Water temperature as a factor in handwashing efficacy

Barry Michaels,* Vidhya Gangar,† Ann Schultz,† Maria Arenas,† Michael Curiale,† Troy Ayers‡ and Daryl Paulson§

*Georgia-Pacific Corporation, Technology Center, PO Box 919 (Hwy. 216), Palatka, Florida 32178, USA; †Silliker Research and Laboratory Services, 160 Armory Drive, South Holland, Illinois 60473, USA; ‡ABC Research, 3437 SW 24th Ave., Gainesville, Florida 32607, USA; and §BioScience Laboratories, PO Box 190, Bozeman, Montana 59771, USA

Correspondence:
Barry Michaels, Georgia-Pacific Corporation, Technology Center, PO Box 919 (Hwy. 216), Palatka, Florida 32178, USA. Tel: 386-312-1184. Fax: 386-312-1198. E-mail: bsmichae@gapac.com

Keywords:
antibacterial soap, handwashing, personal hygiene, skin damage, skin flora, water temperature

Abstract

For many years, sanitarians have specified that the hands of food service workers should be washed and rinsed in warm or hot water to reduce the risk of cross-contamination and disease transmission. In the food service environment, it has been suggested that handwashing with water at higher temperatures contributes to skin damage when frequent handwashing is necessitated, and that insistence on hot water usage is a deterrent to handwashing compliance. Separate handwashing studies involving different water temperatures and soap types (antibacterial versus non-antibacterial) were performed. The 'glove-juice' technique was employed for microbial recovery from hands in both studies. Initial work evaluated antimicrobial efficacy based on water temperature during normal handwashing with bland soap. Uninoculated, sterile menstrua (tryptic soy broth or hamburger meat) was used to study the effects of treatment temperatures (4.4°C, 12.8°C, 21.1°C, 35°C or 48.9°C) on the reduction of resident microflora, while Serratia marcescens-inoculated menstrua was used to evaluate treatment effects on the reduction of transient contamination. Results of this first study indicated that water temperature exhibits no effect on transient or resident bacterial reduction during normal handwashing with bland soap. The follow-up study examined the efficacy and skin irritation potential involving water temperatures with antimicrobial soaps. Hands of participants were contaminated with *Escherichia coli* inoculated ground beef, washed at one of two water temperatures (29°C or 43°C) using one of four highly active (USDA E2 equivalency) antibacterial soaps having different active ingredients (PCMX, Iodophor, Quat or Triclosan). Skin condition was recorded visually and with specialized instrumentation before and after repeated washing (12 times daily), measuring total moisture content, transepidermal water loss and erythema. Overall, the four soap products produced similar efficacy results. Although there were slight increases in Log_{10} reductions, visual skin irritation, loss of skin moisture content and transepidermal water loss at higher temperatures, results were not statistically significant for any parameter.

Introduction

A critical and thorough evaluation of simple handwashing procedures reveals numerous variables to be considered by food service managers in order to achieve maximum or appropriate de-germing of the hands and fingernail regions. Numerous studies have explored issues such as type of soap (i.e. antibacterial versus plain, liquid versus bar), amount of soap, nailbrush use, drying technique (i.e. cloth versus paper towels, paper towels versus air-drying), and application of instant hand sanitizers (postwash liquids). Previous studies indicate that these variables are crucial in achieving effective removal of transient bacteria from the hands under controlled testing conditions. Rarely mentioned in the scientific literature is testing to determine specific guidelines for water temperatures and flow rates. Many of the currently employed handwashing practices are based on untested traditions that could possibly result in compromised skin health. It is expected that warm or hot water would be beneficial in reducing bacterial counts from hands during handwashing, as heat provides energy for the increased solubility and melting of fats, oils and other soils which may serve as vehicles for bacterial transfer from hands. Warm/hot water, combined with the detergents present in soap, should theoretically provide greater emulsification of contaminating soils on the skin, resulting in a more efficient lifting of these soils for rinsing away.

Some food safety experts strongly recommend the use of antimicrobial soaps for food service workers, while others are now focusing on handwashing frequency. With the rise of antibiotic resistance, increased concern has been expressed with respect to antimicrobial soap usage. The reasoning has been that when warm/hot water is combined with antimicrobial soap, the temperature of activation is approached, accelerating chemical reactions and improving kill rates. Soil emulsification should allow for greater exposure of microorganisms in the contaminating soil to the antimicrobial active agents. Thus, bacterial population numbers may be reduced two ways: through soil emulsification and lifting/rinsing away, and inactivation provided by the antimicrobial agent(s) with higher temperatures doing a significantly better job. The infected food worker is the focus of improved hygiene measures, and food safety managers and regulators would be remiss to not try to optimize effectiveness. Asymptomatic food handlers have been identified as being responsible for approximately one-third of outbreaks traced back to the infected worker. Poor personal hygiene has been cited as a contributory factor in an average of 30% of foodborne illness outbreaks occurring in the U.S. between the years of 1973 and 1997 (Bean & Griffin 1990; Bean *et al*. 1996; Olsen *et al*. 2000). The vast majority of foodborne illness outbreak cases attributed to the infected food handler occurs in the food service environment (Michaels *et al*. 2002).

The main initiative in hand hygiene is the reduction of potentially pathogenic microorganisms from contaminated skin surfaces. Optimization of all variables involved in this task must not only provide sufficient removal and/or kill of potential pathogens, but must also refrain from damaging the skin, as this can affect handwashing compliance (Boyce and Pittet 2001) and seriously compromise food service safety. Skin damage associated with work from routine and frequent handwashing has also been seen to result in colonization of workers hands with potential pathogens.

With so many variables involved in such a 'simple procedure', it would make sense to explore and maximize all possible aspects of the process while minimizing negative collateral. This is especially important due to the many observations of food service workers revealing what is considered to be poor habits in handwashing techniques. Studies indicate that handwashing compliance drops considerably without supervision and monitoring, or in situations where skin damage occurs. This further amplifies the need to strengthen knowledge of all variables that might improve or weaken daily handwashing practices throughout the food processing and service industry.

As described by Price, two types of flora exist on the hands, transient and resident species (Price 1938). The transient flora is generally removed fairly easy. They do not have adhesion characteristics that hold them to the skins' surface and are somewhat suppressed by secretions and competitive exclusion by the resident flora (Dunsmore 1972). Resident flora is removed more slowly. Because of coevolution, resident flora have adapted to conditions on the skins' surface that cause rapid die-off of most transients. Invaginations such as the nail fold, hair follicles and sebum-producing sebaceous glands support a rich resident flora. Transient flora may consist of pathogens, spoilage bacteria or harmless environmental species. Under certain conditions, transient flora can change status and become permanent residents. Resident flora, as a rule, are not pathogenic types. Although colonization with coagulase-positive staphylococcus is fairly common (Noble & Pitcher 1978). Frequent or prolonged exposure of the skin to microbial contamination in soils, skin damage or fissures provide portals of entry to deeper tissue, and may result in many pathogenic bacteria found among the resident species (Price 1938; Kaul & Jewett 1981). Food workers in a number of different food industry segments (including catering and bakery) have been found colonized by varying numbers of potential pathogens (Seligman & Rosenbluth 1975).

The effective water temperature used for washing and rinsing hands was a topic of intense discussion at the U.S. Year 2000 Conference for Food Protection. This biannual conference assembles federal and state regulators, food safety academicians, food service industry scientists and safety managers to establish and recommend guidelines to the United States Food and Drug Administration (FDA) for inclusion into the FDA Model Food Code. This code, as adopted by individual US states, forms the basis for food safety regulation and enforcement activities to the food service industry. Several submitters of issues, brought before science and technology council (Council III), expressed their concern regarding the use of higher water temperatures as recommended of the food service/processing industry (Table 1). The United States Food and Drug

Table 1 Submitters and handwashing water temperature issues at the year 2000 Conference for Food Protection

Submitter	Issue	Reason
L. Wisniewski (Select Concepts – Consulting)	'Warm Water'	1. Hand Discomfort Decreases Frequency
M. Scarborough (Georgia Department of Human Resources, Division of Public Health)	37.7°C (100°F)	1. No Science (43°C vs. 37.8°C) 2. Plumbing Code @ 100°F Max. (Safety Concerns)
J. Budd (Healthminder/Sloan Valve Company)	35°C (95°F)	1. No Scientific Basis 2. Max Soap Efficacy at 35°C 3. Hand Comfort 4. Hot Water Discourages Hand Washing
E. Rabotoski (Wisconson ConferenceFood Protection)	'Tempered' 29.5°C (85°F) to 43°C (110°F)	1. Hand Discomfort 2. Possible Scalding
B. Adler (Minnesota Department of Health)	Impose Temp. Range 43°C 110°F To 54.4°C (130°F)	1. Need upper limit or subject to OSHA 2. Food workers Don't Wash 25 Sec. So Cannot Scald.
Reimers (H.E.B. Grocery Company)	'Tempered' To Warm	1. No Science . 2. Max Soap Efficacy 3. 43°C Risks Injury 4. Waste Water as Wait for Temp. at 43°C

Administration (FDA) Food Code provides recommendations for the food service industry to follow regarding food handling practices, application of HACCP principles and personal hygiene implementation (US Public Health Service 1999; US Public Health Service 2001). The main goal of the FDA has been the creation of uniform practices throughout all of the United States. The 1999 FDA Food Code requires sinks used for handwashing to be equipped so as to be 'capable of providing water of at least 43°C (110°F), accomplished through use of a mixing valve or a combination faucet' [tap] (US Public Health Service 1999).

All but one of the submitters requested temperature decreases with the intent of improving hand comfort, as the discomfort associated with higher temperatures results in decreases in hand washing frequency or compliance. Several submitters note a lack of scientific information on the subject. There is concern that a minimum handwashing temperature of 43°C (110°F), in addition to causing discomfort, will result in injury or scalding and may even be in conflict with local plumbing codes. Two submitters point out that soaps currently available target maximum effectiveness at around 35°C (95°F). Two submitters requested that the minimum temperature of 110°F (43°C) be changed to warm water or that it be tempered to a range of 85°F (29.5°C) to 110°F (43°C). and finally, one submission sought to place an upper temperature limit of 130°F (54.4°C), for fear that these regulations would be subject to Occupational Safety and Health Administration (OSHA) scrutiny and criticism without a limit. Interestingly, it was noted in this submission, through reference to the Consumer Product Safety Commission, that second or third-degree burns have been shown to occur in the elderly at temperatures not much over 43°C (110°F). Council I and the General assembly of voting delegates passed a recommendation to lower the regulatory water temperature minimum to 29.5°C (85°F). In recognition of concern expressed by a number of stakeholders with regards to the issue of handwashing water temperature, the initial results of the work described in this report and the will of state voting delegates, the 2001 Food Code lowered the required handwash water temperature to 37.8°C (100°F) (US Public Health Service 2001).

The universe of food handling situations requiring effective personal hygiene spans from temporary handwash stations set up in produce fields and county fairs to advanced state of the art clean room style kitchens used to produce extended shelf life ready-to-eat foods sold at retail. In quick service restaurants, workers frequently switch between food and money handling. Due to the potential for money to carry potential pathogens, as described by Michaels, hands may require washing from up to 40 times or more in an 8-h shift (Michaels 2002). In many of these situations, it is difficult to provide water meeting strict temperature ranges. With regard to international settings, it is doubtful that underdeveloped parts of the world will easily be able to tap into warm/hot water supplies, much less into clean water sources at all. Water temperature shortcomings have been a common point of criticism by food safety experts when reviewing handwashing procedures in the developing world as part of HACCP activities. Further, no matter where the location, it is difficult to manage and monitor food handlers to insure that minimum temperature levels are maintained during all handwashing activities. When subject to regulatory inspections, in the U.S., violations are given to food industry entities based on Food Code specifications. In some cases, based on accumulation of violations with water temperature being one of them, mandatory 48 h closure can result. This appears to be both costly and unnecessary based on the results of the studies described here.

In an extensive literature review of the effect of water temperature on hygienic efficiency, only two existing experimental studies shed light on this issue. Both of these involved hand sampling studies, in which the objective was to remove, identify and enumerate as many bacteria on the hands as possible, either as normal or transient flora. In hand scrubbing experiments, Price found that at temperatures from 24°C (75.2°F) to 56°C (132.8°F) there was no difference in de-germing rate (Price 1938). Since he scrubbed hands with a brush for a specific period of time, each in turn in a series of sterile wash basins, he might have been capable of seeing differences upon counting the flora in each basin. After conducting over 80 experiments in a 9-year period, Price concluded that the largest variable in determining the rate of removal of bacteria from the hands was the vigorousness of scrubbing. Other factors such as soap used or water temperature were less important. In later hand sampling experiments by Larson and others (implementing the glove juice method for recovery of microorganisms), no differences in isolation rates were seen at either 6°C (42.8°F) or 23°C (73.4°F) (Larson *et al.* 1980). While this information is inconclusive and does not answer questions concerning bacterial loads suspended in a confounding soil, they tend to indicate that there may not be a noticeable difference in efficacy over a range of temperatures from 6°C (42.8°F) to 56°C (132.8°F).

Various menstrua have been used for handwashing efficacy studies. For studies involving transient flora, the most often used soil is tryptic soy broth (TSB). Microorganisms exhibit good survivability, with even distribution of contaminating microorganisms into skin cracks, creases and invaginations being possible. Ground beef probably represents the most appropriate menstrua because of concern for risks of *E. coli* O157:H7 infection, but is only occasionally used (Sheena & Stiles 1982; Stiles & Sheena 1985). Meade and others have shown numerous sporadic cases of foodborne illness have been tied to poor personal hygiene after ground beef preparation (Mead *et al.* 1997). In addition, due to it's viscosity, thixotrophic properties and level of organic soil, it would appear to be a good surrogate for fecal material.

A review of pertinent literature was also undertaken to determine if, independent of efficacy, facts on skin damage support a lowering of the temperature. The Consumer Product Safety Commission (CPSC) has noted that residential water heater thermostat settings should be set at 49°C (120°F) to reduce the risk of the majority of tap water scald injuries. Although the majority of scalding attributed to the home occur in children under the age of five and the elderly, third-degree burns are known to result in a two second exposure to 66°C (150°F), six-seconds at 60°C (140°F) and 30 s at 54.4°C (130°F) (US Consumer Product Safety Commission 2000). As we age, our skin becomes thinner, loosing suppleness. This fact is important as many seniors are now actively involved in the food service industry. Due particularly to the elder risk, some have recommended that water be delivered from the tap at even lower temperatures of less than 43°C (110°F) (Stone *et al.* 2000).

The activity of soaps, friction and rinsing become crucial since the temperatures recommended in handwashing water alone would not provide thermal destruction of pathogenic microorganisms. Relevant to the discomfort issue associated with hot water is a previously conducted study by Horn and Briedigkeit involving dishwashing soaps (Horn & Briedigkeit 1967). In that study, participants were only able to withstand water temperatures at 43°C, 45°C, and 49°C (110°F, 113°F and 120°F), with tolerance levels due to discomfort peaking at one-minute (Horn & Briedigkeit 1967). Even though considerably longer than the 10–25 second exposure period that would result from handwashing, it is indicative of the fact that temperatures from 43°C and upwards (110°F and upwards) are at or near the human discomfort threshold.

Friction has been described as a key element in removing microbial contaminants from hands (Price 1938; Kaul & Jewett 1981). Friction applied during hand drying is instrumental in finishing the process (Madeline & Tournade 1980; Knights *et al.* 1993; Michaels *et al.* 2002). Removal of transient flora appears to be even more friction dependent than removing resident flora. Surfactant and antimicrobial compounds in soap are responsible for lifting soil and killing microorganisms suspended in the soil. When using bland soap to wash hands, handwashing efficacy appears to be dependent on the effects of surfactant action of the soap along with friction applied during the washing and rinsing process. Rinsing also provides the necessary removal by dilution. To facilitate appropriate rinsing of the hands, some personal hygiene consultants have suggested the practice of using thicker, higher viscosity soaps in larger doses, which would require a longer, more vigorous rinsing routine.

Price, upon noticing that in his scrubbing experiments that water temperature had little effect at degerming of the skin, commented that water applied to the skin at a given temperature quickly reaches equilibrium with normal skin surface temperature unless hands are totally immersed (Price 1938).

Skin oils derived from sebum are liquid in the sebaceous gland and solidify on the skin surface. Beef tallow has a melting point range between 35°C and 40°C (95°F and 104°F), while lard or butterfat are liquefied at around 30°C (86°F) (Lide 1990). If handwashing efficacy for both resident and transient floras embedded in both natural and artificially applied fats depended on thermal melting, then log10 reduction figures should have been greatest at the highest temperature and least at temperatures causing fats and sebum to congeal.

Fats such as tallow or lard are distinguished from oils in that the latter are liquids at room temperature. Hand soap formulations are designed to lift soil through their foaming action, dispersing and solubilizing organic soils through action of detergent surfactants. Primary micelles are formed, having hydrophilic and hydrophobic groups attached to each end of the surfactant monomer. Soaps with multiple surfactants form mixed micelles, which increases efficiency with various soil mixtures. In water and organic soil mixtures, these form complex micelle structures around hydrocarbon moieties (encapsulation) resulting in microemulsions. Thus, the soap provides a 'bridge' between the oily droplet and water, permitting the soapy water to 'wash away' greasy material.

Materials and methods

The quantity of soap used for handwashing has the ability to effect handwashing efficacy, as shown by Larson (Larson *et al.* 1987). Various investigators (Michaud *et al.* 1972, 1976; Ojajarvi 1980; Stiles & Sheena 1987; Mahl 1989; Larson *et al.* 1990; Rotter & Koller 1992; Miller & James-Davis 1994; Paulson 1994) have used soap amounts in the range of 2.5–5.0 mL in their handwashing efficacy protocols. The higher levels are considered excessive, except in the area of hospital infection control. Many food service operations set soap dispensers at 1 mL per pump, and employees often times use multiple pumps. For this study, 3 mL of soap was chosen to represent an amount found to be significantly effective in an earlier study described (Larson *et al.* 1987).

Determination of appropriate handwashing duration for these studies (15 s) was arrived at through review of various governmental regulatory standards, test method guidelines and food safety specialist recommendations along with previous handwashing study observations. Suggested lathering times by specific entities are: The 1999 FDA Food Code (US Public Health Service 1999) (20 s), The American Society for Testing and Materials (American Society for Testing and Material 1995) (15 s), The Association for Professionals in Infection Control and Epidemiology (APIC) (Jennings & Manian 1999) (minimum of 10 s), and The American Society for Microbiology (American Society For Microbiology 1996) (a 10–15 second vigorous scrub). Several studies support a washing duration of at least 10 s, with sufficient transient removal efficiency achieved by 30 s. A study by Stiles and Sheena involving workers in a meat processing facility determined that a wash of 8–10 s was too short for adequate soil removal from the hands (Stiles & Sheena 1987). A study by Ojajarvi compared a 15 second and 2 minute wash, with the latter providing only an additional 3% transient bacterial reduction (Ojajarvi 1980). One observational study in food service indicates average duration times of 20 s in a silver service restaurant kitchen (Ayers 1998).

In our first study, the effects of water temperature on the reduction of both resident (normal) and transient bacteria during handwashing was performed at each of the following temperatures: 4.4°C (40°F), 12.8°C (55°F), 21.1°C (70°F), 35°C (95°F), or 48.9°C (120°F). Two separate laboratories participated in this work. Silliker Laboratories (South Holland, IL, USA) was responsible for transient flora experiments while BioScience Laboratories (Bozeman, MI, USA) performed normal flora studies. For transient flora studies, the experimental subjects' hands were artificially contaminated with Serratia marcescens in Tryptic Soy Broth (TSB) or irradiated ground hamburger. Sterile, uninnoculated TSB and irradiated ground hamburger were used as confounding soils in testing for the reduction of the resident flora. Following hand contamination, baseline microbial counts were acquired using the 'glove-juice' method on one hand. Hands were moistened and washed/lathered for 15 seconds with 3 mL bland (nonantibacterial) soap, rinsed for 10 seconds (water flow rate of 7 L/minute) at the assigned water temperature (also used for the prelather moistening), and the opposing hand was then sampled using the same glove-juice technique. No drying of hands was performed, which would have had the effect of diminishing differences between experimental groups. Baseline and postwash readings were then compared to obtain bacterial reduction values. For this study, no skin condition assessments were performed.

