel.

Inappropriate behavior in the kitchen, including improper use of wiping materials, is likely the cause of many sporadic illnesses *(73, 79)*. The degree of misuse of cleaning cloths and the opportunities for cross-contamination between raw and cooked meat were revealed in the investigation of two major *E. coli* O157 outbreaks, one in Scotland in 1996 and the other in South Wales in 2005 *(68)*. The investigation report of the Scottish outbreak (496 cases and 20 deaths) revealed a lack of separate cleaning schedules and equipment to reduce the risks of cross-contamination, e.g., separate knives, tables, scales, and vacuum packer *(69)*. In the South Wales investigation, one employee stated that he cleaned the body of the machine with hand washing solution and a cloth. The cloth was an ordinary household cloth and was changed about every 14 days. It was kept in the sink and was soaked in bleach overnight. Worn and dirty brushes also were used in the cleaning process. None of the machines was cleaned during the day, although sometimes they were wiped down by hand with a cloth and ''fairy liquid'' (mild detergent). There was no color coding of buckets, cloths, and cleaning equipment to differentiate uses such as toilets, sinks, or floors. Carcasses also were being wiped down with dirty cloths, and the same clothes were used during handling of raw meat and cooked products.

It is not surprising that wiping cloths have been implicated as factors leading to illnesses; these cloths can contain up to 3×10^{13} bacteria of 28 different species such as *Salmonella, S. aureus,* coliforms, and *Enterobacter* 14 to 15, 20, 31, and 50% of the time, respectively *(27, 30, 76, 85)*. Crockery and cutlery items wiped with these cloths also can become contaminated *(53, 76)*. Yepiz-Gomez et al. *(115)* examined dish cloths used to wipe tabletops in restaurants and found that the heterotrophic bacterial plate count on tabletops was 45-fold higher after than before wiping. Similarly, *E. coli* levels on tabletops were 19 times higher after wiping. Sharma et al. *(79)* summarized the extent of sponge and cloth contamination by *Campylobacter jejuni, L. monocytogenes,* and *S. aureus* and found that microwaving and dishwashing treatments significantly lowered ($P < 0.05$) aerobic bacterial counts more than did any chemical treatment. Cleaning effectiveness and cleanliness in food service establishments is significantly correlated with the microbial contamination level of wiping cloths ($P \leq 0.05$) *(93)*. An outbreak linked to wiping cloths was documented in England in 2007; a restaurant was forced to close after 17 diners contracted *Salmonella* after eating tiramisu made with raw egg. A wiping cloth used at the premises was found to contain the *Salmonella (94)*.

The warm, moist condition of kitchen wipes and the accumulated food scraps provide a ready environment for rapid bacterial growth *(27, 28, 53, 70, 74)*. Because liquid squeezed from sponges and dish rags can have extremely high microbial counts (up to 10^9 CFU per drop) *(27)*, workers' hands easily become contaminated through handling these items *(28, 30, 75)*. Even clean laundered cloth wipes or sponges can become heavily contaminated within a short time after initial use if they are not adequately sanitized *(14, 26, 27)*.

Disinfection of these objects with quaternary ammonium chloride sanitizers or detergent–chlorine bleach combinations is either not performed or is not efficient enough to eliminate contamination in heavily constructed, multilayer, saturated wiping cloths *(27, 76, 77, 85)*. Thus, reusable cleaning cloths should not be permitted at the commercial level *(92)*, and disposable towels or wipes are recommended *(8, 26, 35, 92)*. Bacterial counts and scanning electron micrographs confirm the attachment of bacteria to disposable gloves and cleaning tools associated with the preparation areas of RTE foods in retail delicatessens, suggesting that these gloves and tools may provide reservoirs for the bacterial contamination *(23)*.

In food manufacturing facilities, if cleaning tools and equipment such as scrapers, brushes, buckets, floor brushes, vacuum cleaners, and squeegees are not cleaned, sanitized, and maintained regularly they can become a source of contamination by *Listeria* and other pathogenic organisms. Because of the way it is used, this equipment can transfer microorganisms to many different areas. Cleaning equipment should therefore be specific to its zone or area of use, e.g., high risk, low risk, and type of surface it is used on (food contact surface versus non–food contact surface) *(60)*. After use, the tools and equipment should be thoroughly cleaned and, if appropriate, disinfected and dried, as per written instructions. Handheld equipment should be cleaned on a daily basis by removing any gross debris manually, cleaning with detergent, and submerging in a soak tank of disinfectant. Wall hanger systems also should be used for the tidy and hygienic storage of cleaning equipment. When used regularly in specific areas, cleaning equipment may be stored in trays of disinfectant until use. The chemical in these trays should be changed regularly, e.g., every 2 to 4 h, because any soil in the solution will neutralize the antimicrobial effect of the sanitizer.