The first study was performed using a non-antibacterial soap and examined temperature effects on bacterial reductions based on the solubility of greasy soils. It did not address the increased temperature effect on antimicrobial activation or possible skin damage. Therefore, the second study was undertaken, which not only involved a comparison of the microbial reduction effects of four antibacterial soaps at two different temperatures, but also evaluated skin conditions on the hands of participants throughout the study. The potential of each soap to cause negative skin changes at each water temperature combination was assessed by measuring the skin moisture content, rate of water loss from the skin, skin scaliness by computerized analysis of a digitized skin image, and by visual assessment of the dryness and erythema. This study was performed at BioScience Laboratories, employing eight subjects and using four different antimicrobial soaps, each having a different antimicrobial active ingredient. The soaps had antimicrobial activity equivalent to USDA E2 ratings (50-p.p.m. chlorine equivalency). The active ingredients in these products were Quaternary Ammonium (3% dual Quat formulation), Triclosan (1%), Parachlorometaxylenol (PCMX-3%), and Iodophor (7.5% PVP-I). Participants consisting of paid volunteers performed multiple handwashes during two five-day test periods (weeks one and two) seven days apart using *Escherichia coli* (ATCC #11229) contaminated gamma irradiated ground beef. On days one through five of weeks one and two, the skin condition was evaluated visually, for moisture content using the Corneometer® CM825, for total evaporative water loss using the TC350 Tewameter, and digitally using the Skin Visiometer® SV 500 with Visioscan® VC98. The visual skin dryness and erythema (redness) scoring was performed by a single blinded (unaware of subjects antimicrobial soap product/water temperature configuration) evaluator trained in assessment of skin damage or irritation using a 0–6 scoring system (see Table 2) as originally described by Griffith and others (Griffith *et al.* 1969). Log_{10} reduction data was determined with the first wash of days one, three and five under each water temperature condition. After handling the contaminated ground beef in a way to uniformly contaminate hands, one hand was sampled immediately (again, using the 'glove-juice' technique) for a baseline reading. The subjects' then washed both hands at the specific water temperature (85° ± 2°F for week one and 110° ± 2°F for week two) with their randomly assigned product with their opposing hand being sampled to establish microbial counts. Each subject then washed 11 consecutive times with their assigned test product each day drying hands between washes, then hands were evaluated visually and digitally 30 minutesfollowing the last wash. In all washing cases, lathering was performed for 15 seconds and rinsing for 10 seconds with three mL of the assigned test product.

Table 2 Grading scale for evaluating the skin of the hands*

Grade	Description
0	No visible damage, 'perfect' skin
1	Slight dryness, ashen appearance, usually involving dorsum only
2	Marked dryness, slight flaking involving dorsum only
3	Severe dryness dorsum, marked flaking, possibly fissures in webs
4	Severe flaking dorsum, surface fissures possibly with slight palmar dryness
5	Open fissures, slight erythema (>10% of dorsal and interdigital surface), with or without severe dryness, no bleeding
6	Bleeding cracks, deep open fissures, or generalized erythema (>25% of area)

*Griffith *et al.* 1969.

Results and discussion

After extensive statistical analysis of the results from the first set of experiments, it was determined that there was no significant difference in bacterial $\log_{10}$ reductions for either resident or transient bacteria at any of the test washing and rinsing temperatures. See Figs 1 and 2 for transient and resident flora data, respectively. Average $\log_{10}$ reduction results for each soap are presented in Fig. 3.

After extensive statistical analysis of the second experiment with antibacterial soaps involving the 2 sample *T*-test, Kruskal–Wallis test and Mann–Whitney test, no statistical difference in $\log_{10}$ reductions was detected between the two wash temperatures for any of the products or as a group. Overall, the four products produced similar handwashing efficacy results. Although most of the washes at the higher temperature did produce a slight increase in bacterial reductions, it was not enough to be considered statistically significant. Figure 4 shows Tewameter® readings measuring *trans* epidermal water loss, while Figs 5 and 6 show visual dryness and baseline adjusted Corneometer® values, respectively. Skin scaliness values using a Visiometer® are shown in Fig. 7. Along with the slight additional reduction of bacteria at the higher temperature was increased skin visual dryness, increased transepidermal water loss and decreased scaliness, also determined to be statistically insignificant. Skin scaliness is highest on day one and two at the higher temperature but for days three, four and five, this reverses.

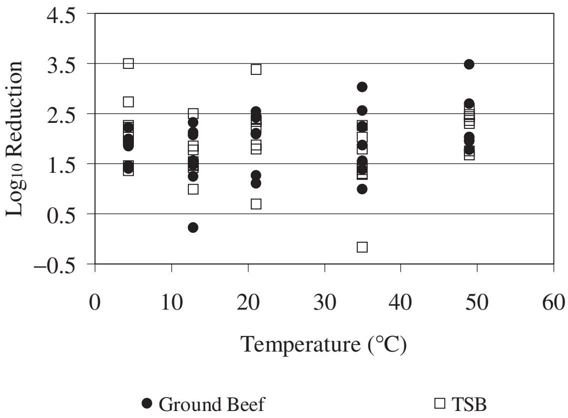

Figure 1 Handwashing efficacy (Log_{10} reduction) for transient flora (*S. marcescens*) in ground beef and TSB at selected water washing and rinsing temperatures.

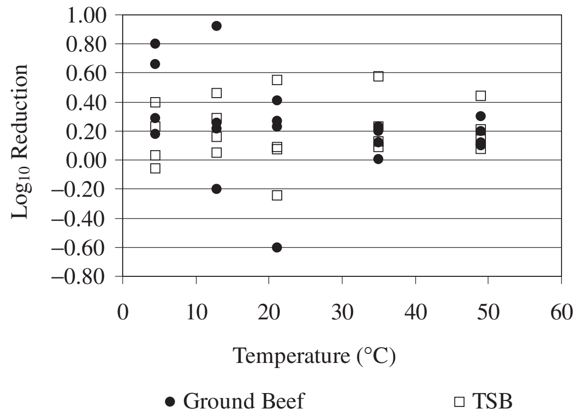

Figure 2 Handwashing efficacy (Log_{10} reduction) for resident flora in ground beef and TSB at selected water washing and rinsing temperatures.

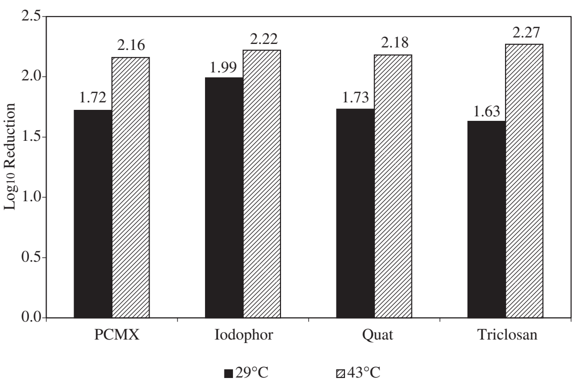

Figure 3 Average Log_{10} reduction of transient flora (*E. coli*) in ground beef using selected antimicrobial soaps.

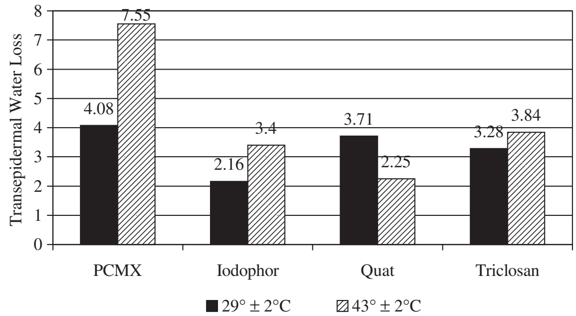

Figure 4 Average Tewameter® readings selected antimicrobial soaps at 2 different water temperatures.

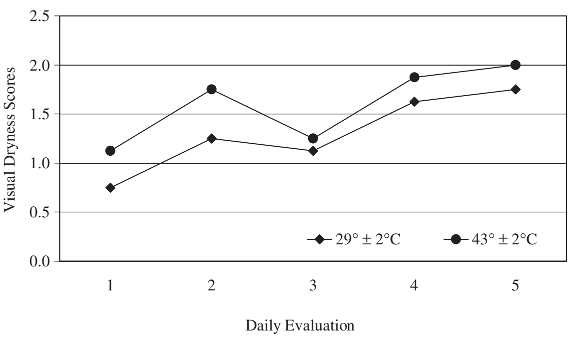

Figure 5 Average baseline-adjusted visual dryness scores (8 subjects) resulting from washing hands with 4 different E2 antimicrobial soaps for 5 days (12 ×/day).

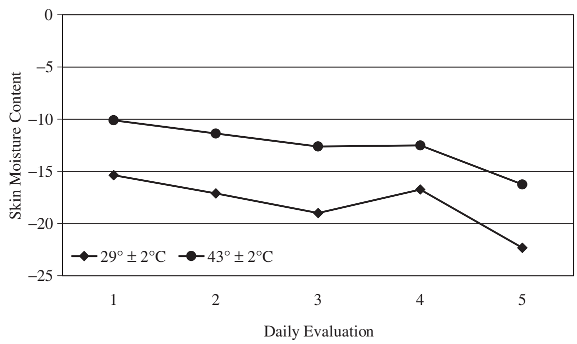

Figure 6 Baseline-adjusted Corneometer® readings (8 subjects) resulting from washing hands with 4 different antimicrobial soaps for 5 days (12 ×/day) at two different handwashing temperatures.

It is conceivable that the higher temperatures more rapidly removed loose layers of stratum corneum.

The results from both of these experiments are in agreement regarding the lack of hygienic benefits of washing hands at higher water temperatures and particularly at temperatures at the upper end of human tolerance, sometimes described as 'hot as you can stand'. From the first study, it is realized that higher water temperatures have no significant effect on the

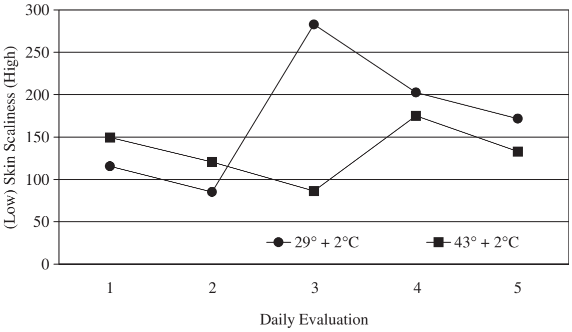

Figure 7 Average baseline-adjusted skin scaliness (8 subjects) resulting from washing hands with 4 different antimicrobial temperatures as measured using Visiometer®.

reduction of resident or transient bacteria in either easy to remove soil (TSB) or difficult to remove soil (ground beef) when using plain soap at a wide range of temperatures and using a standard hand wash. The second study provides additional support to the results of the first study by showing no statistically significant effect for the use of 110°F water (compared to 85°F water) to remove transient microorganisms embedded in ground beef from the hands when using any one of four different antibacterial based soaps or antibacterial soaps as a group. This experiment did show the trend toward higher kill as well as higher level of skin damage supporting propositions put forward by both camps. Log_{10} reductions do reflect slightly greater efficacy at higher temperatures but not at the level of significance expected, most probably due to the rapid equilibration to hand temperature described by Price (Price 1938).

Water has been identified as a skin irritant in its own rite, and part of this irritant potential can be exacerbated by temperature increase (Tsai & Maibach 1999). Repeated water exposure causes extraction or dilution of natural moisturizing factors in the stratum corneum. The water-holding property of the stratum corneum is provided in part by intercellular lipids and lipid rich sebaceous gland secretions (Noble & Pitcher 1978). The intercellular lipids, which when chromatographically fractionated, can be separated into cholesterol, cholesterol esters, phospholipids, free fatty acids, glycolipids and ceramide (Noble 1975; Imokawa *et al.* 1986). Loss of these lipid components results in a chapped and scaly skin appearance (Imokawa & Hattori 1985). Water induced irritation is known to exist in workers involved in continuous wet work, resulting in chapped and dry skin after wet work is completed (Halkier-Sorensen & Thestrup-Pedersen 1991).

Instances of primary irritant dermatitis to certain chemicals has been found to occur when hot water at 43°C (110°F) was used rather than lukewarm at 23°C–25°C (73°F–77°F) (Rothenborg *et al.* 1977). Detergent/surfactant formulations are known to cause changes to the stratum corneum such as disaggregation, swelling and morphological deterioration of corneocytes (Shukuwa *et al.* 1997). It has been found that heat plays a part in accelerating irritation of certain chemicals found in these detergent formulations. Berardesca and others found a significant difference between the temperatures of 20°C and 40°C (68°F and 104°F) in skin irritation to 5% sodium lauryl sulphate solution for a 4-day exposure period (Berardesca *et al.* 1995; Ohlenschlaeger *et al.* 1996). This irritation is documented using transepidermal water loss (TEWL) measurements, erythema (skin redness), skin reflectance, hydration (capacitance) and desquamation (stripping). Gross hand edema has been found to occur at temperatures between 35°C (95°F) and 45°C (113°F) when hands are completely immersed at those temperatures (King 1993). A significant increase in blood flow has also been shown in comparisons between 37°C and 43°C degrees (99°F and 110°F) (Nagasaka *et al.* 1987). Overall, these studies tend to show that food service workers derive no significant measurable benefit by using hot water (105°F +) to wash and rinse hands. Use of water at higher temperatures does seem to result in physiological changes collectively described as skin damage. There may be severe consequences of frequent use of hot water for handwashing at temperatures above 43°C (110°F), which can damage skin and heighten susceptibility to both allergens present in the food service environment and/or colonization (Larson *et al.* 1998). Rather, water temperature should be set at what is considered comfortable and generally conducive to handwashing.

The central components of effective handwashing thus consist of soap use in a way that promotes emulsification of soil (through vigorous friction/mechanical action) followed by thorough rinsing and drying, which again adds friction to the equation. Guidelines for handwashing in food service should probably not specify water temperature descriptors other than perhaps the word ‘comfortable’ when it comes to defining effective handwash standards. ‘Warm’ or ‘tempered’ would probably be acceptable, but more importantly as indicated by Jennings and Manian (1999), ‘running water’ should be to rinse away emulsified soils and associated transient contamination. Fingertips should be pointed down and hands rinsed and dried in a way to focus on parts of the hand that have shown to be missed during normal handwashing. This includes fingertips, thumbs and fingernail regions.

Conclusions

A review of the literature on the subject of handwashing water temperature requirements showed considerable variation with respect to expert opinion on optimal temperature for removal of microbial contaminants form hands. There in fact was a virtual absence of data to back up the various positions on the subject. Sanitarians and food safety experts have specified water temperatures varying from room temperature (running water) up to 'as hot as you can stand', the latter of which is probably in the range of from 49°C (120°F) to 55°C (131°F). Regulations in the US and elsewhere tend to focus on temperatures between 43°C (110°F) and 49°C (120°F). Concern that these temperatures could be detrimental to skin health without documented efficacy led to the experiments described here. Hands were contaminated with soils similar to those encountered in the food service environment. These soils contained marker bacteria allowing handwashing efficacy to be determined at specified water temperatures against both transient flora and resident flora simultaneously.

The initial experiment involved testing with bland non-antimicrobial soap at 5 temperatures from 4.4°C (40°F) to 49°C (120°F). Independent of soil or bacterial type (resident or transient) there was no significant difference in efficacy attributed to water temperature. In the second experiment antimicrobial soaps (4) were used having different antimicrobial active ingredients, at each of two water temperatures, 29.5°C (85°F) and 43°C (110°F). Skin condition was monitored with frequent handwashes (12 ×/day) for the second set of water washing temperature experiments. In this experiment, even though slightly higher efficacy with was seen with antimicrobial soaps at higher temperatures, overall, there was no statistical difference in efficacy as measured in Log_{10} reduction at the two water temperatures (regardless of soil or microflora types). Concomitant to the increase in efficacy at higher temperatures was a consistent trend for increases in measures of skin damage, such as skin moisture content, transepidermal water loss and erythema. This was also found not to be statistically significant.

Both the trend for higher efficacy of soaps with attendant skin damage at higher temperatures are grounded in theory. Under the conditions of these experiments neither was shown to be proven for practical application. Since efficacy is not markedly improved at higher temperatures but rather the real danger exists of skin damage, requirements for specific handwashing water temperature should be relaxed to improve acceptance of frequent handwashing by food workers at appropriate times to reduce foodborne illness potential. Water temperature should be in a comfortable range, perhaps tempered.

As has been shown by many previous researchers, overall handwashing effectiveness is more dependent on the vigorousness of execution than details such as the type of soap, the length of handwash or in this case water temperature. The results obtained in these experiments confirm the observations made by Price (Price 1938) and Larson (Larson *et al.* 1980) indicating water temperature had little or no effect on the removal of bacteria from hands. While their original reports dealt with optimizing skin sampling efficacy, for the types of experiments performed and described in the current report.

Unfortunately, food service regulatory authorities, health inspectors and environmental health officers in the US and elsewhere have fixated on handwashing water temperature because it is measurable and in the somewhat mistaken belief that higher temperatures would result in cleaner hands. Up until recently, the existence of adequate hygiene facilities (functioning toilet, toilet paper, functioning sink, soap and paper towels) and water temperature measurement were to some extent the only measurable qualities whereby food safety inspectors could cite food service facilities for violation. Poor personal hygiene is often used after the fact to describe as a contributing factor aiding to an outbreak. With handwash monitoring devices employees' handwashing can be monitored, documented and verified within the HACCP framework (Michaels 2002). With this new technology and information from this report indicating that water temperature for handwashing is relatively unimportant, perhaps regulatory authorities will be able to focus on other more important factors having a bigger impact on food safety.

References

American Society For Microbiology. Handwashing Survey Fact Sheet. (1996). *American Society for Microbiology.* 9–25.

American Society for Testing and Material. (1995). Standard test method for evaluation of health care personnel handwash formulation by utilizing fingernail regions. *American Society for Testing and Material* E1327–E1390.

Ayers T (1998). Assessment of Variables Associated with Effective Handwashing. University of Florida, Department of Food Science and Human Nutrition: Gainesville, Florida, USA.

Bean NH, Goulding JS, Frederick CL, Angulo J (1996) Surveillance for Foodborne-Disease Outbreaks – United States, 1988–92: Morbidity and Mortality Weekly Report. Centers for Disease Control, Surveillance Summary **45** (**5**):1–66.

Bean NH, Griffin PM (1990). Foodborne Disease Outbreaks in the United States, 1973–87. *Pathogens, Vehicles, and Trends in Journal of Food Protection* **53**: 804–17.

Berardesca E, Vignoli GP *et al*. (1995). Effects of water temperature on surfactant-induced skin irritation. *Contact Dermatitis* **32**:83–7.

Boyce JM and Pittet D Centers for Disease Control and Prevention (CDC) (2001). Draft Guideline for Hand Hygiene in Healthcare Settings. The HICPAC/SHEA/APIC/IDSA 2001 Hand Hygiene Task Force and the Healthcare Infection Control Practices Advisory Committee, CDC, Atlanta, pp. 1–56.

Dunsmore JM (1972). The Effect of Hand Washing on the Bacteria of Skin. *Australian Journal of Dairy Technology* **27**:137–40.

Griffith JF, Weaver JE, Whitehouse HD, Pool RL, Newman EA, Nixon CA (1969). Safety Evaluation of Enzyme Detergents. *Oral and Cutaneous Toxicity, Irritancy and Skin Sensitization Studes Cosmetic Toxicology* **7**:581–93.

Halkier-Sorensen L, Thestrup-Pedersen K (1991). Skin physiological changes in employees in the fish processing industry immediately following work. *Contact Dermatitis* **25**:19–24.

Horn H, Briedigkeit H (1967). On epidemiological and hygienic aspects of the use of modern dishwash detergents. *Zentralbl Gesamte Hygiene* **13**:334–6.

Imokawa G, Akasaki S, Hattori M, Yoshizuka N (1986). Selective recovery of deranged water-holding properties by stratum corneum lipids. *Journal of Investigative Dermatology* **87**:758–61.

Imokawa G, M.Hattori. (1985). A possible function of structural lipids in the water-holding properties of the stratum corneum. *Journal of Investigative Dermatology* **84**:282–4.

Jennings J, Manian FA (1999). APIC Handbook of Infection Control. Association for Professionals in Infection Control and Epidemiology, Inc.: Washington, DC, USA.

Kaul AF, Jewett JF (1981). Agents and Techniques for Disinfection of the Skin. *Surgery Gynecology Obstetrics* **152**:677–85.

King TI 2nd (1993). The effect of water temperature on hand volume during volume tric measurement using the water displacement method. *Journal of Hand Therapy* **6**:202–4.

Knights B, Evans C, Barrass S, McHardy B (1993). Hand drying: an assessment of efficiency and hygiene of different methods. A survey carried out by the Applied Ecology Research Group for the Association of Makers of Soft Tissue Papers: University of Westminster, UK.

Larson EL, Butz AM, Gullette FL, Laughon BA (1990). Alcohol for surgical scrubbing? *Jounal of Infection Contrological and Hospital Epidemiology* **11**:139–43.

Larson EL, Eke PI, Wilder MP, Laughon BE (1987). Quantity of soap as a variable in handwashing. *Infection Contrology* **8**:371–5.

Larson EL, Hughes CA, Pyrek JD, Sparks SM, Cagatay EU, Bartkus JM (1998). Changes in bacterial flora associated with skin damage on hands of health care personnel. *American Journal of Infection Contrology* **26**:513–21.

Larson EL, Strom MS, Evans CA (1980). Analysis of three variables in sampling solutions used to assay bacteria of hands. type of solution, use of antiseptic neutralizers, and solution temperature. *Journal of Clinical Microbiology* **12**:355–60.

Lide DR (1990). Handbook of Chemistry and Physics. CRC Press: Boca Raton, Ann Arbor, Boston.

Madeline P, Tournade F (1980). Hand drying by means of disposable products and with hot air. *Le Prevention Bucco – Dentaire* **4**:24–5.

Mahl MC (1989). New method for determination of efficacy of health care personnel hand wash products. *Journal of Clinical Microbiology* **27**:2295–9.

Mead PS, Finelli L, Lambert-Fair MA *et al*. (1997). Risk factors for sporadic infection with *Escherichia coli* O157 H7 *Archives of Internal Medicine* **157**:204–8.

Michaels B (2002). Focus on personal hygiene through HACCP. *International Food Hygiene* **12**:18–21.

Michaels B, Griffith C, Badawid S *et al*. (2002) Risk assessment of food warkers hygiene practices and intervention strategies. *Journal of Food Protection* **65**(sup A):148.

Michaels B, Gangar V, Ayers T *et al*. (2001). The significance of hand drying after handwashing. In: *Culinary Arts and Sciences III* (eds. Edwards JSA & Hewedi MM), pp 294–301, Al-Karma Press, Al-fayoum.

Michaud RN, McGrath MB, Goss WA (1972). Improved experimental model for measuring skin degerming activity on the human hand. *Antimicrobial Agents Chemotherapy* **2**:8–15.

Michaud RN, McGrath MB, Goss WA (1976). Application of a gloved-hand model for multiparameter measurements of skin-degerming activity. *Journal of Clinical Microbiology* **3**:406–13.

Miller ML, James-Davis LA (1994). A field study evaluating the effectiveness of different hand soaps and sanitizers dairy. *Food and Environmental Sanitation* **14**:155–60.

Nagasaka T, Hirata K, Nunomura T, Cabanac M (1987). The effect of local heating on blood flow in the finger and the forearm skin. *Canadian Jouranl of Physiology Pharmacology* **65**:1329–32.

Noble WC (1975). Skin as a microhabitat. *Postgrad Medical Journ* **51**:151–5.

Noble WC, Pitcher DG (1978). Microbial ecology of the human skin. *Advance Microbiology Ecology* **2**:245–89.

Ohlenschlaeger J, Friberg J, Ramsing D, Agner T (1996). Temperature dependency of skin susceptibility to water and detergents. *Acta Dermatologica Venereologica* **76**:274–6.

Ojajarvi J (1980). Effectiveness of hand washing and disinfection methods in removing transient bacteria after patient nursing. *Journal of Hygiene (London)* **85**:193–203.

Olsen SJ, MacKinnon LC, Goulding JS, Bean NH, Slutsker L (2000). Surveillance for foodborne-disease outbreaks – United States, 1993–97. Morbidity and Mortality Weekly Report Centers for Disease Control, Surveillance Summary. **49** (**1**): 1–62.

Paulson DSA (1994). Comparative Evaluation of Different Hand Cleansers. *Dairy, Food and Environmental Sanitation* **14**:524–8.

Price PB (1938). The bacteriology of normal skin; a new quantitative test applied to a study of the bacterial flora and the disinfectant action of mechanical cleansing. *Journal of Infectious Disease* **63**:301–18.

Rothenborg HW, Menne T, Sjolin KE (1977). Temperature dependent primary irritant dermatitis from lemon perfume. *Contact Dermatitis* **3**:37–48.

Rotter ML, Koller W (1992). Test models for hygienic handrub and hygienic handwash: the effects of two different contamination and sampling techniques. *Journal of Hospital Infection* **20**:163–71.

Seligmann R, Rosenbluth S (1975). Comparison of bacterial flora on hands of personnel engaged in non-food and food industries; study of transient and resident bacteria. *Journal of Milk Food and Technology* **38**:693–7.

Sheena AZ, Stiles ME (1982). Efficacy of germicidal hand wash agents in hygienic hand disinfection food handlers. *Journal of Food Protection* **45**:713–20.

Shukuwa T, Kligman AM, Stoudemayer TJ (1997). A new model for assessing the damaging effects of soaps and surfactants on human stratum corneum. *Acta Dermatologica Venereolgy* **77**:29–34.

Stiles ME, Sheena AZ (1985). Efficacy of low-concentration iodophors for germicidal hand washing. *Journal of Hygiene, Cambridge* **94**:269–77.

Stiles ME, Sheena AZ (1987). Efficacy of germicidal hand wash agents in use in a meat processing plant. *Journal of Food Protection* **50**:289–95.

Stone M, Ahmed J, Evans J (2000). The continuing risk of domestic hot water scalds to the elderly. *Burns* **26**:347–50.

Tsai TF, Maibach HI (1999). How irritant is water? An overview. *Contact Dermatitis* **41**:311–4.

US Public Health Service (1999) Food and Drug Administration Food Code. US Public Health Service. National Technical Information Service, Springfield.

US Consumer Product Safety Commission (CPSC) (2000) Tap Water Scalds. US Consumer Product Safety Commission. Document 5098, CPSC Publications, Washington.

US Public Health Service (2001). Food and Drug Administration Food Code. US Public Health Service. National Technical Information Service, Springfield.

Journal of Food Protection, Vol. 73, No. 10, 2010, Pages 1937–1955

Review

Outbreaks Where Food Workers Have Been Implicated in the Spread of Foodborne Disease. Part 9. Washing and Drying of Hands To Reduce Microbial Contamination

EWEN C. D. TODD,[1]* BARRY S. MICHAELS,[2] DEBRA SMITH,[3] JUDY D. GREIG,[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]*Campden BRI, Chipping Campden, Gloucestershire GL55 6LD, UK;* [4]*Public Health Agency of Canada, Laboratory for Foodborne Zoonoses, 160 Research Lane, Unit 206, Guelph, Ontario, Canada N1G 5B2; and* [5]*6110 Troon Lane S.E., Olympia, Washington 98501, USA*

MS 10-004: Received 7 January 2010/Accepted 13 April 2010

ABSTRACT

During various daily activities at home and work, hands quickly become contaminated. Some activities increase the risk of finger contamination by pathogens more than others, such as the use of toilet paper to clean up following a diarrheal episode, changing the diaper of a sick infant, blowing a nose, or touching raw food materials. Many foodborne outbreak investigation reports have identified the hands of food workers as the source of pathogens in the implicated food. The most convenient and efficient way of removing pathogens from hands is through hand washing. Important components of hand washing are potable water for rinsing and soaps to loosen microbes from the skin. Hand washing should occur after any activity that soils hands and certainly before preparing, serving, or eating food. Antimicrobial soaps are marginally more effective than plain soaps, but constant use results in a buildup of the antimicrobial compound on the skin. The time taken to wash hands and the degree of friction generated during lathering are more important than water temperature for removing soil and microorganisms. However, excessive washing and scrubbing can cause skin damage and infections. Drying hands with a towel removes pathogens first by friction during rubbing with the drying material and then by wicking away the moisture into that material. Paper rather than cloth towels should be encouraged, although single-use cloth towels are present in the washrooms of higher class hotels and restaurants. Warm air dryers remove moisture and any surface microorganisms loosened by washing from hands by evaporation while the hands are rubbed together vigorously; however, these dryers take too long for efficient use. The newer dryers with high-speed air blades can achieve dryness in 10 to15 s without hand rubbing.

This article is the ninth in a series of articles concerning food workers and foodborne illness. In the first three articles, the authors described the types of outbreaks that were identified during a review of 816 outbreak investigation reports and discussed how workers contributed to these outbreaks. In the next three articles, the authors discussed infective doses, pathogen carriage, sources of contamination, pathogen excretion by infected persons, and transmission and survival of pathogens in food environments *(72, 220–224)*. The seventh article contained an outline of the various barriers, some more effective than others, created to prevent microbial and physical contaminants from reaching food during production and preparation *(226)*. The eighth article considered the benefits and liabilities of glove use *(225)*. The present article includes the rationale for hand hygiene and the need for removing as much soil as possible from the hands, the use of different hand soap types, the conditions for effective hand washing, and the importance of complete drying of the hands. After leaving home and arriving at work, food workers must wash their hands effectively before starting food preparation so pathogens are not transferred to food from the home and outdoor environments.

Episodes of diarrhea frequently occur in all populations. In the United Kingdom, an estimated one in five persons experiences an intestinal infectious disease episode per year, with similar rates in the remainder of Europe *(237)*. A telephone-based population survey conducted in 1996 and 1997 across U.S. FoodNet sites revealed about 1.4 episodes of diarrhea per person per year *(87)* compared with an apparent improvement to 0.72 episodes for the years 1998 and 1999 *(95)*. However, Imhoff et al. *(95)* stated that the differences probably could be explained by the questions asked (diarrhea alone and vomiting and diarrhea) and the different populations surveyed rather than any real change in patterns. In a later study in four developed countries, Scallon et al. *(200)* found that at least one episode of diarrhea was reported by 7.6% of respondents in Canada, 7.6% of respondents in the United States, 6.4% of respondents in Australia, and 3.4% of respondents in Ireland for a 4-week study period. These percentages

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

translate to approximately one episode of diarrhea per year for each person in the United States and Canada and a slightly lower rate for Australia. These surveys indicate that the incidence of intestinal infectious disease with diarrhea is unacceptably high for developed countries.

A large percentage of these illnesses are contracted in the home *(28)*. Child care givers in England washed their hands with soap after changing a dirty diaper only on 42% of observed occasions, and one in five toilet users did not wash their hands with soap afterward *(43)*. After diapers were changed, fecal contamination was found in living rooms, bathrooms, and kitchens and on faucets and soap dispensers. A study of illness transmission in Boston, MA, households with children enrolled in child care centers revealed that although both gastrointestinal and respiratory illnesses are frequently transmitted between family members, only two-thirds of survey respondents correctly believed that contact transmission was important for spread of colds, and less than half thought contact transmission was important for spread of gastrointestinal illnesses such as the ''stomach flu'' *(121)*. There was limited understanding of how changing diapers or eating foods prepared by a person with gastroenteritis were risk factors for becoming infected with a pathogen. Parents reported washing their hands very frequently after changing a diaper or using the toilet, although they did not necessarily believe that fecal-oral transmission was important. However, the authors thought it was also likely that the parents overreported the frequency of hand washing after bathroom use because of perceived social expectations. Most respondents used soap; only 8% of respondents reported using alcohol gels ''most'' of the time following potential fecal contamination of hands. However, the authors stated that the effectiveness of soaps and alcohol against enteric pathogens depends on the agent involved and the product and that alcohol is an excellent virucide when used for rotavirus-contaminated surfaces but is not as effective against noroviruses. Hand washing with plain soap may actually further spread virus contamination.

Food workers may have their hands contaminated from various sources, even if they are not suffering from enteric infections or are asymptomatic carriers. Food workers have their hands frequently contaminated with *Staphylococcus aureus (48), Listeria monocytogenes (99),* coliforms and staphylococci *(92), Escherichia coli (181),* and *Salmonella (49)*. Staphylococci are common colonizers of the nasopharynx and can be transferred via mucus and saliva to hands when the face is touched, which frequently occurs *(222, 223)*. Danielsson and Hellberg *(46)* found that in clinically well meat workers, enterotoxin-producing *S. aureus* and *Staphylococcus epidermidis* were present in 22% of nasal swabs, 6% of throat swabs, and 4 of 16 superficial skin lesions. They also found that 42% of workers with ''slight colds'' harbored staphylococcal species in their noses. Unlike hand contamination with staphylococci from the nasopharynx, the enteric bacteria that contaminate the hands of food workers more often are associated with raw foods of animal origin rather than poor personal hygiene after visiting the toilet. In contrast, workers in plants preparing foods from nonanimal sources, e.g., vegetables, cookies, or chocolate, or in offices or laboratories have relatively few *Enterobacteriaceae* contaminants on their hands *(181, 208)*. Workers must be particularly dedicated to proper hand hygiene to avoid contamination of foods during preparation.

HAND WASHING

Rationale for hand washing. Hand washing is both an esthetic and sanitary process that removes dead skin cells, sweat, sebaceous secretions, associated resident bacteria, transient microorganisms, and any organic material adhering to the hands. Price *(186)* proposed that there are two sets of bacterial flora: resident and transient. The transient organisms include the pathogenic bacteria, viruses, and parasites obtained through contact with other persons, the environment (including water, sewage, and animals), unprocessed food or ingredients, and food contact surfaces. An effective hand wash method should remove most transient and resident microorganisms and is typically facilitated by the use of soaps, detergents, and antimicrobial compounds. However, hand washing never achieves sterility because of the presence of the resident skin flora, and hands can become recontaminated with transients immediately after the washing and drying process if they come in contact with a contaminated surface or an infected person. However, some antimicrobial soaps will inhibit transient bacteria from attaching if these soaps have been used over a period of time and compound residues have built up on the skin. The efficacy of microbial removal depends on the type and level of microbial and organic matter contamination present, the use of potable versus nonpotable water, the wash time, the type and volume of soap used, the extent to which the fingers, palms, backs of hands, subungual area beneath the nails, and wrists are exposed to the washing process, and the amount and vigorousness of the rubbing of fingers and palms during rinsing. The principles of hand washing are universal; they do not change because of gender, skin color, or size of the hand. Thus, the information in this article applies to all persons involved in the food or health care industries, and these hygiene measures also should be encouraged at home.

Many studies have been conducted to demonstrate that hand washing can be effective for removing bacteria from hands and reducing the spread of foodborne illness and respiratory disease in numerous household situations *(3, 79, 81, 90, 100, 180, 183, 202, 214, 227, 243)*. When these hand hygiene studies were evaluated as a group, diarrheal infections were reduced by 41% (standard deviation, 24%). Diarrheal and respiratory infections and absences were reduced by averages of 32, 23, and 36%, respectively, in another composite grouping of 25 group hand hygiene studies conducted at child care centers *(15, 16, 22, 34, 36, 104, 106, 109, 170, 185, 195, 230)*, schools *(29, 53, 75, 80, 88, 101, 138, 164, 166, 198, 229, 240)* and colleges *(122, 238, 239)* that had hand hygiene programs focused on frequent washing with soap and water and/or use of alcohol sanitizers. These findings of these studies indicate that hand washing can be effective for reducing but does not eliminate disease transmission *(149)*.

The concept of hand washing in actual practice varies considerably from extensive scrubbing to a brief rinse of the hand *(48, 151)*. Thumbs, palms, spaces between fingers, and fingertips (including the fingernail area) are areas where contamination is most likely to remain.

A hygienic water source, typically potable water from a piped system or deep well, is vital for effective hand washing. Even in developing countries with limited resources, spread of disease can be limited by proper hygiene. A successful program of hygiene promotion must identify and target only those few practices that are the major source of risk in any setting. In regions where sanitary waste disposable systems are limited, safe stool disposal (a primary barrier to transmission) may be more important than hand washing before eating, which constitutes a secondary barrier *(45)*.

An investigation of epidemic cholera in West Africa revealed that hand washing by all family members with consistent use of soap had a protective effect against cholera *(215),* and hand washing by families, specifically after defecation, was associated with reduced risk of the disease. However, even with contaminated water in slum settings, hand washing with soap measurably improved women's hand cleanliness *(129)*. Curtis and Cairncross *(44)* analyzed 17 studies of hand hygiene in different nations, mostly developing countries. These authors found that hand washing could reduce the risk of diarrheal illness by 42 to 47% and claimed that hand washing would avert approximately one million deaths. However, most of these 17 surveys had methodological flaws, such as relying on oral reports; only 2 contained observational studies and none had compliance data for washing. Unfortunately, conditions in developing countries may not have improved substantially since that study.

Lopez-Quintero et al. *(127)* assessed hand washing behaviors and intentions among school children in Bogotá, Colombia, to help identify and overcome barriers to proper hygiene practices. Only 33.6% of those surveyed reported always or very often washing hands with soap and clean water before eating and after using the toilet and that only about 7% of students reported regular access to soap and clean water at school. Students with proper hand washing behavior were less likely to report previous-month gastrointestinal symptoms or previous-year school absenteeism. The authors concluded that even though there may have been a willingness to wash hands among students, scarcity of adequate facilities in most schools prevented children from adopting proper hygienic behavior.

Removal of soil. The bioburden of hands can be visible or not and may require different hygienic steps to remove it. Visibly soiled hands are typically those with visible dirt or contamination with proteinaceous material, blood, other body fluids (e.g., fecal material or urine), or food (e.g., meat protein). The first step in hand washing is removal of the bioburden, which is typically composed of inanimate material with trapped microorganisms. Water soluble material is easier to remove than fat, oil, or grease, but soaps can facilitate the removal of these lipid substances. Variables affecting hand hygiene efficacy include soil type, contamination level, microorganism(s) of concern, hand washing agent (antimicrobial versus nonantimicrobial soaps and sanitizers), scrubbing and rinsing procedures, drying method, duration of washing, duration of drying, and frequency of carrying out the procedure. Transient flora are generally removed easily, whereas resident species are more difficult.

Hand hygiene practices of food workers are dependent on the type of work involved and the type and nature of the soil. Soil has already been partly discussed in a previous article *(222)*. The contamination level of hands after toilet use, changing diapers, or handling contaminated raw foods and food packing material can all contribute to soil containing up to 1 million enteric bacteria per hand *(135)*. Most surface microorganisms are easily flushed off with washing, but some remain in cracks, crevices, skin folds, and nail regions. When *E. coli* and *Pseudomonas fluorescens* were mixed with ground beef and rubbed onto hands, 75% of the organisms were removed with tap water and 95% were removed with a single hand washing episode using a soap with a mild antimicrobial agent (former E1 designation, see ''Soaps'' section) *(204)*. *Campylobacter* was removed by washing with water or soap as long as hands were dried with paper towels afterward, providing physical removal; when hands were simply shaken dry, *Campylobacter* was still detectable *(40)*. *Giardia* can be removed from hands with soap and hand washing; when 10,000 cysts were placed in the palm of the hand, hand washing eliminated 99% of them *(134)*. Hand drying would have removed many of the remaining 100 cysts.

Leyden et al. *(123)* developed a new approach to quantifying the bacterial flora on the hand surface by using computer-assisted image analysis of bacterial growth of large full-hand touch plates. Image analysis pixel intensity values were significantly correlated ($P < 0.0001$) with CFUs determined by the glove juice method *(231)*. Image analysis of impressions from hands treated with various antimicrobial agents in detergent bases revealed that 4% chlorhexidine gluconate produced a 96% reduction after 30 s of washing and 98% reduction after 3 min of washing, 7.5% povidone-iodine and 1% triclosan produced 77 and 70% reductions after 3 min of washing, respectively, and 70% isopropanol produced a 98% reduction after 30 s of washing.

To measure the type of soil encountered in a food processing or food service environment, Charbonneau et al. *(39)* built on the methodology of Leyden et al. *(123)* and had volunteers handle raw chicken or ground meat. After handling the meat, hands were allowed to dry for 1 min before being cleaned, to represent a typical scenario encountered during food preparation activities. The bacteria transferred during typical food preparation activities before and after washing with sanitizers was quantified. A 20-s wash with nonmedicated liquid soap and water was more effective for removing bacteria from the palms of hands than was an application of gel sanitizer containing 70% alcohol.

When both products were used in sequence more bacteria were transferred, and Charbonneau et al. suggested that the use of alcohol on hands after washing may actually increase the transfer rate of bacteria that are normally sequestered, possibly deeper in layers of skin. This hypothesis is counter to the recommendations of the Food Code *(235),* that state that alcohol-based hand rubs should be used only in combination with hand washing before and after handing food. Triclosan significantly reduced bacterial levels, but concentrations greater than 1.0% did not increase efficacy substantially. For some volunteers, a significant amount of bacteria remained on their hands after washing with plain soap and water for 15 s, possibly because of poor washing technique or because of the condition of the skin.