Cleaning systems are more limited in food service establishments. Mops, brushes, and cloths should be boiled after use or discarded *(14)*, activities unlikely to be carried out in most food service establishments. Perhaps these types of cleaning items should not be present at all. The Manual of Naval Preventive Medicine *(63)* states that no dish cloths, dish mops, soap, or steel wool should be used for cleaning food utensils or food equipment. Viruses are more difficult to remove than bacteria, and cloths used for cleaning can actually transfer viruses to other environments. Barker et al. *(9)* found that detergent-based cleaning with a cloth to produce a visibly clean surface consistently failed to eliminate norovirus contamination. To eliminate contamination, it was necessary to wipe the surface clean using a cloth soaked in detergent and then apply the combined hypochlorite-detergent. When detergent cleaning alone or combined hypochlorite-detergent treatment failed to eliminate norovirus contamination from the surface and the cleaning cloth was then used to wipe another surface, the virus was transferred to the surface and to the hands of the worker.

The American Dietetic Association (ADA) recommends washing dish cloths and towels often using the hot cycle of a domestic washing machine, sanitizing sponges in a chlorine bleach solution (1 teaspoon [5 ml] of bleach added to 1 quart [0.9 liter] of water), and replacing worn sponges frequently. In an ADA survey, 49% of respondents self-reported that they changed their cloths, rags, or sponges daily or several times each week *(24)*, an optimistic proportion of the population in our opinion. When a sponge or cloth is used to wipe a drip from raw meat, this cleaning item must be cleaned and sanitized in a diluted bleach solution before it is used again. Bleach solutions must be prepared fresh at least daily. The ADA also recommends using different towels for different tasks, e.g., one for drying hands, another for drying dishes, and another for wiping the counter. A typical sanitation guideline for food service facilities states that wiping cloths are to be kept clean and stored in a sanitizing solution, and the use of sponges is not recommended.

The composition of sanitizing wipes is important. Several materials are known to inactivate some disinfectants; thus, compatibility between disinfectant and wipe is critical for quality control *(7, 50)*. A nonwoven wipe has significantly lower levels of viable aerobic and anaerobic vegetative cells and spores than does a cotton cloth wipe *(58)*. The lower activity of sanitizer when used with a cotton wipe can be explained by the positively charged functional portion of the quaternary molecule that becomes attached to the negatively charged fabric. This attachment reduces the effectiveness of the sanitizer, thus lowering the concentration of available sanitizer *(13, 50)*. This phenomenon is similar to that observed for binding of other organic materials, including protein *(2, 13)*, such as when heavy soils quickly destroy the effectiveness of hypochlorite sanitizers. When saturated with quaternary ammonium chloride sanitizer (200 ppm) and then cleaned in a wide variety of solutions and treatments, including washing machine cycles, the nonwoven wipe consistently and significantly ($P \leq 0.05$) became cleaner than did woven cloths treated under the same conditions (<5-log reduction). Some of the microfiber cloths tested by Moore and Griffith *(61)* transferred significantly less organic debris and microorganisms back to food contact surfaces than did other cloths. However, different makes of microfiber cloths have different characteristics, and the label ''microfiber'' should not imply superior cleaning efficacy. A more recent study, researchers evaluated the ability of 10 microfiber cloths to remove microbial contaminants from stainless steel, furniture laminate, and ceramic tile surfaces. Tests were conducted using MRSA, *C. difficile* spores, and *E. coli*. At the first and single use, none of the cloths significantly outperformed the others. Cloth performance overall, however, decreased with repeated use on a succession of contaminated surfaces. After repeated washing of reusable cloths, cloth performance improved after 75 washes and then declined after 150 washes, although in most instances performance after 150 washes was better than that after the first wash *(25)*. Thus, microfiber cloths can be used effectively in food environments but must be cleaned on a regular schedule. For practical purposes, disposable wipes in general may be more convenient.

CONCLUSION

Building design can have an impact on reducing the risks of pathogen contamination of food, but design modifications are more likely to be effective in food processing environments than in food service operations. In food service establishments, space is limited and personnel often perform multiple tasks, from handling raw material to serving customers and taking money. Little research has been done on the health risks associated with food handlers who wear outdoor clothing to work or on the effectiveness of utensils and food shields for preventing contamination of food. Single-use work clothes are not always practical or regularly changed, and laundered clothes should be worn in areas where workers come into contact with pathogens of human or raw food origin. Clean utensils can prevent direct hand contact but may allow cross-contamination between raw and cooked products. When these utensils are handled by employees, transfer of pathogens to RTE foods can occur. The risks from aerosol contamination are not known, and food shields have limited value for preventing such contamination, which can occur through sneezing *(98)* or through projectile vomiting, as demonstrated in norovirus infection outbreaks *(97)*. If there is a risk of aerosol transmission, it is best to discard all exposed food and sanitize food contact surfaces.

Because of the uncertain or limited effectiveness of some of these barriers, multiple hurdles are better than one or two hurdles, and when coupled with glove use and proper handwashing, these steps should minimize the opportunities for pathogens to reach the food being prepared. No single barrier can be completely effective for preventing contamination of food during preparation. Multiple hurdles are required to reduce the likelihood of pathogens reaching the consumer. Consequently, the use of a combination of physical and chemical barriers, and in some cases complete avoidance of an activity is most effective. Gloves are an additional barrier to prevent direct contact of hand skin with food and food contact surfaces, and their effectiveness is discussed in another article in this series *(100)*.

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