To reduce the potential for bacterial transfer, food workers may need to wash their hands for longer than 15 s or may need to wash more often *(235).* Thorough rinsing is important because this action also removes potential skin irritants and contact sensitizers originating in food, soaps, metals, and facility disinfectants that could lead to dermatitis. Rinsing with hot water >120°F (49°C) may cause scalding, irritation, pain, removal of the protective fatty layer, cracking, fissures, and possible pathogen colonization, which can discourage future hand washing and result in subsequent increases in microbial counts on hand surfaces *(154).*

Hand hygiene products. There are no universally accepted definitions for hand hygiene products, and these products are not usually listed in government agency documents. Because the terminology has changed over the years and is confusing to those not using these products on a regular basis, the following are frequently used terms and definitions based on data from two Web sites *(11, 187).*

1. An alcohol-based hand rub (ABHR) contains alcohol (in a lotion, rinse, gel, or foam) and is designed for application to the hands to reduce the growth of microorganisms. Such preparations may contain one or more types of alcohol with excipients (inactive substances used as carriers for the active ingredients of a medication), other active ingredients, and humectants (emollients or moisturizers, e.g., propylene glycol).
2. Antimicrobial soap (or detergent) contains an antiseptic agent at a concentration sufficient to reduce or inhibit the growth of microorganisms.
3. An antiseptic agent is an antimicrobial substance applied to the skin to reduce the microbial flora or inhibit the growth of microorganisms. Examples include alcohols, chlorhexidine gluconate, chlorine derivatives, iodine, parachlorometaxylenol, chloroxylenol, quaternary ammonium compounds, and triclosan. Antiseptics were formerly called sanitizers in some settings, and the term is still in use today.
4. Detergents (surfactants) are compounds that possess a cleaning action. They are composed of hydrophilic and lipophilic parts and can be divided into four groups: anionic, cationic, amphoteric, and nonionic. Detergents are often referred to as soaps in everyday language.
5. Hand hygiene is a general term that applies to hand washing, an antiseptic hand wash, an antiseptic hand rub, or surgical hand antisepsis.
6. Moisturizers and emollients are materials added to hand creams to improve their performance and the feel of the skin. Moisturizers add moisture to the skin, and emollients provide a softening or soothing effect, smoothing dry and scaly skin areas.
7. Plain soap is a detergent that does not contain antimicrobial agents or that contains very low concentrations of antimicrobial agents that are effective solely as preservatives.
8. Prework (barrier) cream is a moisturizing hand cream with good barrier properties against water and aqueous solutions.
9. Substantivity is an attribute of certain active ingredients that adhere to the stratum corneum (i.e., that remain on the skin after rinsing or drying) to provide an inhibitory effect on the growth of bacteria remaining on the skin.
10. Waterless antiseptic agents do not require the use of exogenous water; a typical example is an ABHR. After application, the individual rubs the hands together until the agent has dried and by this process reduces the number of viable microorganisms on the hands. The term includes different types of hand rubs (liquid formulations, gels, foams, leaflets, towelettes, and wipes).

Soaps. Soaps have been recommended for cleaning the body for centuries and more recently, since the advent of the ''germ theory,'' to loosen dirt and remove microorganisms from hands in the home, the health care environment, and food processing and food service operations *(150).* Natural soaps are sodium or potassium salts of fatty acids, originally made by boiling lard or other animal fat with lye or potash (potassium hydroxide). Hydrolysis of the fats and oils occurs, yielding glycerol and crude soap. Soap acts as an emulsifier, suspending oil and dirt and allowing them to be washed off; it decreases water surface tension and binds to dirt, oil, and bacteria. Hard water reduces the effectiveness of soaps. Strong detergents are more effective than soaps for cleaning with hard water because these detergents contain a synthetic surfactant and other chemicals that may improve the cleaning ability. Such detergents are not usually used for hand cleaning. Milder detergents are the most frequently used agents for hand washing and are typically called soaps.

Antibacterial agents, which have been added to soaps in recent years, inactivate pathogens more effectively than does soap alone. Employee (''E'') classifications were once used to describe and categorize antimicrobial hand soaps and sanitizing compounds. This E classification system was applied to U.S. Department of Agriculture–approved hand washing products in meat processing plants but was discontinued in 1998 (the classifications are now maintained by NSF International), although some researchers still use the E classification in their publications. Bland or plain soap is a nonantimicrobial soap, E1 is a weak antimicrobial product, and E2 products contain the equivalent of 50 ppm of chlorine. Triclosan, triclocarban-trichlorocarbamide, and parachlorometaxylenol-chloroxylenol are commonly used for their antibacterial and deodorant activities in consumer cleansing products.

Antimicrobial soaps are considered drugs and are regulated by the U.S. Food and Drug Administration (FDA) because they are intended to inhibit or kill certain skin flora *(78, 234)*. However, the effectiveness of these different types of soaps and detergents is still being researched. Gillespy and Thorpe *(63)* found that germicidal soaps or prework creams were not remarkably more effective than ordinary soap for reducing the numbers of bacteria transferable from the skin to handled objects. More recent experiments have confirmed this finding; removal of transient microorganisms with either plain soap or soap with an antibacterial compound was not significantly different ($P > 0.05$), with reductions of 39.5 to 43.9% for plain soap and 43.8 to 52.4% for an antibacterial soap *(163)*. Washing with a nonantimicrobial soap removes most transients, whereas soaps that include a disinfectant are additionally effective at lowering the resident organism population *(52, 56)*. Products that have a detergent effect alone or a disinfection action alone did not perform as well as did the combination products, and dirt and grease must be washed off for adequate disinfection of the skin.

Adequate exposure time is also important for soaps with antimicrobial compounds to be effective. When hand washing frequency requirements range from 5 to 30 times per 8-h shift *(30, 31)*, soap selection is extremely important to maintain compliance. The selection of hand washing products should be determined by specific efficacy requirements for the particular venue, pathogen considerations, and frequency of washing. When frequent hand washing is needed, a gentle product is required for acceptance by personnel. Soaps should have good lathering ability, acceptable scent, and consistency and should not contain components that will cause skin irritation or dryness. Newer formulations contain emollients or additional antimicrobial active ingredients. In the United States, all ingredients must comply with FDA indirect food additive regulations and must be listed in the *Approved Drug Products with Therapeutic Equivalence Evaluations (234)* or have active antimicrobial ingredients listed in the FDA monograph for over-the-counter health care antiseptic drug products *(55)*. In Europe, disinfectants and antiseptics are regulated by the European Committee for Standardization. These products are registered based on standard tests for bactericidal, virucidal, fungicidal, and other biological activities on surfaces and in suspension *(133)*. Although the addition of emollients has resulted in products with a wide level of acceptability, sticky emollient residues build up on hands and can pick up and transfer microbial contaminants *(54, 157)*. The materials used to make lavatory brushes and mops, e.g., nylon, methacryloyl isocyanate styrene, polyurethane, polypropylene, polyvinyl chloride, and acetate, inactivate some antimicrobial ingredients in soaps or sanitizers *(41, 141)*.

The benefit of chlorhexidine gluconate (CHG) is not in its fast action during a 15-s wash but in its long-term effect. After repeated use over several days, the residual effect substantially reduced the normal skin microflora *(119)*. The possibility that long-term use of antibacterial compounds such as triclosan can lead to antibiotic resistance in bacteria has raised concerns for regular users of antimicrobial soaps. However, no evidence of antibiotic resistance was found by Drankiewicz and Dundes *(51)* for staphylococci and several gram-negative bacterial species isolated from hands of individuals in a community setting.

Soaps containing triclosan in the concentrations commonly used in community settings (0.1 to 0.45%, wt/vol) may not be any more effective than plain soap for preventing infections and reducing bacterial levels on the hands *(2)*. According to Fuls et al. *(58)*, antimicrobial hand soaps are more effective for removing enteric bacteria than are nonantimicrobial soaps, but these authors found that wash time and soap volume also were important factors. The transfer of 8.02 log CFU of *E. coli* to plastic balls following a 15-s hand wash with antimicrobial soap resulted in bacterial counts of 2.49 log CFU compared with 4.22 log CFU ($P < 0.001$) on balls held by hands washed with nonantimicrobial soap. Increasing the wash time from 15 to 30 s reduced *Shigella flexneri* on hands by 2.90 to 3.33 log CFU ($P = 0.086$) for the antimicrobial soap compared with 1.67 to 1.72 log CFU ($P > 0.6$) for nonantimicrobial soap. Increasing the soap volume positively impacted bacterial reductions for both the antimicrobial (3.83-log reduction, $P < 0.001$) and the nonantimicrobial (1.08-log reduction) soaps. This indicates that nonantimicrobial soaps are less active than those containing antimicrobial compounds, but their effectiveness can be improved with longer wash time and greater soap volume. Larson et al. *(118)* found that the range of soap volumes used for hand washing was 1 to 3 ml and that 3 ml of antiseptic soap resulted in a significantly greater reduction in log microbial counts than did 1 ml of soap. In 2008, feedback obtained via an electronic questionnaire sent by Campden BRI to more than 1,000 representatives of Campden food industries worldwide indicated that the majority (67%) of personnel used at least 3 ml of soap to wash their hands *(208)*.

The possibility of the development of antimicrobial resistance in the resident flora due to long-term exposure to antibacterial compounds has raised concerns *(197)*, especially the risk of triclosan cross-resistance among different species of bacteria *(2)*. However, this type of antimicrobial resistance has not yet been demonstrated in operational settings *(30)*.

Effect of friction during hand washing. Friction is well known as one of the most important elements in hand washing, dislodging microflora from the skin surface during both the washing and rinsing stages *(186)*. Antimicrobial agents in soaps have too little contact time to have bactericidal effects during a single use or with sporadic washings, making the mechanical aspect and friction the most important part of hand washing *(213)*. In several experiments, hand washing with water alone was more effective for removing bacteria applied to hands than was washing with water and soaps because of the greater friction used during the water washing *(21, 40, 50, 154, 199, 201)*. Unfortunately, any aspect of the hand washing process that decreases friction (e.g., soft water versus hard water, soft bristle brushes versus coarse bristle brushes) and any type of soap by its nature will reduce the mechanical removal of any microflora, particularly when hands are soiled *(186)*. Wipes also decrease friction *(153)*.

Cleaning long and artificial fingernails. Outbreaks have been linked to workers with long or artificial fingernails, which are very difficult to clean even with appropriate soaps, hand rubs, or gels *(224)*. An outbreak of *Serratia marcescens* infection in cardiovascular surgery patients was associated with a surgical nurse who wore artificial nails *(176)*. A more recent outbreak among hemodialysis patients was traced to a nurse who was carrying *S. marcescens* under an artificial fingernail *(64)*. The *S. marcescens* strains isolated from the five patients and the nurse were identical.

In laboratory studies, McNeil et al. *(143)* found that significantly more health care workers with artificial acrylic nails had pathogens remaining after hand cleansing with soap or gel than did those without such nails. Artificial nails also are a common cause of onychomycosis, which can lead to an increased risk of transmission of microbiological infections *(205)*.

In a study to determine differences in microflora under the nails of health care workers wearing painted artificial nails and those with unpolished natural nails, significantly more workers with artificial nails had pathogens remaining after hand cleansing with soap or gel *(143)*. The naturally occurring pathogens found under the nails before the cleaning began were gram-negative bacilli, *S. aureus,* or yeasts. The workers used their normal cleansing process and did not use nailbrushes. Of health care workers with artificial nails, only 11% could remove pathogens with antibacterial soap compared with 38% that could remove pathogens with gel (60% alcohol). Of those workers without artificial nails, only 14% cleaned with soap, whereas 80% cleaned with gel. In previous studies, more pathogens were isolated from nails of health care workers wearing artificial fingernails than from nails of workers with natural nails. Artificial fingernails also may interfere with hand cleansing because of a desire to protect the manicure. This work revealed that artificial acrylic fingernails could contribute to the transmission of pathogens, and soap alone was not efficient for cleaning. Artificial nail use by health care workers should be discouraged.

McGinley et al. *(142)* isolated staphylococci from under the nails of all 26 adult volunteers examined. Most strains were coagulase negative, but 2 of 26 strains were *S. aureus*. Other gram-negative bacteria (e.g., *Pseudomonas, Enterobacter,* and *Serratia*), yeasts, and molds also were commonly isolated from the subungual region. The subungual spaces had an average of 5.39 log CFU compared with 2.55 to 3.53 log CFU for other hand sites, indicating that these are the areas most difficult to keep clean.

In another study, Lin et al. *(125)* used nonpathogenic *E. coli* and feline calicivirus as bacterial and viral indicators, respectively, to assess the efficacy of different hand washing practices. Hands and nails were washed with tap water, regular liquid soap, antibacterial liquid soap, alcohol-based hand antiseptic gel (equivalent to an ABHR), regular liquid soap followed by alcohol gel, or regular liquid soap plus a nailbrush. The greatest reduction of inoculated microbial populations was obtained by washing with liquid soap plus a nailbrush, and the least reduction was obtained by rubbing hands with the alcohol gel. This finding seems to contradict the results of McNeil et al. *(143)*. Lower but not significantly different ($P > 0.05$) reductions of *E. coli* and feline calicivirus counts were obtained from beneath artificial fingernails than from beneath natural fingernails. Significantly higher *E. coli* and feline calicivirus counts were recovered from hands with artificial nails than from hands with natural nails both before and after hand washing.

Chipped fingernail polish or fingernail polish worn for more than 4 days fosters increased bacterial numbers on the nails *(18, 246)*. Microbial cell numbers also were correlated with fingernail length, with higher numbers beneath longer nails. In fingernail studies, overall lower levels of *E. coli* were removed from artificial than from natural nails, and a significant improvement ($P \leq 0.05$) over all other methods occurred when a nailbrush was used, including a soap wash followed by use with alcohol hand antiseptics.

These results indicate that best practices for fingernail sanitation by food workers include maintaining short fingernails and scrubbing them with soap and a nailbrush while washing hands. The best practice for fingernails is to maintain short, healthy, natural nails without polish because these nails are more easily cleaned, reducing the risk of microbial transmission and decreasing the incidence of glove tears *(96)*. Current guidelines call for the use of gloves when food service workers have artificial nails and handle food *(233)*. According to the Food Code *(235),* artificial nails are prohibited for food workers unless gloves are worn.

Duration and frequency of hand washing. Hand washing efficiency is affected by two aspects of hand washing: how well (soaps, friction, and duration) and how often (frequency) it is done. Both aspects are important for limiting hand contamination. The duration of the hand washing process is a critical factor for removing microorganisms, as has been demonstrated through experiments conducted with hands artificially contaminated with pathogens or their indicator organisms. A 2.54- and 2.80-log reduction of *S. aureus* and *Pseudomonas aeruginosa,* respectively, was achieved after 30 s of hand washing *(128)*. In another study *(208),* a 30-s wash was better for removing *E. coli* from hands than was a 15-s wash. The average reduction achieved by 38 volunteers in three replicate trials of a standardized hand washing protocol based on EN 1499 *(9)* was 2.25 log CFU for 15 s and 2.42 log CFU for 30 s. Although these data reveal a significant difference ($P = 0.036$) between 15- and 30-s washes, in everyday practice the difference is not meaningful. In other experiments, microbial counts have increased after hand washing *(38, 113, 124, 172),* as discussed by Guzewich and Ross *(78)*. However, these scenarios tended to be situations in which there was an extended wash period. Chamberlain et al. *(38)* found more microorganisms on hands after a 3-min hand washing than after a 10-s hand washing. The lengthy wash time probably both removed the transient microorganisms and disrupted the upper epidermis layers to release the underlying resident organisms. However, this higher number of residual microorganisms was found only when the transient bacterial population was low, and lengthy wash times rarely occur in food worker operations (wash time is more likely 30 s or less). Most pathogens of concern are transient and would be removed earlier in the wash process. The 2009 version of the Food Code *(235)* states that hands and arms should be washed for at least 20 s, with 10 to 15 s of vigorous scrubbing, and that individuals must use a paper towel or other barrier when touching surfaces to prevent recontamination of hands after washing.

Hand washing times of 15 to 30 s have been recommended by different agencies around the world with slightly different emphases. The Canadian Ontario Ministry of Health and Long-term Care *(175)* recommends 15 s, and the Canadian Food Inspection Agency *(35)* advises washing hands with warm water and soap for 15 to 20 s after handling raw food of animal origin. The U.S. Centers for Disease Control and Prevention (CDC) *(37)* recommend the use of soap and clean running water for 20 s. The New Zealand Food Safety Authority *(167)* uses the 20+20 rule: wash hands for 20 s with soap and hot water and dry for 20 s with a clean, dry towel or paper towel. However, in a national survey in shopping centers, only 7.8% of persons who washed their hands did so for at least 20 s, and only 1.3% practiced the 20+20 recommendation. The World Health Organization *(245)* stated that 20 to 30 s is necessary to disinfect the hands with an alcohol-based formulation, and 40 to 60 s total should be used for washing hands with soap and water, rinsing, and drying them. These wash times are sometimes popularized by advertisements suggesting that everyone recite the alphabet or sing the ''Happy Birthday'' song or a similar-length ditty during washing to obtain maximum pathogen removal *(4)*.

Association guidelines also vary. The American Society for Testing and Materials (ASTM) protocol *(6)* is as follows: wet hands under warm water (100 to 108°F [38 to 42°C]), apply 3 ml of hand washing product, rub vigorously over all hand surfaces concentrating on inter-digital spaces and nail beds, apply a small amount of water, and lather for 15 s, rinse for 30 s, and dry with a clean paper towel. The CDC, in its guidelines for hand washing and hospital environmental control *(61)*, recommended that plain soap be used for routine hand washing, with a vigorous rubbing of all surfaces of lathered hands for at least 10 s followed by thorough rinsing under a stream of water. The American Society for Microbiology *(5)* recommends vigorous scrubbing for 10 to 15 s, and the Association for Professionals in Infection Control and Epidemiology *(14)* recommends 15 to 20 s of vigorous hand washing. Ojajäryi *(173)* found that hand washing for 2 min removed only 3% more transient microorganisms than did a 15-s wash, and Rotter *(196)* found a 0.6- to 1.1-log reduction in microbial flora after 15 s and a corresponding 1.8- to 2.8-log reduction after 30 s, both indicating diminishing returns after 30 s. Washing for too long may damage the skin, and Chamberlain et al. *(38)* found that washing for 3 min brings the skin resident flora to the surface, increasing the number of microorganisms recovered from hands.

Observations of workers in different settings have revealed that less time is spent on actual washing than has been recommended. In health care settings, washing times ranged from 4.7 to 48 s in 17 studies of 11 to 1,016 wash events, for a typical time of 9.5 s *(17, 32, 59, 68, 70, 108, 111, 120, 130, 145, 169, 184, 188, 219)*. Although most of the studies were conducted in the United States and the United Kingdom, health care personnel in five developing countries had similar wash times. The lowest recorded average time was about 5 s, for nurses in the United Kingdom and in medical and surgical wards in Saudi Arabia *(17, 69)*. Fewer observations were made of workers in food preparation settings, but wash times were similar to those of health care staff (5 to 15 s; mean, 9 s) *(8, 27, 33, 203, 228)*. As expected, without supervision people tend to wash their hands for even shorter times and minimally. Wash times in public rest rooms ranged from 4 to 12 s, with an average of about 9 s, for sample sizes of 52 to 292 wash events *(33, 51, 103, 188, 228)*. Three studies in schools produced mean wash times of 8 s *(33, 51, 228)*. Apparently, the worst offenders rarely wash for <5 s, but this short time may be sufficient to only loosen the soil and not remove it, and subsequent transfer of microorganisms to the next surfaces touched may be easier than if the hands had remained dry and unwashed. Under these conditions, it is questionable whether a quick wetting is better than no washing, but there are also many situations where no washing was observed.

Limited studies have been conducted on frequency of hand washing, especially in food processing, preparation, and service operations. Specific studies have indicated how often persons washed their hands after using the rest room or toilet in public, school, and household settings. Only 58 to 92% of these individuals washed with water, and of those who used water, only 8 to 50% also used soap *(20, 33, 51, 74, 76, 103, 228)*. Where the gender of the participants was known, males washed 48 to 71% (mean, 59%) of the time; females washed 58 to 92% (mean, 76%) of the time. However, the difference was less apparent in their use of soap: males used soap 30% of the time, and females used soap 25% of the time. These data can be compared with the only food service worker observations reported (United States), in which workers of both sexes washed 32% of the time, and those who washed used soap 28% of the time (sample size, 231) *(71)*. Overall, the average time taken to wash hands was 9 s, and 58% of individuals washed for 7 to 11 s. These findings suggest no real differences between worker wash habits and those of the general public and school children, indicating that less than one-third of workers washed their hands and fewer used soap after any number of potentially contaminating events in food preparation settings. Japanese researchers divided the wash period into prewash (water only), soap lathering, and rinsing *(228)*. Prewash was rarely done; soap lathering lasted 2 to 6 s (mean, 3.5 s), and rinse lasted 3 to 8 s (mean, 6 s). When only water was used, the wash time was even shorter: 2 to 5 s (mean, 3 s), essentially a quick wetting of the hands. Similar wash times with water only (4.4 to 5 s) were observed in the United Kingdom and the United States *(8, 103)*.

A more recent and extensive survey on frequency of hand washing by the public was conducted in August 2007 using both telephone interviews for self-reporting and observations of on-site behavior *(212)*. Although 92% (95% in 2000) of adult Americans self-reported always washing their hands after using a public restroom and 86% (86% in 2000) self-reported always washing their hands after using the bathroom in their home, only one-quarter (25%) self-reported always washing their hands after handling money, and one-third (34%) self-reported always washing their hands after coughing or sneezing. Only 73 and 78% stated they washed their hands after changing a diaper or before handling or eating food, respectively. Diaper changing presents a risk for transfer of pathogens to the caregiver's hands. For example, Gibson et al. *(62)* found *Shigella* at 10^5 to 10^9 CFU/g in feces of infected children, and 10^2 to 10^6 CFU/g can occur in asymptomatic infants; 0.1 g can easily remain on the hands after a soiled diaper has been changed. These authors estimated that the risk of illness spread from infected babies to others ranged from 24 in 100 to 21 in 100,000 persons, depending on how much *Shigella* is present in the diaper feces and what kind of soap is being used for hand washing after diaper changing. Individuals with a higher level of education were more diligent about washing their hands after using a public restroom or changing diapers, but those with lower incomes tended to be more likely to wash after petting a dog or a cat and before handling or eating food.

In the same month (August 2007), Harris Interactive observed the behavior of 6,076 adults (3,065 men and 3,011 women) in public restrooms at six locations (sports facilities, train stations, ferry terminal, and museums sufficiently equipped with soap, running water, and towels) in four major U.S. cities and recorded whether the adults washed their hands after using the facilities *(212)*. Because the same sites were used in the 2005 survey, the results could be compared. The proportion of men observed washing their hands fell from 75% in 2005 to 66% in 2007; the decrease was less extreme in women, from 90% in 2005 to 88% in 2007. In 2003, the observations of 7,451 individuals in public restrooms located in six major airports revealed a 78% compliance rate for washing hands, ranging from 71% in New York City to 96% in Toronto. York et al. *(248)* found that the frequency of hand washing at appropriate times in food preparation during peak business hours was low (30%) but increased after employee training (38%) and after introduction of specific interventions to encourage good food safety practices (54%).

Hand washing water temperature. Common sense suggests that water temperatures between 110 and 120°F (43 and 49°C) should be used for washing and rinsing hands (as hot as is comfortable), and for many years sanitarians have specified that the hands of food service workers should be washed and rinsed in warm or hot water to reduce the risk of cross-contamination and disease transmission. However, the use of water at these temperatures has not been supported by research. Hand washing with water at higher temperatures may contribute to skin damage when frequent hand washing is required, and insistence on hot water usage may be a deterrent to hand washing compliance. As early as 1938, Price *(186)* found that water temperature did not make a difference in removal of resident microflora when a brush was used aggressively.

Michaels and coworkers *(154, 159, 160)* later found specifically that water temperature is not influential in hand hygiene efficacy when plain or antimicrobial soaps are used, and there was no significant difference in resident microflora removal rates between washing and rinsing with 70 and 120°F (21 and 49°C) water. These researchers employed the ''glove juice'' technique to recover microorganisms from hands. In these experiments, hands were placed in polyethylene bags rather than gloves to which was added a stripping solution containing 1% triton. Hands were then massaged for 60 s, and an aliquot of rinsate was removed for bacterial enumeration. The procedure was based on an FDA methodology *(231)*. Uninoculated sterile tryptic soy broth or hamburger meat was used to study the effects of treatment temperatures (4.4, 12.8, 21.1, 35, or 48.9°C) on the reduction of resident microflora, and tryptic soy broth or hamburger meat inoculated with *S. marcescens* was used to evaluate treatment effects on the reduction of transient contamination. No significant differences in bacterial reductions of either resident or transient bacteria were found for any of the washing and rinsing temperatures during normal hand washing with a nonantimicrobial soap. Therefore, the authors recommended that because efficacy is not markedly improved at the higher temperatures but there is a risk of skin damage, requirements for specific hand washing water temperature should be relaxed below stated regulatory levels of 110 to 120°F (43 to 49°C) to improve acceptance of frequent hand washing by food workers as required for operational purposes. The authors argued that the vigorous friction during washing is more effective for removal of bacteria than is the type of soap, the length of the wash time, or the temperature of the water.

In subsequent experiments with antimicrobial soaps containing different active ingredients, researchers found a slight but insignificant difference in efficacy between 85 and 110°F (29.4 and 43°C) water, whereas measures of skin damage increased but also insignificantly *(159)*. Conversely, washing and rinsing hands at excessively low temperatures, equivalent to those found in a refrigerated cutting room, is uncomfortable and also may result in poor hand washing compliance. The 2001 FDA Food Code amended the 1999 version by decreasing the recommended water temperature for hand washing to 100°F (37.7°C) based on the ASTM standards for evaluating hand washing formulations *(7, 232)*. Laestadius and Dimberg *(110)* in a letter to the editor of the *Journal of Occupational and Environmental Medicine* reviewed the literature concerning temperature of hand washing and the skin damage resulting from hot water. Based on the lack of evidence from the limited literature cited above that hot water had any advantages over cooler water, these authors challenged a statement from the Canadian Center for Occupational Health (CCOP) that recommended hot water for hand washing. Because of possible confusion between warm and hot water, Laestadius and Dimberg used the following temperature classification: (i) cold water, <65°F (<13.3°C); (ii) cool to tepid water, 65 to 90°F (13.3 to 32.2°C); (iii) warm water, 90 to 98°F (32.2 to 36.7°C); and (iv) hot water, 98 to 105°F (36.7 to 40.6°C). Under these definitions, the ASTM and Food Code standards are in the lower range for hot water. The 1998 Canadian Infection Control Guidelines did not specify any water temperature, and the CCOP reversed its position to recommend use of warm instead of hot water. Thus, the temperature of hand washing water should be comfortable, preferably warm but not hot.

Double hand washing. Double hand washing is meant to address residual fecal finger contamination, including entrapment of feces in the subungual region of the nails after defecation or contact with door knobs or other restroom surfaces *(91, 147, 161),* and must include full hand hygiene procedures of washing, rinsing, and drying. A nailbrush is used to produce lather on fingertips, hands, and arm surfaces during initial hand washing. The hands are then rinsed and relathered, without using the nailbrush, by vigorously rubbing hand and arm surfaces, thoroughly rinsed, and then dried with disposable paper towels. A double wash is recommended when employees begin a shift and after they use the toilet. Although this sequential approach has been considered to enhance the efficacy of hand washing, research has shown only a slight gain in cleanliness with the second washing *(242)*. Snyder *(210)* found that double hand washing was valuable as an alternative to gloving because of the high degree of enteric bacteria removal. The first wash with a nailbrush decreased *E. coli* populations 1,000-fold on fingertips, with a further 50-fold reduction after the second wash. However, because the experimental work was limited to three volunteers using a bacterial load in broth and not heavy soil, other studies with bacteria in ground beef and viruses in vomitus should be conducted to determine whether the >4-log reduction can be achieved under more extreme contamination conditions in food or equipment handling situations. Snyder *(211)* noted that after a nailbrush is used about 10 times, enough organic material will accumulate in the brush storage sanitizer solution that bacteria could begin to grow, allowing the storage solution to become a source of bacterial contamination for workers' hands. This possible contamination is the reason why nailbrushes are not recommended for use in high-care food handling facilities in Europe *(207)*.

SKIN DAMAGE THROUGH EXCESSIVE WASHING

Skin damage by scrubbing. Many workers perform hand washing appropriately and successfully, but some workers scrub hands too aggressively *(31, 152),* resulting in cracked skin and sores that adversely affect hand hygiene. The use of brushes particularly can cause the skin to become red, dry, chapped, and rough, making the primary barrier against microbial invasion subject to infection. Blood vessels and nerve endings *(60, 117)* in the dermis are easily exposed, leading to dry chapped skin *(1, 98, 107),* fissures *(112, 114, 136),* and irritation and pain *(94, 169)*. Pain occurs as the outer layer of skin, the stratum corneum, becomes eroded, and this pain discourages thorough cleaning and increases the tendency to reduce the frequency of nailbrush use or even hand washing *(113, 142, 174)*. Skin damage may occur because of the way a nailbrush is constructed or the type and stiffness of the bristles; the composition and shape of the bristle tips can influence the degree to which the skin is cut or abraded *(193, 206),* especially the sensitive skin of the fingertip *(57, 105, 193)*. Nylon brushes and cloths cause friction amyloidosis *(89, 217, 244)*. In a study of nurses' hands in four hospitals, skin damage was significantly correlated with the type of soap used at work ($P = 0.01$), number of hand washes per shift ($P = 0.0003$), and number of times gloves were worn ($P = 0.008$) *(116)*. Skin damage was not correlated with reported duration of hand washing or brand of glove.

The nursing literature indicates that skin damage and skin squamous cell shedding are both reduced when scrubbing is performed without a brush *(73)*. Scrubbing has consequences beyond skin damage; investigations of nosocomial outbreaks revealed that patient infections occurred when scrubbing by health care workers resulted in hand dermatitis and ultimately lower hand washing compliance. Hand lotions often are used to reduce the risk of chapped hands; however, lotions can occasionally be contaminated, as found in an outbreak of *Pseudomonas* infection in a neonatal intensive care unit *(19),* which ended when the hand lotion was removed. Because of the difficulty of cleaning under fingernails without doing mechanical damage to the stratum corneum, ABHRs have been considered to replace the nailbrush *(97, 114)*. Loeb et al. *(126)* found that scrubbing hands with a brush was no better than alcohol and soap treatment for removing normal flora. Early ABHRs were associated with negative skin changes and dry fissured dermatitis. Current products still may cause stinging where small cuts or dermatitis is present, have undesirable added fragrances, and are flammable *(31)*. However, Huynh and Commens *(94)* recommended ABHRs as an alternative to traditional scrubbing to reduce skin damage.

Occupational dermatitis. Occupational dermatitis is widespread in many industries, including those involving food manufacture and preparation. In the United Kingdom, an estimated 84,000 people across all industries have dermatitis caused or made worse by their work, resulting in 132,000 lost working days each year and costs to employers of £20 million *(84)*. The food and catering industries account for about 10% of all cases of occupational dermatitis, with chefs, cooks, kitchen and catering assistants, bar tenders, workers manufacturing many different types of foods, and cleaners at greatest risk. Other than excessive scrubbing of hands, dermatitis can be caused by contact with specific substances at work. In catering and food occupations, prolonged contact with water, soaps, and detergents is responsible for about 55% of dermatitis cases

(84). Other causes of dermatitis are disinfecting tablets used to wash and sanitize vegetables, curry spices, horseradish, mustard, garlic, citrus fruits, and latex gloves *(84)*. Dermatitis can affect both forearms and hands, and extreme cases can lead to open bleeding and painful lesions, causing workers to stay off work or even change jobs. Fresh wound dressings should be applied after hand drying.

S. aureus is a frequent colonizer of skin lesions, making the worker with dermatitis extra cautious about creating barriers between the skin and food or food contact surfaces. Hand contact with sanitizers also can promote skin lesions. Sanitizers (disinfectants) are designed to clean food contact surfaces and tend to be more chemically active than hand soaps or detergents (antiseptics) used for hands. Sanitizers are used under written approved protocols by companies for sanitation standard operating procedures. Under U.S. federal regulations, chemicals sold as sanitizers must kill 99.999% of 75 million to 125 million nonpathogenic *E. coli* and *S. aureus* cells during a 30-s exposure *(241)*. These products include chlorine compounds (e.g., sodium hypochlorite and chlorine dioxide), iodophors, quaternary ammonium compounds, peroxyacetic acid, and acid-ionic and fatty acid sanitizers. The key elements for these sanitizers are concentration, temperature, and contact time. To avoid problems, workers must protect themselves from direct contact with sanitizers during use. Employees can protect themselves and others by reading and understanding sanitizer package labels, knowing the characteristics of each of these chemicals, and preparing appropriate concentrations for use. These steps were not followed in a United Kingdom meat processing plant where 55 employees suffered from hand dermatitis *(85)*. Hands were routinely washed with a cleanser (30 to 40 washes per day) and often immersed in overly hot, softened water containing chlorine dioxide. Gloves were not routinely used, and there was no attempt to check the condition of workers' skin. The dermatitis outbreak was eventually controlled when the management (i) reduced and controlled water temperature at 32°C (90°F), (ii) regulated chlorine dioxide dosing at a continuous acceptable level, (iii) reduced washing by 30% throughout a shift but maintained adequate food hygiene standards, (iv) supplied and encouraged the use of appropriate moisturizing cream, and (v) introduced routine skin monitoring. More information on occupational dermatitis in the food industry is available through the United Kingdom Health and Safety Executive information sheets *(84, 85)*.

HAND DRYING

Removal of microorganisms through drying. Transmission of microbes is more likely to occur from wet skin than from dry skin *(66, 67, 131, 137, 148, 218)* because of the physical aspects of moisture droplet transfer between one surface and another and because the bacteria may be in a physiological state more favorable to colonizing new environments. Patrick et al. *(177)* found that moist hands transfer microorganisms more readily than do dry hands to chamois representing skin, licorice strips representing food, and plastic pipette tips representing utilities (food contact surfaces). Hand drying has two effects: removal of moisture through absorption and removal of microorganisms through friction. The friction generated during hand drying is even more important than that generated during washing because the soaping stage has loosened the microorganisms from the skin. The drying stage physically removes microorganisms in a film of water from the skin by wiping and depositing them on a towel *(23, 42)*. The coarser the grain of paper used, the more efficient the friction effect will be for organism removal *(24, 162)*. Thus, hand hygiene efficiency is a combination of washing efficiency (soap, water, rubbing, and rinsing) and hand drying *(149, 151, 156)*. Data generated by several investigators indicate that the washing phase is approximately 85% effective and the drying process provides a further 90% reduction in transient flora *(132, 158)*. Based on laboratory testing with artificial contaminants, including *Salmonella* (which can survive for several hours on fingertips), hand washing, including washing, rinsing, and drying, commonly produces a 2- to 3-log reduction (99 to 99.9%) *(181)*, although Patrick et al. *(177)* claimed that 10 s of drying hands with a towel alone reduced the microbial population transferred to skin, food, and food contact surfaces by about 2 log units. Hand drying effectiveness includes speed of drying, degree of dryness, effective removal of contaminating microorganisms, and prevention of cross-contamination *(78, 151)*.

Hand drying materials. Ballistic water droplet generation and spread by shaking the hands instead of drying or during any hand drying technique, including wiping wet hands on clothing, should be considered a risk factor for contamination of food contact surfaces. Moist surfaces may subsequently encourage microbial growth and generation of biofilms. Consensus among previous studies on the best methods for drying hands after washing was not found *(12, 24, 25, 139, 146, 218, 236)* partly because most of these older studies were conducted before air drying was improved and different drying assessment methods were used. Although cloth towels are popular because of their rapid drying, they become contaminated through multiple usages, and continuous cloth towels run the risk of end-of-roll contamination by the last user, resulting in transfer of organisms through communal use and through contact with surfaces in sinks, on counter tops, or even on the floor. Once pathogens are deposited on towels, they can survive long enough to contaminate food and contact surfaces. In a study of bacterial survival on cloth tea towels used for drying dishes *(140)*, *E. coli* O157:H7 was recovered from dishes after air drying for 72 h, and some dishes remained contaminated with *Salmonella* after towel drying, but this pathogen did not survive as long as did *E. coli*.

Paper towels are generally considered to be more hygienic than cloth towels for hand drying *(12, 67)*. Cellulose fiber is the main material in institutional paper towels, which are usually made of rougher paper than used for domestic paper towels. Rubbing hands with the paper removes transient organisms and dead skin cells (squames) and is more likely to reach the bacteria from deeper layers because of friction and absorption of moisture *(66)*. Although coarse paper towels are more effective than those made with softer paper, Heenan *(86)* argued that attention should be paid to providing adequate supplies of paper towels that are user friendly; harsh, nonabsorbent paper towels could discourage their use. Sprunt et al. *(213)* found that all types of hand washing agents (even water) were effective when hands were dried with paper towels, and the difference observed among the different sequential washing steps was not considered significant.

Paper towel dispensers may differ in deliverability through design and paper type. Harrison et al. *(82, 83)* evaluated the efficiency of paper towel dispensers for male and female participants of different heights, each pulling 400 paper towels in controlled hand drying simulations. Considerable variation in dispensing efficiency was found between different towel brands; one towel had significantly superior dispensing properties ($P < 0.05$) in the generic dispenser. Participants of a shorter height experienced a lower incidence of dispensing malfunction using all towel products and type. Therefore, managers of food operations should carefully consider, for economic and hygienic reasons, the design and location of towel dispensers and the types of towels purchased. Paper towels should be readily available and adequately soft to encourage drying but should still have enough texture to remove pathogens during rubbing *(24, 86, 162)*.

Foot-operated pedals on waste disposal units can prevent recontamination of hands *(65)*. In a survey of 12 food processing or food service facilities, Michaels et al. *(158)* found coliforms, *E. coli,* and *S. aureus* on paper towel dispenser equipment, indicating that wet hands grasping the dispensers to obtain paper towels deposited some transient contaminants before drying began. Thus, hand-operated paper towel dispensers have their limitations. Paper towels also can serve as a barrier between faucet handles and door knobs to prevent recontamination of hands after washing.

Hand drying systems. Air drying units and disposable paper towels are increasingly replacing cloth towels except in high-end hotels and restaurants, where cloth towels are monitored for their use and replaced as required. Differing results have been obtained when comparing paper towels and hot air dryers. Gustafson et al. *(77)* evaluated four different hand drying procedures: cloth towels accessed by a rotary dispenser, paper towels from a stack on the hand washing sink, warm forced air from a mechanical hand-activated dryer, and spontaneous room air evaporation. One hundred adult volunteers had their hands artificially contaminated with *Micrococcus luteus,* washed with a nonantibacterial soap, and dried, and the remaining organisms were collected using a modified glove-juice sampling procedure. Gustafson et al. found no significant differences in residual *M. luteus* among drying methods.

Air driers that are used in many communal washrooms, allow one user at a time, and take up to 1 min to dry the hands have not been convenient and lead to avoidance or incomplete drying. Patrick et al. *(177)* found that 96% of water was removed from hands in 10 s with cloth towels and in 45 s under warm air. In several studies, on average people spent 22.5 s drying hands, and 41% wiped their hands unhygienically on clothes *(24, 102, 139, 191)*. Because towels are seen as more effective and faster *(191)* than air for drying hands, towels tend to be preferred by workers. Contradictory evidence has also been found concerning increased contamination of hands due to recirculated air and saturation of air dryer filters with bacteria *(115)*.

Yamamoto et al. *(247)* argued that holding hands stationary and not rubbing them under warm air driers was best for removing bacteria, and UV light helped destroy the bacteria during warm air drying. They also stated that paper towels were useful for removing bacteria from fingertips but not from palms and fingers and that hand rubbing during the drying process repopulates the skin with commensal (resident) bacteria. Consequently, when hand rubbing is involved, the bacterial counts on hands will frequently be higher after than before the washing and drying process because the rubbing process tends to draw out commensal bacteria to the skin's surface from deep inside the pores and under the fingernails. Consequently, Yamamoto et al. concluded that rubbing hands under a conventional warm air drier will contribute to both the bacterial load on the surface of the skin and the possible subsequent transfer of bacteria from the hands to other surfaces. This conclusion is in contrast to those from other research but may be explained by the fact that paper drying involves two processes: (i) absorption of water to wick away moisture and bacteria and (ii) friction to remove the surface organisms. Most skin surface contaminants, including pathogens and fecal indicators, are found on fingers, and commensals are found on all parts of hands.

Some researchers have suggested that hot air dryers may disperse microorganisms some distances through the air; for this reason hand towels were considered safer in a clinical area *(66, 168)*. Ngeow et al. *(168)* found that dispersal of marker bacteria by an air dryer occurred within a radius of about 3 ft (1 m) from the dryer and to the investigator's laboratory coat. When paper towels were used for hand drying, no dispersal of marker bacteria was found. Some studies indicate that dryers can become reservoirs for human pathogens; microbial counts on hands using such driers increased by more than 500% in experiments by Knights et al. *(102)* and Redway et al. *(191)*. In the latter study, bacteria were isolated from swabs taken from the airflow nozzles and air inlets of 35 hot air dryers in nine types of locations (including hospitals, eating places, railway stations, public houses, colleges, shops, and sports clubs). Bacteria were relatively numerous in the airflow and on the inlets of 100% of dryers sampled and in 97% of the nozzles. Staphylococci and micrococci (probably from skin and hair) were blown out of all of the dryers sampled specifically for these bacteria, and 95% had evidence of *S. aureus*. At least six species of enteric bacteria were isolated from the airflows of 63% of the dryers, indicating fecal contamination. A similar 500% increase in aerobic bacteria and coliform counts was noted for hot air dryers located at a seafood processing plant *(161)*. In a similar study, Michaels et al. *(155)* examined 30 hot air driers in various locations (fast food facilities, food processing centers, supermarkets, hospitals, retirement homes, and hotels) using air exposure samples with petri plates before and after operation and found a >500% increase in bacterial load, which included *S. aureus, Enterobacteriaceae,* and mold. In a study of hand washing and hand drying efficacy using a quantitative microbial risk assessment approach, the authors concluded that hot air dryers were less effective than paper towels for removing microorganisms from hands *(165)*. However Taylor et al. *(218)* did not find that hand dryers were more likely to contaminate the environment with airborne microorganisms than was the act of drying with paper towels. These authors found that air emitted from the outlet of the driers contained significantly fewer microorganisms than did air entering the driers, and drying of hands with hand driers was no more likely to generate airborne microorganisms than was drying with paper towels.

Levels of microorganisms on external surfaces of hand driers were not significantly different from those on other washroom surfaces. Differences in such reported results may reflect the different test situations, such as used by Ansari et al. *(12),* who compared the efficiency of paper, cloth, and electric warm air drying for elimination of rotaviruses and *E. coli* on fingerpads washed with 70% isopropanol, a medicated liquid soap, or an unmedicated liquid soap. These authors found that regardless of hand washing agent, electric drying produced the highest and cloth drying the lowest reduction in the numbers of both test organisms.

Redway and Fawdar *(190)* summed up the results of the following different studies. In some of these studies *(24, 25, 102, 103, 168, 191, 192),* warm air dryers were hygienically inferior to towels and could actually increase the number of bacteria on the hands after use. In other studies *(47, 77, 139, 146, 177, 218),* little significant difference was found between the three hand drying methods. Only Ansari et al. *(12)* found that warm air dryers were generally hygienically superior to paper towels. Yamamoto et al. *(247)* found that warm air dryers reduced bacterial numbers when individuals held their hands stationary in the airflow rather than rubbing them, which caused an increase in bacteria, but this method requires a longer time to dry the hands. These authors also found that paper towels reduced the bacterial numbers on the fingertips more than did warm air dryers, a result that agrees with those of the experiments by Redway and Fawdar *(190)*. Much of these differences can be explained by different protocols and sampling procedures *(190)*.

Hand drying machines with faster airflow are currently being installed in public washrooms because when hands are not dried properly after washing, transfer of remaining microorganisms to other surfaces is more likely to occur. Most warm or hot air hand dryers rely on evaporation to remove the water from hands, which often takes ≥30 s with rigorous hand rubbing to achieve a satisfactory effect. A new version of an electric hand drier (Airblade, Dyson, Chicago, IL) was introduced into the United Kingdom in 2006 and the United States in 2007. The Airblade is different from other conventional hand dryers in that instead of having a wide jet of heated air, it uses a ''blade,'' ''knife,'' or ''sheet'' of unheated air traveling at 400 mph (643 kph) through a 0.3-mm gap to strip the water rapidly from wet hands and processes the excess water with a disinfecting iodine resin filter; the water is then dispersed in a mist *(26)*. Hands are not rubbed together. The Dyson Airblade dries hands in 10 s and uses approximately 80% less electricity than do conventional hand dryers.

Snelling et al. *(209)* compared the Airblade with two other warm air driers. Hands of volunteers were contaminated by handling uncooked chicken. Washing was performed using the European standard hand washing technique (EN1499:1997 *(9)*) with nonmedicated liquid soap. After the drier was used, the fingers of each hand were pressed onto a strip of sterile aluminum foil. Bacteria transferred to the foil were eluted and enumerated. The authors found that for a drying time of 10 s the Airblade led to significantly less bacterial transfer than did the other driers ($P < 0.05$). When the other driers were used for longer times (30 to 35 s), the trend was for the Airblade to perform better, but the results were not significant ($P > 0.05$). In this study, rubbing hands while using the driers counteracted the reduction in overall bacterial numbers.

Research sponsored by the paper towel industry revealed that paper towels and the Airblade were equally efficient at drying hands in 10 s and better than a warm air drier at 20 s *(190),* but concerns were raised about the Airblade's hygienic performance. For this study, participants were asked to visit a public washroom in a normal fashion and return to the laboratory without washing their hands. Finger and palm prints were then made on the following media: nutrient agar (for total aerobic bacteria), cystine-lactose-electrolyte–deficient medium (for *Enterobacteriaceae* and enterococci), and mannitol-salt agar (for staphylococci). Participants then washed and rinsed their hands for a total of 10 s using liquid soap from a dispenser and running tap water and dried their hands using paper towels (as many sheets as needed in 10 s), a warm air drier (20 s), or the Airblade (10 s). Both types of paper towel reduced the mean numbers of all types of bacteria tested on the fingerpads and the palms, by 44.6 to 91.5% for fingerpads and from 32.8 to 85.2% for palms. The warm air dryer increased the mean numbers of all types of bacteria tested on the fingerpads by 114.1 to 414% and on the palms by 230.4 to 478.8%. The Airblade increased the mean numbers of most types of bacteria tested on the fingerpads (28.0 to 193.3%) and the palms (9.1 to 82.2%). Increases were found with all types of bacteria on all three growth media. The paper towels worked better possibly because the friction generated removed dirt, grease, bacteria, and skin squames from the hands, whereas the air dryers do not generate such friction. Although Redway and Fawdar *(190)* claimed that the hygienic performance of paper towels was superior to that of two types of electric dryer for reducing the numbers of bacteria on both the fingerpads and the palms, the fact that this research was sponsored by the paper industry begs for an independent peer-reviewed study. Such a study should be focused on actual performance in the food industry rather than with volunteers in the laboratory. The mist generated by these fast driers also should be evaluated for bacterial and viral content in addition to monitoring the hands of the users. However, the rapid drying achieved with these fast air driers makes compliance for hand drying more likely in the food service and food processing industries. In the United States, the Airblade is currently the only product that is certified by NSF International under the hygienic commercial hand dryer specification P335 *(171),* and in the latest version of the Food Code *(235)* the FDA permits the use of such high-velocity blades of nonheated, pressurized air for hand drying.

In a recent survey of *Enterobacter* in food industries, 100% of the companies used paper towels in their high- and low-risk food handling areas. In areas where good manufacturing practices are mandated (low-risk areas with dirty incoming raw materials such as meat, fruit, and bakery ingredients), paper towels were preferred (82%) over fabric towels (9%) and warm air hand dryers (5%) *(208)*. Other issues are associated with paper towel use. Paper fragments can enter the food as extraneous matter, and paper towel use has an adverse environmental impact with respect to waste disposal and environmental sustainability.

In January 2009, a survey of 2,000 persons in four major European markets (Germany, France, United Kingdom, and Sweden) was carried out by the Intermetra Business and Market Research Group, a trade organization representing tissue paper producers *(10)*. This survey revealed that public restrooms are of high importance; 28% of the users did not wish to dry their hands if they did not find a ''suitable'' hand drying device. These users considered cloth towels that have already been used by others and drying devices that are unclean as unacceptable (72 and 59% of users, respectively). The largest group, almost three-quarters of all respondents (72%), put hygiene as the highest requirement for dryers, with speed of drying of less importance (only 22% of users). Paper hand towels provided the highest hygiene perception by almost all respondents (96%). Most users (50%) claimed that the driest feeling comes from using paper towels, and warm air dryers (30% of users) were considered more efficient than pull-down cloth towel rolls (18% of users). However, most of the participants probably had not yet experienced the high-velocity blades of pressurized air driers, such as the Airblade system (which dries much more rapidly than warm air drying equipment), now commonly found in public places in the United Kingdom and increasingly in other countries. In combining all the aspects of preferences, 63% of the survey respondents choose paper hand towels first, followed by warm air dryers (28%), and cloth towel rolls (10%).

Although this survey was conducted on a general population, food workers will take their hand washing and drying preferences into the work place. In contrast to the Intermetra survey findings, recent studies at Campden BRI revealed that hygiene concerns were not a problem for paper towels and air driers. No practical differences were found between the use of a Dyson Airblade, a warm air hand dryer, or paper towels with regard to the generation and spread of microbial aerosols. The number of airborne microbes generated by each of these hand drying methods was considered so low that they would not contribute to environmental microbial loads. As high-velocity air driers increasingly enter the work environment and are in use in public facilities, there will be more opportunities to evaluate their hand drying and hygienic efficiency in a variety of occupational settings.

CONCLUSION

Everybody's hands are frequently contaminated with enteric microorganisms, and food workers are no exception. These workers may be even more exposed because of their work with raw food ingredients and their frequent contact with fellow workers and the public. Fortunately, even hands carrying considerable fecal contamination, e.g., after diapering a child, taking care of an incontinent patient, or working in a slaughterhouse, are rarely contaminated with pathogens or pathogens are present in such low numbers that their transfer to ready-to-eat food is not sufficient to cause illness. Many people, workers included, therefore feel that their hygiene routines are sufficient because no adverse consequences have been experienced over many years of performing the same procedures. Gross hygiene errors in two United Kingdom catering facilities (Scotland and Wales) that had used the same hygiene practices for years were identified only through public inquiries after many cases of *E. coli* O157:H7 infection and several deaths had occurred *(178, 179)*. Underreporting of illness is sufficiently extensive *(13, 144)* that some consumers of food prepared by careless workers may have experienced undocumented illnesses, but there is no penalty to the establishment unless the outbreaks are so massive that they cannot be ignored. Thus, frequent contamination of workers' hands, such as butchery and meat department employees working with raw meat products, is likely and may result in contaminated cooked meat products. Hand hygiene compliance at the retail food service level is known to be inadequate *(189, 216)*. Because it is not possible to maintain a complete oversight system at any jurisdictional level, it is not possible by legislation to achieve 100% compliance for proper hygienic practices in food establishments. An interest in public health safety is what motivates management and employees to take extra steps to produce safe products, and these steps include hand hygiene practices that limit any contaminants coming in contact with food being produced for the public. Compliance begins with a commitment by management to designate safety as the number 1 concern in the establishment *(93)* and to introduce regular training programs for safe production of food and for when and how to wash hands effectively *(182, 194)*.

REFERENCES

1. Adams, R. M. 1990. Occupational skin disease, 2nd ed. W. B. Saunders, Philadelphia.
2. Aiello, A. E., E. L. Larson, and S. B. Levy. 2007. Antibacterial soap use: efficacy and risks. *Clin. Infect. Dis.* 45:S137–S147.
3. Alam, N., F. J. Henry, M. M. Rahaman, and B. Wojtyniak. 1989. Mothers' personal and domestic hygiene and diarrhoea incidence in young children in rural Bangladesh. *Int. J. Epidemiol.* 18:242–247.
4. Alspach, G. 2008. Protecting your patients, colleagues, family, and yourself from infection: first wash. *Crit. Care Nurse* 28:7–12.

Available at: http://ccn.aacnjournals.org/cgi/reprint/28/1/7.pdf. Accessed 2 March 2010.
5. American Society for Microbiology. 1996. Handwashing tips. Available at: www.asmusa.org/pcsrc/ochtip.htm. Accessed 23 December 2009.
6. American Society for Testing and Materials. 1987. E1174-87 standard test method for evaluation of health care personnel or consumer handwash formulation. American Society for Testing Materials, West Conshohocken, PA.
7. American Society for Testing and Materials. 2009. ASTM E1327-07 standard test method for evaluation of antimicrobial handwash formulations by utilizing fingernail regions. Available at: http://www.astm.org/Standards/E1327.htm. Accessed 24 July 2009.
8. Anderson, J. B., T. A. Shuster, K. E. Hansen, A. S. Levy, and A. Volk. 2004. A camera's view of consumer food-handling behaviors. *J. Am. Diet. Assoc.* 104:186–191.
9. Anonymous. 1997. Chemical disinfectants and antiseptics. Hygienic handwash. Test methods and requirements (phase 2/step 2). British Standard BSEN 1499:1997. Available at: http://www.standardsdirect.org/standards/standards1/StandardsCatalogue24_view_11959.html. Accessed 22 December 2009.
10. Anonymous. 2009. With hygiene top of mind. Available at: http://www.cleaninginternational.com/int_pulito_market0409_02.asp. Accessed 14 October 2009.
11. Anonymous. 2010. Basic hand hygiene. Triune Medical Technologies, Hartford, Huntingdon, Cambridgeshire, UK. Available at: http://triunemeditech.net/Handhygiene.aspx. Accessed 3 March 2010.
12. Ansari, S. A., V. S. Springthorpe, S. A. Sattar, W. Tostowaryk, and G. A. Wells. 1991. Comparison of cloth, paper, and warm air drying in eliminating viruses and bacteria from washed hands. *Am. J. Infect. Control* 19:243–249.
13. Arthur, A., E. Gournis, D. McKeown, and B. Yaffe. April 2009. Foodborne illness in Toronto. Toronto Public Health, Toronto. Available at: http://www.toronto.ca/health/moh/pdf/staffreport_april15_2009_appx_a.pdf. Accessed 2 December 2009.
14. Association for Professionals in Infection Control and Epidemiology. 1995. APIC guideline for handwashing and hand antisepsis in. health care settings. APIC Guidelines Committee. Association for Professionals in Infection Control and Epidemiology. *Am. J. Infect. Control* 23:251–260.
15. Barros, A. J. D., D. A. Ross, W. V. C. Fonseca, L. A. Williams, and D. C. Moreira-Filho. 1999. Preventing acute respiratory infections and diarrhoea in child care centres. *Acta Paediatr.* 88:1113–1118.
16. Bartlett, A. V., B. A. Jarvis, V. Ross, T. M. Katz, M. A. Dalia, S. J. Englender, and L. J. Anderson. 1988. Diarrheal illness among infants and toddlers in day care centers: effect of active surveillance and staff training without subsequent monitoring. *Am. J. Epidemiol.* 127:808–817.
17. Basurrah, M., and T. Madani. 2006. Handwashing and gloving practice among health care workers in medical and surgical wards in a tertiary care centre in Riyadh, Saudi Arabia. *Scan. J. Infect. Dis.* 38:620–624.
18. Baumgardner, C. A., C. S. Maragos, M. J. Walz, and E. Larson. 1993. Effects of nail polish on microbial growth of fingernails: dispelling sacred cows. *AORN J.* 58:84–88.
19. Becks, V. E., and N. M. Lorenzoni. 1995. *Pseudomonas aeruginosa* outbreak in a neonatal intensive care unit: a possible link to contaminated hand lotion. *Am. J. Infect. Control* 23:396–398.
20. Bermúdez-Millán, A., R. Pérez-Escamilla, G. Damio, A. González, and S. Segura-Pérez. 2004. Food safety knowledge, attitudes, and behaviors among Puerto Rican caretakers living in Hartford, Connecticut. *J. Food Prot.* 67:512–516.
21. Bidawid, S., J. M. Farber, and S. A. Sattar. 2000. Contamination of foods by food handlers: experiments on hepatitis A virus transfer to food and its interruption. *Appl. Environ. Microbiol.* 66:2759–2763.
22. Black, R. E., A. C. Dykes, K. E. Anderson, J. G. Wells, S. P. Sinclair, G. W. Gary, Jr., M. H. Hatch, and E. J. Gangarosa. 1981. Handwashing to prevent diarrhea in day-care centers. *Am. J. Epidemiol.* 113:445–451.
23. Blackmore, M. A. 1987. Hand-drying methods. *Nurs. Times* 83:71–74.
24. Blackmore, M. A. 1989. A comparison of hand drying methods. *Catering Health* 1:189–198.
25. Blackmore, M. A., and E. M. Prisk. 1984. Is hot air hygienic? A comparison of the efficiency of hot air, cotton and paper towels. *Home Econ.* 4:14–15.
26. Blass, E. 3 October 2006. Dyson's Airblade dries hands with 400MPH blast of air. Engadget. Available at: http://www.engadget.com/2006/10/03/dysons-airblade-dries-hands-with-400mph-blast-of-air/. Accessed 16 March 2010.
27. Block, S. S. 1983. Disinfection, sterilization and preservation, 3rd ed. Lea & Febiger, Philadelphia.
28. Bloomfield, S. 2001. Gastrointestinal disease in the domestic setting: what are the issues? *J. Infect.* 43:23–29.
29. Bowen, A., H. Ma, J. Ou, W. Billhimer, T. Long, E. Mintz, R. M. Hoekstra, and S. Luby. 2007. A cluster-randomized controlled trial evaluating the effect of a handwashing-promotion program in Chinese primary schools. *Am. J. Trop. Med. Hyg.* 76:1166–1173.
30. Boyce, J. M. 2001. Antiseptic technology: access, affordability, and acceptance. *Emerg. Infect. Dis.* 7:231–233.
31. Boyce, J. M., and D. Pittet. 2002. Guideline for hand hygiene in health-care settings. Recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. *Infect. Control Hosp. Epidemiol.* 23(Suppl.):S3–S40.
32. Broughall, J. M., C. Marshman, B. Jackson, and P. Bird. 1984. An automatic monitoring system for measuring handwashing frequency in hospital wards. *J. Hosp. Infect.* 5:447–453.
33. Buchtmann, L. 2002. Hand washing understanding and behavior by Australian consumers. Food Safety Information Council. Available at: http://www.foodsafety.asn.au/publications/articlesandsurveys/handwashingsurvey.cfm. Accessed 22 December 2009.
34. Butz, A. M., E. Larson, P. Fosarelli, and R. Yolken. 1990. Occurrence of infectious symptoms in children in day care homes. *Am. J. Infect. Control* 18:347–353.
35. Canadian Food Inspection Agency. 2009. Canada's approach to avian influenza, October 2009. Available at: http://www.inspection.gc.ca/english/anima/heasan/disemala/avflu/bacdoc/appdeme.shtml. Accessed 2 March 2010.
36. Carabin, H., T. W. Gyorkos, J. C. Soto, L. Joseph, P. Payment, and J. P. Collet. 1999. Effectiveness of a training program in reducing infections in toddlers attending day care centers. *Epidemiology* 10:219–227.
37. Centers for Disease Control and Prevention. 2009. Clean hands save lives! Available at: http://www.cdc.gov/cleanhands/. Accessed 2 March 2010.
38. Chamberlain, A. N., M. A. Halablab, D. J. Gould, and R. J. Miles. 1997. Distribution of bacteria on hands and the effectiveness of brief and thorough decontamination procedures using non-medicated soap. *Zentbl. Bakteriol.* 285:565–575.
39. Charbonneau, D. L., J. M. Ponte, and B. A. Kochanowski. 2000. A method of assessing the efficacy of hand sanitizers: use of real soil encountered in the food service industry. *J. Food Prot.* 63:495–501.
40. Coates, D., D. N. Hutchinson, and F. J. Bolton. 1987. Survival of thermophilic campylobacters on fingertips and their elimination by washing and disinfection. *Epidemiol. Infect.* 99:265–274.
41. Colquitt, H. R., and I. M. Maurer. 1969. Hygienic mop maintenance in hospitals. *Br. Hosp. J. Soc. Serv. Rev.* 79:2177–2179.
42. Crow, S. 1985. Air hand dryer or paper towel dispensers? *Infect. Control* 6:4–5. (Letter to the Editor.)
43. Curtis, V., A. Biran, K. Deverell, C. Hughes, K. Bellamy, and B. Drasar. 2003. Hygiene in the home: relating bugs and behaviour. *Social Sci. Med.* 57:657–672.
44. Curtis, V., and S. Cairncross. 2003. Effect of washing hands with soap on diarrhoea risk in the community: a systematic review. *Lancet Infect. Dis.* 3:275–281.

45. Curtis, V., S. Cairncross, and R. Yonli. 2000. Domestic hygiene and diarrhoea—pinpointing the problem. *Trop. Med. Int. Health* 5:22–32.
46. Danielsson, M. L., and B. Hellberg. 1984. Prevalence of enterotoxigenic staphylococci in nose, throat and skin lesions in meat-workers. *Acta Vet. Scand.* 25:242–249.
47. Davis, J. G., J. R. Blake, D. J. White, and C. M. Woodall. 1969. The types and numbers of bacteria left on hands after normal washing and drying by various methods. *Med. Officer* October:235–238.
48. de Wit, J. C. 1985. The importance of hand hygiene in contamination of foods. *Antonie Leeuwenhoek* 51:523–527.
49. de Wit, J. C., and E. H. Kampelmacher. 1981. Some aspects of microbial contamination of hands of workers in food industries. *Zentbl. Bakteriol. Mikrobiol. Hyg. B* 172:390–400.
50. de Wit, J. C., and E. H. Kampelmacher. 1982. Microbiological aspects of washing hands in slaughter-houses. *Zentbl. Bakteriol.* (*Orig. B*) 176:553–561.
51. Drankiewicz, D., and L. Dundes. 2003. Handwashing among female college students. *Am. J. Infect. Control* 31:67–71.
52. Dunsmore, J. M. 1972. The effect of hand washing on the bacteria of skin. *Aust. J. Dairy Technol.* 27:137–140.
53. Dyer, D., A. Shinder, and F. Shinder. 2000. Alcohol-free instant hand sanitizer reduces elementary school illness absenteeism. *Fam. Med.* 32:633–638.
54. Engly, F. 1995. Personal communication with B. Michaels.
55. Federal Register. 17 June 1994. Tentative final monograph (TFM) for health care antiseptic drug products; proposed rule. *Fed. Regist.* 59(116):31440. Available at: http://www.fda.gov/ohrms/dockets/ac/05/briefing/2005-4098B1_02_03-FDA-TAB1.pdf. Accessed 13 November 2009.
56. Fischler, G. E., J. L. Fuls, E. W. Dail, M. H. Duran, N. D. Rodgers, and A. L. Waggoner. 2007. Effect of hand wash agents on controlling the transmission of pathogenic bacteria from hands to food. *J. Food Prot.* 70:2873–2877.
57. Fisher, A. A. 1987. Contact urticaria and anaphylactoid reaction due to corn starch surgical glove powder. *Contact Dermatitis* 16:224–225.
58. Fuls, J. L., N. D. Rodgers, G. E. Fischler, J. M. Howard, M. Patel, P. L. Weidner, and M. H. Duran. 2008. Alternative hand contamination technique to compare the activities of antimicrobial and nonantimicrobial soaps under different test conditions. *Appl. Environ. Microbiol.* 74: 3739–3744.
59. Furtado, G. H. C., S. L. Santana, A. P. Coutinho, L. B. Perdiz, S. B. Wey, and E. A. S. Medeiros. 2006. Compliance with handwashing at two intensive care units in Sao Paulo, Brazil. *J. Infect. Dis.* 10:33–35.
60. Galle, P. C., H. D. Homesley, and A. L. Rhyne. 1978. Reassessment of the surgical scrub. *Surg. Gynecol. Obstet.* 147:215–218.
61. Garner, J. S., and M. S. Favero. 1986. CDC guideline for handwashing and hospital environmental control, 1985. *Infect. Control* 7:231–243.
62. Gibson, L. L., J. B. Rose, C. N. Haas, C. P. Gerba, and P. A. Rusin. 2002. Quantitative assessment of risk reduction from hand washing with antibacterial soaps. *J. Appl. Microbiol. Symp. Suppl.* 92:136S–143S.
63. Gillespy, T. G., and R. H. Thorpe. 1962. Hand washing tests. Technical memorandum 47. Campden BRI, Chipping Campden, UK.
64. Gordin, F. M., M. E. Schultz, R. Huber, S. Zubairi, F. Stock, and J. Kariyil. 2007. A cluster of hemodialysis-related bacteremia linked to artificial fingernails. *Infect. Control Hosp. Epidemiol.* 28:743–744.
65. Gould, D. 1992. Hygienic hand decontamination. *Nurs. Standard* 6: 33–36.
66. Gould, D. 1994. The significance of hand-drying in the prevention of infection. *Nurs. Times* 90:33–35.
67. Gould, D. 2000. Innovations in hand hygiene. Manual from SSL International. *Br. J. Nurs.* 9:2175–2176, 2178–2180.
68. Gould, D., and A. Chamberlain. 1994. Infection control as a topic for ward-based nursing education. *J. Adv. Nurs.* 20:275–282.
69. Gould, D., and A. Chamberlain. 1997. The use of a ward-based educational teaching package to enhance nurses' compliance with infection control procedures. *J. Clin. Nurs.* 6:55–67.
70. Graham, M. 1990. Frequency and duration of HW in an intensive care unit. *Am. J. Infect. Control* 18:77–81.
71. Green, L. R., C. A. Selman, V. Radke, D. Ripley, J. C. Mack, D. W. Reimann, T. Stigger, M. Motsinger, and L. Bushnell. 2006. Food worker hand washing practices: an observational study. *J. Food Prot.* 69:2417–2423.
72. Greig, J. D., E. C. D. Todd, C. A. Bartleson, and B. S. Michaels. 2007. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 1. Description of the problem, methods, and agents involved. *J. Food Prot.* 70:1752–1761.
73. Gruendemann, B. J., and N. B. Bjerke. 2001. Is it time for brushless scrubbing with an alcohol-based agent? *AORN J.* 74:859–873. Available at: http://findarticles.com/p/articles/mi_m0FSL/is_6_74/ai_81218976/pg_7. Accessed 13 November 2009.
74. Guinan, M. 1999. Hand hygiene practices in a school setting in UK. Unpublished report.
75. Guinan, M., M. McGuckin, and Y. Ali. 2002. The effect of a comprehensive handwashing program on absenteeism in elementary schools. *Am. J. Infect. Control* 30: 217–220.
76. Guinan, M., M. McGuckin, and A. Sevareid. 1997. Who washes hands after using the bathroom? *Am. J. Infect. Control* 25:424–425.
77. Gustafson, D. R., E. A. Vetter, D. R. Larson, D. M. Ilstrup, M. D. Maker, R. L. Thompson, and F. R. Cockerill 3rd. 2000. Effects of 4 hand-drying methods for removing bacteria from washed hands: a randomized trial. *Mayo Clin Proc.* 75:705–708.
78. Guzewich, J., and M. P. Ross. 1999. Evaluation of risks related to microbiological contamination of ready-to-eat food by food preparation workers and the effectiveness of interventions to minimize those risks. U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition, Washington, DC.
79. Haggerty, P. A., K. Muladi, B. R. Kirkwood, A. Ashworth, and M. Manunebo. 1994. Community-based hygiene education to reduce diarrhoeal disease in rural Zaire: impact of the intervention on diarrhoeal morbidity. *Int. J. Epidemiol.* 23:1050–1059.
80. Hammond, B., Y. Ali, E. Fendler, M. Dolan, and S. Donovan. 2000. Effect of hand sanitizer use on elementary school absenteeism. *Am. J. Infect. Control* 28: 340–346.
81. Han, A. M., and T. Hlaing. 1989. Prevention of diarrhoea and dysentery by hand washing. *Trans. R. Soc. Trop. Med. Hyg.* 83:128–131.
82. Harrison, W. A., C. J. Griffith, T. Ayers, and B. Michaels. 2003. Bacterial transfer rates and cross-contamination potential associated with paper towels dispensing. *Am. J. Infect. Control* 31:387–392.
83. Harrison, W. A., C. J. Griffith, and B. Michaels. 2003. A technique to determine contamination exposure routes and the economic efficiency of folded paper towel dispensing systems. *Am. J. Infect. Control* 31:104–108.
84. Health and Safety Executive. 1997. Occupational dermatitis in the catering and food industries. Food sheet 17. Available at: http://www.hse.gov.uk/pubns/fis17.pdf. Accessed 12 October 2009.
85. Health and Safety Executive. 2009. Managing skin exposure risks at work. HSE 262. Available at: http://www.hse.gov.uk/pubns/priced/hsg262.pdf. Accessed 12 October 2009.
86. Heenan, A. L. J. 1996. Handwashing solutions. *Prof. Nurs.* 11:615–622.
87. Herikstad, H., S. Yang, T. J. Van Gilder, D. Vugia, J. Hadler, P. Blake, V. Deneen, B. Shiferaw, F. J. Angulo, and the FoodNet Working Group. 2002. A population-based estimate of the burden of diarrheal illness in the United States: 1996–7. *Epidemiol. Infect.* 129:9–17.
88. Hezel, L., C. Bartlett, J. W. Hileman, L. Dillon, and T. Cessna. 2000. Effective hand washing in an elementary school. *Sch. Nurs. News* 17:26–30.
89. Hidano, A., M. Mizuguchi, and Y. Higaki. 1984. Friction melanosis. *Ann. Dermatol. Venereol.* 111:1063–1071. (In French.)

90. Hill, J. M., M. E. Woods, and S. D. Dorsey. 1988. A human development intervention in the Philippines: effect on child morbidity. *Social Sci. Med.* 27:1183–1188.
91. Hobbs, B. C., and R. J. Gilbert. 1978. Food poisoning & food hygiene. Food & Nutrition Press, Westport, CT.
92. Horwood, M. P., and V. A. Minch. 1951. The numbers and types of bacteria found on the hands of food handlers. *Food Res.* 16:133–136.
93. Howells, A., K. R. Roberts, C. W. Shanklin, V. K. Pilling, L. A. Brannon, and B. B. Barrett. 2008. Restaurant employees perceptions of barriers to three food safety practices. *J. Am. Diet. Assoc.* 108:1345–1349.
94. Huynh, N. T., and C. A. Commens. 2002. Scrubbing for cutaneous procedures can be hazardous. *Aust. J. Dermatol.* 43:102–104.
95. Imhoff, B., D. Morse, B. Shiferaw, M. Hawkins, D. Vugia, S. Lance-Parker, J. Hadler, C. Medus, M. Kennedy, M. R. Moore, and T. Van Gilder. 2004. Burden of self-reported acute diarrheal illness in FoodNet surveillance areas, 1998–1999. *Clin. Infect. Dis.* 38:S219–S226.
96. Jumaa, P. A. 2005. Hand hygiene: simple and complex. *Int. J. Infect. Dis.* 9:3–14.
97. Kalmár, P., and R. H. Steinhagen. 1984. Surgical hand disinfection using alcoholic rubbing disinfectants. *Chirurg* 55:280–287. (In German.)
98. Kavli, G., E. Angell, and D. Moseng. 1987. Hospital employees and skin problems. *Contact Dermatitis* 17:156–158.
99. Kerr, K. G., D. Birkenhead, K. Seale, J. Major, and P. M. Hawkey. 1993. Prevalence of *Listeria* spp. on the hands of food workers. *J. Food Prot.* 56:525–527.
100. Khan, M. U. 1982. Interruption of shigellosis by hand washing. *Trans. R. Soc. Trop. Med. Hyg.* 76:164–168.
101. Kimel, L. S. 1996. Handwashing education can decrease illness absenteeism. *J. Sch. Nurs.* 12:14–16.
102. Knights, B., S. Barrass, C. Evans, and B. McHardy. 1993. Hand drying: an assessment of efficiency and hygiene of different methods. Applied Ecology Research Group, University of Westminster, London.
103. Knights, B., K. Redway, and V. Edwards. 1997. A study of hand washing habits in public toilets and the bacterial contamination of the hands before and after washing. Report. Deb Group Ltd., Denby, Derbyshire, UK.
104. Kotch, J. B., A. H. Faircloth, K. A. Weigle, D. J. Weber, R. M. Clifford, T. O. Harms, P. S. Rolandelli, F. A. Loda, P. N. Gallagher, Jr., R. W. Edwards, D. LaBorde, and M. P. McMurray. 1994. Evaluation of an hygienic intervention in child day-care centers. *Pediatrics* 94:991–994.
105. Koutroupi, K. S., and J. C. Barbenel. 1990. Mechanical and failure behaviour of the stratum corneum. *J. Biomech.* 23:281–287.
106. Krilov, L. R., S. R. Barone, T. M. Cusack, F. S. Mandel, D. J. Gaber, and J. R. Rubino. 1996. Impact of an infection control program in a specialized preschool. *Am. J. Infect. Control* 24:167–173.
107. Kristiansen, B. E., and R. L. Johnsen. 1994. Preoperative hand disinfection. *Tidsskr. Nor. Laegeforen.* 114:3463–3465. (In Norwegian.)
108. Kuzu, N., F. Ozer, S. Aydemir, A. N. Yalcin, and M. Zencir. 2005. Compliance with hand hygiene and glove use in a university-affiliated hospital. *Infect. Control Hosp. Epidemiol.* 26:312–315.
109. Ladegaard, M. B., and V. Stage. 1999. Hand-hygiene and sickness among small children attending day care centers. An intervention study. *Ugeskr. Laeg.* 161:4396–4400. (In Danish.)
110. Laestadius, J. G., and L. Dimberg. 2005. Hot water for handwashing—where is the proof? *J. Occup. Environ. Med.* 47:434–435.
111. Lam, B. C. C., J. Lee, and Y. L. Lau. 2004. Hand hygiene practices in a neonatal intensive care unit a multimodal intervention and impact on nosocomial infection. *Pediatrics* 113:562–571.
112. Larson, E., and M. Killien. 1982. Factors influencing handwashing behavior of patient care personnel. *Am. J. Infect. Control* 10:93–99.
113. Larson, E. L. 1984. Effects of handwashing frequency, agent used and clinical unit on bacterial colonization of the hands. *Am. J. Infect. Control* 12:76–82.
114. Larson, E. L. 1985. Handwashing and skin. Physiologic and bacteriologic aspects. *Infect. Control* 6:14–23.
115. Larson, E. L. 1995. APIC Guidelines Committee. APIC guideline for handwashing and hand antisepsis in health care settings. *Am. J. Infect. Control* 23:251–269.
116. Larson, E. L., J. L. Bryan, L. M. Adler, and C. Blane. 1997. A multifaceted approach to changing handwashing behavior. *Am. J. Infect. Control* 25:3–10.
117. Larson, E. L., P. I. Eke, and B. E. Laughon. 1986. Efficacy of alcohol based hand rinses under frequent use conditions. *Antimicrob. Agents Chemother.* 30:542–544.
118. Larson, E. L., P. I. Eke, M. P. Wilder, and B. E. Laughon. 1987. Quality of soap as a variable in hand washing. *Infect. Control* 8:371–375.
119. Larson, E. L., and B. E. Laughon. 1987. Comparison of four antiseptic products containing chlorhexidine gluconate. *Antimicrob. Agents Chemother.* 31:1572–1574.
120. Larson, E. L., K. J. McGinley, A. Foglia, J. J. Leyden, N. Borland, J. Larson, L. C. Altobelli, and E. Salazar-Lindo. 1992. Handwashing practices and resistance and density of bacterial hand flora on two pediatric units in Lima, Peru. *Am. J. Infect. Control* 20:65–72.
121. Lee, G. M., J. A. Salomon, J. F. Friedman, P. L. Hibberd, D. Ross-Degnan, E. Zasloff, S. Bediako, and D. A. Goldman. 2005. Illness transmission in the home: a possible role for alcohol-based hand gels. *Pediatrics* 115:852–860.
122. Lee, M. B. 2000. Frequency of handwashing and protection of health. *Can. J. Infect. Control* Fall:89–91.
123. Leyden, J. J., K. J. McGinley, M. S. Kaminer, J. Bakel, S. Nishijima, M. J. Grove, and G. L. Grove. 1991. Computerized image analysis of full-hand touch plates: a method for quantification of surface bacteria on hands and the effect of antimicrobial agents. *J. Hosp. Infect.* 18(Suppl. B):13–22.
124. Lilly, H. A., E. J. L. Lowbury, and M. D. Wilkins. 1979. Detergents compared with each other and with antiseptics as skin degerming agents. *J. Hyg.* (*Lond.*) 82:89–93.
125. Lin, C. M., F. M. Wu, H.-K. Kim, M. P. Doyle, B. S. Michaels, and L. K. Williams. 2003. A comparison of handwashing techniques to remove *Escherichia coli* and calicivirus under natural or artificial fingernails. *J. Food Prot.* 66:2296–2301.
126. Loeb, M. B., L. Wilcox, F. Smaill, S. Walter, and Z. Duff. 1997. A randomized trial of surgical scrubbing with a brush compared to antiseptic soap alone. *Am. J. Infect. Control* 25:11–15.
127. Lopez-Quintero, C., P. Freeman, and Y. Neumark. 2009. Hand washing among school children in Bogotá, Colombia. *Am. J. Public Health* 99:94–101.
128. Lowbury, E. J. L., H. A. Lilly, and J. P. Bull. 1964. Disinfection of hands: removal of transient organisms. *Br. Med. J.* 2(5403):230–233.
129. Luby, S. P., M. Agboatwalla, A. Raza, J. Sobel, E. D. Mintz, K. Baier, R. M. Hoekstra, M. H. Rahbar, R. Hassan, S. M. Qureshi, and E. J. Gangarosa. 2001. Microbiologic effectiveness of hand washing with soap in an urban squatter settlement, Karachi, Pakistan. *Epidemiol Infect.* 127:237–244.
130. Lund, S., J. Jackson, J. Leggett, L. Hales, R. Dworkin, and D. Gilbert. 1994. Reality of glove use and handwashing in a community hospital. *Am. J. Infect. Control* 22:352–357.
131. Mackintosh, C. A., and P. N. Hoffman. 1984. An extended model for transfer of micro-organisms via the hands; differences between organisms and the effect of alcohol disinfection. *J. Hyg.* (*Camb.*) 92:345–355.
132. Madeline, P., and F. Tournade. 1980. Hand drying by means of disposable products and with hot air. *Prev. Bucco Dent.* 4:24–25.
133. Manivannan, G. 2007. Disinfection and decontamination: principles, applications and related issues. CRC Press, Boca Raton, FL.
134. Manthriratna, G. A. 1989. Efficacy of handwashing as an aid in the control of rotavirus and *Giardia* transmission. M.S. thesis. University of Arizona, Tucson.

135. Marie, J. M. 2002. Use of microbial risk modeling to determine the benefit of topical antimicrobial products. Master's thesis. Drexel University, Philadelphia.
136. Marples, M. J. 1965. The ecology of the human skin. Charles C Thomas, Springfield, IL.
137. Marples, R. R., and A. G. Towers. 1979. A laboratory model for the investigation of contact transfer of microorganisms. *J. Hyg.* (*Lond.*) 82:237–248.
138. Master, D., S. H. Hess Longe, and H. Dickson. 1997. Scheduled hand washing in an elementary school population. *Fam. Med.* 29: 336–339.
139. Matthews, J. A., and S. W. B. Newsom. 1987. Hot air electric hand driers compared with paper towels for potential spread of airborne bacteria. *J. Hosp. Infect.* 9:85–88.
140. Mattick, K., K. Durham, G. Domingue, F. Jørgensen, M. Sen, D. W. Schaffner, and T. Humphrey. 2003. The survival of foodborne pathogens during domestic washing-up and subsequent transfer onto washing-up sponges, kitchen surfaces and food. *Int. J. Food Microbiol.* 85:213–226.
141. Maurer, I. M., A. Efstratiou, and H. M. Watson. 1972. Lavatory brushes in hospitals. *Br. Hosp. J. Social Serv. Rev.* 82(Suppl.):19–22.
142. McGinley, K. J., E. L. Larson, and J. J. Leyden. 1988. Composition and density of microflora in the subungual space of the hand. *J. Clin. Microbiol.* 26:950–953.
143. McNeil, S. A., C. L. Foster, S. A. Hedderwick, and C. A. Kauffman. 2001. Effect of hand cleansing with antimicrobial soap or alcohol-based gel on microbial colonization of artificial fingernails worn by health care workers. *Clin. Infect. Dis.* 32:367–372.
144. Mead, P. S., L. Slutsker, V. Dietz, L. F. McCaig, J. S. Bresee, C. Shapiro, P. M. Griffin, and R. V. Tauxe. 1999. Food-related illness and death in the United States. *Emerg. Infect. Dis.* 5:607–625.
145. Meengs, M. R., B. K. Giles, C. D. Chisholm, W. H. Cordell, and D. R. Nelson. 1994. Hand washing frequency in an emergency department. *Ann. Emerg. Med.* 23:1307–1312.
146. Meers, P. D., and K. Y. Leong. 1989. Hot-air hand dryers. *J. Hosp. Infect.* 14:169–171.
147. Mendes, M. F., and D. J. Lynch. 1976. A bacteriological survey of washrooms and toilets. *J. Hyg.* (*Camb.*) 76:183–190.
148. Merry, A. F., E. Miller, G. Findon, C. S. Webster, and S. P. W. Neff. 2001. Touch contamination levels during anaesthetic procedures and their relationship to hand hygiene procedures: a clinical audit. *Br. J. Anaesth.* 87:291–294.
149. Michaels, B. 2002. Handwashing: an effective tool in the food safety arsenal. *Food Quality* 9:45–53.
150. Michaels, B. 2002. Skin sampling techniques, chap. 26, p. 395–410. *In* D. Paulson (ed.), Handbook of topical antimicrobials and their applications. Marcel Dekker, New York.
151. Michaels, B., and T. Ayers. 2000. Hazard analysis of the personal hygiene process, p. 191–200. *In* Proceedings of the 2nd National Sanitation Foundation International Conference on Food Safety, Savannah, GA, 11 to 13 October 2000.
152. Michaels, B., and T. Ayers. 2002. Handwashing (and drying)—the most effective means of reducing the risk of infection, p. 151–168. *In* Proceedings of the Third International Conference on Food Safety, Porto, Portugal, 24 to 25 May 2002.
153. Michaels, B., T. Ayers, and D. Paulson. 2001. Efficacy of tissue wipes containing BAC for decontaminating hands. Unpublished report.
154. Michaels, B., J. Budd, T. Ayers, C. Beausoleil, and D. Paulson. 2001. Evaluation of the combined effects of selective handwashing temperatures and antimicrobial soaps on microbial reduction efficacy and skin irritation. *J. Food Prot.* 64(Suppl. A):92.
155. Michaels, B., A. D'Onorio, M. Arenas, M. Cellis, and V. Gangar. 2001. Microbiological survey of hot-air dryers from various locations. *J. Food Prot.* 64(Suppl. A):95.
156. Michaels, B., V. Gangar, T. Ayers, E. Meyers, and M. S. Curiale. 2001. The significance of hand drying after handwashing, p. 294–303. *In* J. S. A. Edwards and M. M. Hewedi (ed.), Proceedings of the 3rd International Conference on Culinary Arts and Sciences, Cairo, Egypt, 18 to 19 April 2001.
157. Michaels, B., V. Gangar, C. M. Lin, and M. Doyle. 2003. Use limitations of alcoholic instant hand sanitizer as part of a food service hand hygiene program. *Food Serv. Technol.* 3:71–80.
158. Michaels, B., V. Gangar, E. Meyers, H. Johnson, and M. Curiale. 2000. The significance of hand drying after handwashing. *J. Food Prot.* 63(Suppl. A):106.
159. Michaels, B., V. Gangar, A. Schultz, M. Arenas, M. Curiale, T. Ayers, and D. Paulson. 2001. Handwashing water temperature effects on the reduction of resident and transient (*Serratia marcescens*) flora when using bland soap. *Dairy Food Environ. Sanit.* 21:997–1007.
160. Michaels, B., V. Gangar, A. Schultz, M. Arenas, M. Curiale, T. Ayers, and D. Paulson. 2002. Water temperature as a factor in handwashing efficacy. *Food Serv. Technol.* 2:139–149.
161. Michaels, B., B. Smith, and M. Pierson. 2001. Pathogenic and indicator bacteria associated with handwashing and drying contact surfaces. *J. Food Prot.* 64(Suppl. A):95.
162. Michaels, B. S., V. Gangar, T. Ayers, H. Guider, M. S. Curiale, and C. Griffith. 2003. Optimization of paper towel hand drying during normal handwashing processes, p. 14. *In* Proceedings of the APIC 30th Annual Conference & International Meeting, San Antonio, TX, 8 to 12 June 2003.
163. Miller, M. L. 1994. A field study evaluating the effectiveness of different hand soaps and sanitizers. *Dairy Food Environ. Sanit.* 14: 155–160.
164. Monsma, M., R. Day, and S. St. Arnaud. 1992. Handwashing makes a difference. *J. Sch. Health* 62:109–111.
165. Montville, R., Y. Chen, and D. W. Schaffner. 2001. Glove barriers to bacterial cross-contamination between hands to food. *J. Food Prot.* 64:845–849.
166. Morton, J. L., and A. A. Schultz. 2004. Healthy hands: use of alcohol gel as an adjunct to handwashing in elementary school children. *J. Sch. Nurs.* 20:161–167.
167. New Zealand Food Safety Authority. 2008. Hand washing survey points the finger at men. New Zealand Food Safety Authority, Wellington, New Zealand. Food Focus February 2008. Available at: http://www.nzfsa.govt.nz/publications/food-focus/2008-02/page-13.htm. Accessed 2 March 2010.
168. Ngeow, Y. F., H. W. Ong, and P. Tan. 1989. Dispersal of bacteria by an electric air hand dryer. *Malays. J. Pathol.* 11:53–56.
169. Nielsen, J. 1996. The occurrence and course of skin symptoms on the hands among female cleaners. *Contact Dermatitis* 34:284–291.
170. Niffenegger, J. P. 1997. Proper handwashing promotes wellness in child care. *J. Pediatr. Health Care* 11:26–31.
171. NSF International. 2010. NSF protocol P335. Hygienic commercial hand dryers. NSF International, Ann Arbor, MI. Available at: http://www.nsf.org/Certified/Protocols/Listings.asp?Company=3E300&Standard=P335. Accessed 16 March 2010.
172. Ojajäryi, J. 1976. An evaluation of antiseptics used for hand disinfection in wards. *J. Hyg.* (*Lond.*) 76:75–82.
173. Ojajäryi, J. 1980. Effectiveness of hand washing and disinfection methods in removing transient bacteria after patient nursing. *J. Hyg.* (*Camb.*) 85:193–203.
174. Ojajäryi, J. 1981. The importance of soap selection for routine hand hygiene in hospital. *J. Hyg.* (*Lond.*) 86:275–283.
175. Ontario Ministry of Health and Long-term Care. 2009. Hand washing: why is hand washing important? Ontario Ministry of Health and Long-term Care, Toronto. Available at: http://www.health.gov.on.ca/english/public/program/pubhealth/handwashing/handwashing_mn.html. Accessed 2 March 2010.
176. Passaro, D. J., L. Waring, R. Armstrong, F. Bolding, B. Bouvier, J. Rosenberg, A. W. Reingold, M. McQuitty, S. M. Philpott, W. R. Jarvis, S. B. Werner, L. S. Tompkins, and D. J. Vugia. 1997. Postoperative *Serratia marcescens* wound infections traced to an out-of-hospital source. *J. Infect. Dis.* 175:992–995.
177. Patrick, D. R., T. E. Miller, and G. Findon. 1997. Residual moisture determines the level of touch-contact associated transfer following handwashing. *Epidemiol. Infect.* 119:319–325.

178. Pennington, H. 1998. Factors involved in recent outbreaks of *Escherichia coli* O157:H7 in Scotland and recommendations for its control. *J. Food Saf.* 18:383–391.
179. Pennington, H. 2009. The public inquiry into the September 2005 outbreak of *E. coli* O157 in South Wales. Her Majesty's Stationery Office, Cardiff, UK. Available at: http://wales.gov.uk/ecolidocs/3008707/reporten.pdf?skip=1&lang=en. Accessed 3 December 2009.
180. Peterson, E. A., L. Roberts, M. J. Toole, and D. E. Peterson. 1998. The effect of soap distribution on diarrhoea: Nyamithuthu Refugee Camp. *Int. J. Epidemiol.* 27:520–524.
181. Pether, J. V. S., and R. J. Gilbert. 1971. The survival of *Salmonella* on finger-tips and transfer of the organisms to food. *J. Hyg.* (*Camb.*) 69:673–681.
182. Pilling, V. K., L. A. Brannon, C. W. Shanklin, K. R. Roberts, B. B. Barrett, and A. D. Howells. 2008. Food safety training requirements and food handlers' knowledge and behaviors. *Food Prot. Trends* 28:192–200.
183. Pinfold, J. V., and N. J. Horan. 1996. Measuring the effect of a hygiene behaviour intervention by indicators of behaviour and diarrhoeal disease. *Trans. R. Soc. Trop. Med. Hyg.* 90:366–371.
184. Pittet, D., P. Mourouga, and T. V. Perneger. 1999. Compliance with handwashing in a teaching hospital. *Ann. Intern. Med.* 130:126–130.
185. Pönkä, A., T. Poussa, and M. Laosmaa. 2004. The effect of enhanced hygiene practices on absences due to infectious diseases among children in day care centers in Helsinki. *Infection* 32:2–7.
186. Price, P. B. 1938. The bacteriology of the normal skin; a new quantitative test applied to a study of the bacterial flora and the disinfectant action of mechanical cleansing. *J. Infect. Dis.* 63:301–308.
187. Queensland Health. 2009. Health service district policy for hand hygiene. Queensland Health, Brisbane, Australia. Available at: http://www.docstoc.com/docs/22344706/Sample-Policy-Template-for-Hand-Hygiene. Accessed 3 March 2010.
188. Quraishi, Z. A., M. McGuckin, and F. X. Blais. 1984. Duration of handwashing in intensive care units: a descriptive study. *Am. J. Infect. Control* 12:83–87.
189. Rediers, H., M. Claes, R. Kinnerk, L. Peeters, and K. A. Willems. 2008. Hand hygiene in the food industry: resolving an enigma? *Food Prot. Trends* 28:568–584.
190. Redway, K., and S. Fawdar. 2008. A comparative study of three different hand drying methods: paper towel, warm air dryer, jet air dryer. European Tissue Symposium. School of Biosciences, University of Westminster, London. Available at: http://www.europeantissue.com/pdfs/090402-2008%20WUS%20Westminster%20University%20hygiene%20study,%20nov2008.pdf. Accessed 16 March 2010.
191. Redway, K., B. Knights, Z. Bozoky, A. Theobald, and S. Hardcastle. 1994. Hand drying: a study of bacterial types associated with different hand drying methods and with hot air dryers. Applied Ecology Research Group, University of Westminster, London.
192. Redway, K., B. Knights, and K. Johnson. 1995. A comparison of the anti-bacterial performance of two hand drying methods (textile towels and warm air dryers) after artificial contamination and washing of the hands. Applied Ecology Research Group, University of Westminster, London.
193. Reiter, C., and W. E. Wetzel. 1991. The finishing of the bristle ends in interdental brushes. *Schweiz. Monatsschr. Zahnmed.* 101:431–437. (In German.)
194. Roberts, K. R., B. B. Barrett, A. D. Howells, C. W. Shanklin, V. K. Pilling, and L. A. Brannon. 2008. Food safety training and foodservice employees' knowledge and behavior. *Food Prot. Trends* 28:252–260.
195. Roberts, L., E. M. Douglas, L. Jorm, C. McGilchrist, M. Patel, and W. Smith. 2000. Effect of infection control measures on frequency of diarrheal episodes in child care: a randomized, controlled trial. *Pediatrics* 105:743–746.
196. Rotter, M. 1996. Hand washing and hand disinfection, p. 1052–1068. *In* C. G. Mayhall (ed.), Hospital epidemiology and infection control, 1st ed. Williams & Wilkins, Baltimore.
197. Russell, A. D. 2001. Mechanisms of bacterial insusceptibility to biocides. *Am. J. Infect. Control* 29:259–261.
198. Sandora, T. J., M. C. Shih, and D. A. Goldmann. 2008. Reducing absenteeism from gastrointestinal and respiratory illness in elementary school students: a randomized, controlled trial of an infection-control intervention. *Pediatrics* 21:e1555–e1562.
199. Sattar, S. A., M. Abebe, A. J. Bueti, H. Jampani, J. Newman, and S. Hua. 2000. Activity of an alcohol-based hand gel against human adeno-, rhino-, and rotaviruses using the fingerpad method. *Infect. Control Hosp. Epidemiol.* 21:516–519.
200. Scallon, E., S. E. Majowicz, G. Hall, A. Bannerjee, C. L. Bowman, L. Daly, T. Jones, M. D. Kirk, M. Fitzgerald, and F. J. Angulo. 2005. Prevalence of diarrhoea in the community in Australia, Canada, Ireland and the United States. *Int. J. Epidemiol.* 34:454–460.
201. Schurmann, W., and H. J. Eggers. 1985. An experimental study on the epidemiology of enteroviruses: water and soap washing of poliovirus 1–contaminated hands, its effectiveness and kinetics. *Med. Microbiol. Immunol.* (*Berl.*) 174:221–236.
202. Shahid, N. S., W. B. Greenough III, A. R. Samadi, M. I. Huq, and N. Rahman. 1996. Hand washing with soap reduces diarrhoea and spread of bacterial pathogens in a Bangladesh village. *J. Diarrhoeal Dis. Res.* 14:85–89.
203. Sheena, A. Z., and M. E. Stiles. 1982. Efficacy of germicidal hand wash agents in hygienic hand disinfection. *J. Food Prot.* 45:713–720.
204. Sheena, A. Z., and M. E. Stiles. 1983. Efficacy of germicidal hand wash agents against transient bacteria inoculated onto hands. *J. Food Prot.* 48:722–727.
205. Shemer, A., H. Trau, B. Davidovici, M. H. Grunwald, and B. Amichai. 2008. Onycomycosis due to artificial nails. *J. Eur. Acad. Dermatol. Venereol.* 22:998–1000.
206. Silverstone, L. M., and M. J. Featherstone. 1988. Examination of the end rounding pattern of toothbrush bristles using scanning electron microscopy: a comparison of eight toothbrush types. *Gerodontics* 4:45–62.
207. Smith, D. L. (Campden BRI). 24 August 2009. Personal communication.
208. Smith, D. L. 2009. Hand hygiene: guidance for best practice. Campden BRI Guideline 62. Campden BRI, Chipping Campden, UK.
209. Snelling, A. M., T. Saville, D. G. Stevens, and C. B. Beggs. 2007. Evaluation of a new ultra-rapid hand drier in relation to hand hygiene, 1733-1209. Abstr. 17th Eur. Congr. Clin. Microbiol. Infect. Dis., Munich, Germany, 31 March to 4 April 2007. Available at: http://www.blackwellpublishing.com/eccmid17/abstract.asp?id=57508. Accessed 16 March 2010.
210. Snyder, O. P., Jr. 2007. Removal of bacteria from fingertips and the residual amount remaining on the hand washing nailbrush. *Food Prot. Trends* 27:597–602.
211. Snyder, O. P., Jr. 2007. Nail brush sanitizer effectiveness study. Available at: http://www.hi-tm.com/Documents2007/nailbrush-sanitizer-effectiveness.pdf. Accessed 19 August 2009
212. Soap and Detergent Association. 2007. National cleaning survey. Available at: http://www.sdahq.org/newsroom/2007_survey/handhygiene/keyfindings.cfm. Accessed 19 August 2009.
213. Sprunt, K., W. Redman, and G. Leidy. 1973. Antibacterial effectiveness of routine hand washing. *Pediatrics* 52:264–271.
214. Stanton, B. F., and J. D. Clemens. 1987. An educational intervention for altering water-sanitation behaviors to reduce childhood diarrhea in urban Bangladesh. II. A randomized trial to assess the impact of the intervention on hygienic behaviors and rates of diarrhea. *Am. J. Epidemiol.* 125:292–301.
215. St. Louis, M. E., J. D. Porter, A. Helal, K. Drame, N. Hargrett-Bean, J. G. Wells, and R. V. Tauxe. 1990. Epidemic cholera in West Africa: the role of food handling and high-risk foods. *Am. J. Epidemiol.* 131:719–728.
216. Strohbehn, C., J. Sneed, P. Paez, and J. Meyer. 2008. Hand washing frequencies and procedures used in retail food services. *J. Food Prot.* 71:1641–1650.

217. Tanigaki, T., S. Hata, Y. Kitano, and S. Sano. 1985. Epidemiological survey of ''nylon cloths friction dermatosis'' in Japan. *J. Dermatol.* 12:498–501.
218. Taylor, J. H., K. L. Brown, J. Toivenen, and J. T. Holah. 2000. A microbiological evaluation of warm air hand driers with respect to hand hygiene and the washroom environment. *J. Appl. Microbiol.* 89:910–919.
219. Taylor, L. J. 1978. An evaluation of handwashing techniques. *Nurs. Times* 74:54–55.
220. Todd, E. C. D., J. D. Greig, C. A. Bartleson, and B. S. Michaels. 2007. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 2. Description of outbreaks by size, severity, and settings. *J. Food Prot.* 70:1975–1993.
221. Todd, E. C. D., J. D. Greig, C. A. Bartleson, and B. S. Michaels. 2007. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 3. Factors contributing to outbreaks and description of outbreak categories. *J. Food Prot.* 70:2199–2217.
222. Todd, E. C. D., J. D. Greig, C. A. Bartleson, and B. S. Michaels. 2008. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 4. Infective doses and pathogen carriage. *J. Food Prot.* 71:2339–2373.
223. Todd, E. C. D., J. D. Greig, C. A. Bartleson, and B. S. Michaels. 2008. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 5. Sources of contamination and pathogen excretion from infected persons. *J. Food Prot.* 71:2582–2595.
224. Todd, E. C. D., J. D. Greig, C. A. Bartleson, and B. S. Michaels. 2009. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 6. Transmission and survival of pathogens in the food processing and preparation environment. *J. Food Prot.* 72:202–219.
225. Todd, E. C. D., B. S. Michaels, J. D. Greig, D. Smith, and C. A. Bartleson. 2010. 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. *J. Food Prot.* 73:1762–1773.
226. Todd, E. C. D., B. S. Michaels, J. D. Greig, D. Smith, J. Holah, and C. A. Bartleson. 2010. Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 7. Barriers to reduce contamination of food by workers. *J. Food Prot.* 73:1552–1565.
227. Torum, B. 1982. Environmental and educational interventions against diarrhea in Guatemala, p. 235–266. *In* L. C. Chen and N. S. Scrimshaw (ed.), Diarrhea and malnutrition: interactions, mechanisms and interventions. Plenum Press, New York.
228. Toshima, Y., M. Ojima, H. Yamada, H. Mori, M. Tonomura, Y. Hioki, and E. Koya. 2001. Observation of everyday hand-washing behavior of Japanese and effects of antibacterial soap. *Int. J. Food Microbiol.* 68:83–91.
229. Tousman, S., D. Arnold, W. Helland, R. Roth, N. Heshelman, O. Castaneda, E. Fischer, K. O'Neil, and S. Bileto. 2007. Evaluation of a hand washing program for 2nd-graders. *J. Sch. Nurs.* 23:342–328.
230. Uhari, M., and M. Mottonen. 1999. An open randomized controlled trial of infection prevention in child day-care centers. *Pediatr. Infect. Dis. J.* 18:672–677.
231. U.S. Food and Drug Administration. 1978. Guidelines for effectiveness testing of surgical hand scrub (glove juice test). *Fed. Regist.* 43:1242–1243.
232. U.S. Food and Drug Administration. 2001. 2001 FDA Food Code and 2009 supplement to the Food Code. Available at: http://www.fda.gov/Food/FoodSafety/RetailFoodProtection/FoodCode/FoodCode2001/ucm089446.htm. Accessed 19 August 2009.
233. U.S. Food and Drug Administration. 2004. FDA report on the occurrence of foodborne illness risk factors in selected institutional foodservice, restaurant, and retail food store facility types. Available at: http://www.fda.gov/Food/FoodSafety/RetailFoodProtection/FoodborneIllnessandRiskFactorReduction/RetailFoodRiskFactorStudies/ucm089696.htm. Accessed 9 July 2009.
234. U.S. Food and Drug Administration, Center for Drug Evaluation and Research. 2005. Approved drug products with therapeutic equivalence evaluations (the Orange Book). Available at: http://www.fda.gov/cder/ob/default.htm. Accessed 13 November 2009.
235. U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition. 2009. FDA Food Code. Available at: http://www.fda.gov/Food/FoodSafety/RetailFoodProtection/FoodCode/FoodCode2009/ Accessed 11 December 2009.
236. Walker, P. E. 1953. Mechanical air drying of hands following preoperative scrubbing. *Public Health Rep.* 68:317–319.
237. Wheeler, J. G., D. Sethi, J. M. Cowden, P. G. Wall, L. C. Rodrigues, D. S. Tompkins, M. J. Hudson, and P. J. Roderick. 1999. Study of infectious intestinal disease in England: rates in the community, presenting to general practice, and reported to national surveillance. *Br. Med. J.* 318:1046–1050.
238. White, C., R. Kolble, R. Carlson, and N. Lipson. 2005. The impact of a health campaign on hand hygiene and upper respiratory illness among college students living in the residence halls. *J. Am. Coll. Health* 53:175–181.
239. White, C., R. Kolble, R. Carlson, N. Lipson, M. Dolan, Y. Ali, and M. Cline. 2003. The effect of hand hygiene on illness rate among students in university residence halls. *Am. J. Infect. Control* 31:364–370.
240. White, C. G., F. S. Shinder, A. L. Shinder, and D. L. Dyer. 2001. Reduction of illness absenteeism in elementary schools using an alcohol free instant hand sanitizer. *J. Sch. Nurs.* 17:258–265.
241. Williams, J., and G. Gonzales. 2009. Improve your sanitation training program. *Food Quality* 16:39–41.
242. Williamson, P., and A. M. Kligman. 1965. A new method for the quantitative investigation of cutaneous bacteria. *J. Invest. Dermatol.* 45:498–503.
243. Wilson, J. M., G. N. Chandler, Muslihatun, and Jamiluddin. 1991. Hand-washing reduces diarrhoea episodes: a study in Lombok, Indonesia. *Trans. R. Soc. Trop. Med. Hyg.* 85:819–821.
244. Wong, C. K., and C. S. Lin. 1988. Friction amyloidosis. *Int. J. Dermatol.* 27:302–307.
245. World Health Organization. 2009. WHO guidelines on hand hygiene in health care. World Health Organization, Geneva. Available at: http://whqlibdoc.who.int/publications/2009/9789241597906_eng.pdf. Accessed 2 March 2010.
246. Wynd, C. A., D. E. Samstag, and A. M. Lapp. 1994. Bacterial carriage on the fingernails of OR nurses. *AORN J.* 60:796, 799–805.
247. Yamamoto, Y., K. Ugai, and Y. Takahashi. 2005. Efficiency of hand drying for removing bacteria from washed hands: comparison of paper towel drying with warm air drying. *Infect. Control Hosp. Epidemiol.* 26:316–320.
248. York, V. K., L. A. Brannon, C. W. Shanklin, K. R. Roberts, A. D. Howells, and E. B. Barrett. 2009. Foodservice employees benefit from interventions targeting barriers to food safety. *J. Am. Diet. Assoc.* 109:1576–1581.