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Risk assessment of hand washing efficacy using literature and experimental data

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Abstract

This study simulated factors that influence the levels of bacteria on foodservice workers' hands. Relevant data were collected from the scientific literature and from laboratory experiments. Literature information collected included: initial bacterial counts on hands and water faucet spigots, bacterial population changes during hand washing as effected by soap type, sanitizing agent, drying method, and the presence of rings. Experimental data were also collected using *Enterobacter aerogenes* as a surrogate for transient bacteria. Both literature and experimental data were translated into appropriate discrete or probability distribution functions. The appropriate statistical distribution for each phase of the hand washing process was determined. These distributions were: initial count on hands, beta (2.82, 2.32, 7.5); washing reduction using regular soap, beta (3.01, 1.91, −3.00, 0.60); washing reduction using antimicrobial soap, beta (4.19, 2.99, −4.50, 1.50); washing reduction using chlorhexidine gluconate (CHG), triangular (−4.75, −1.00, 0); reductions from hot air drying, beta (3.52, 1.92, −0.20, 1.00); reduction from paper towel drying, triangular (−2.25, −0.75, 0); reduction due to alcohol sanitizer, gamma (−1.23, 4.42) − 5.8; reduction due to alcohol-free sanitizer, gamma (2.22, 5.38) − 5.00; and the effect of rings, beta (8.55, 23.35, 0.10, 0.45). Experimental data were fit to normal distributions (expressed as log percentage transfer rate): hand-to-spigot transfer, normal (−0.80, 1.09); spigot to hand, normal (0.36, 0.90). Soap with an antimicrobial agent (in particular, CHG) was observed to be more effective than regular soap. Hot air drying had the capacity to increase the amount of bacterial contamination on hands, while paper towel drying caused a slight decrease in contamination. There was little difference in the efficacy of alcohol and alcohol-free sanitizers. Ring wearing caused a slight decrease in the efficacy of hand washing. The experimental data validated the simulated combined effect of certain hand washing procedures based on distributions derived from reported studies. The conventional hand washing system caused a small increase in contamination on hands vs. the touch-free system. Sensitivity analysis revealed that the primary factors influencing final bacteria counts on the hand were sanitizer, soap, and drying method. This research represents an initial framework from which sound policy can be promulgated to control bacterial transmission via hand contacts.

Keywords: Hand washing; Risk assessment; Bacterial contamination; Simulation

1. Introduction

Cross contamination by microbial pathogens in the kitchen environment may play an important role in sporadic as well as epidemic foodborne illnesses

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(Fendler et al., 1998). During food handling and preparation, bacteria on raw foods can be transferred to the hands of a food worker and subsequently to other surfaces (such as water faucet handles) contacted by contaminated hands. The hand is also a potentially critical point for cross contamination for ill and asymptomatic food workers who may shed high levels of pathogens in their feces (Rocourt and Cos-

Table 1
Summary of literature used to create distributions in the hand washing risk assessment

Reference	Organism	Study objective	Distribution(s)
Bartzokas et al. (1987)	*Serratia marcescens*	Compare the efficacy of triclosan, CHG, and regular soaps	Antimicrobial soap CHG soap Regular soap
Blackmore (1989)	Natural flora	Determine the effect of hot air drying, paper towel drying, and cotton towel drying, as well as to determine the microbial quality of towels	Hot air drying Paper towel drying
Blackmore and Prisk (1984)	Natural flora	Determine the effect of hot air drying, paper towel drying, and cotton towel drying	Hot air drying Towel drying
de Wit (1985)	Natural flora	Quantify the amount of bacteria on the hands of workers in various industries	Initial count
Dyer et al. (1998)	*Serratia marcescens*	Compare two alcohol hand sanitizers and one alcohol-free hand sanitizer	Alcohol-free sanitizer Alcohol sanitizer
Hobson et al. (1998)	Natural flora	Compare the efficacy of alcohol hand scrub with 4% CHG and 7.5% povidone iodine formulations with and without brushes	Alcohol sanitizer Antimicrobial soap CHG soap
Jacobson et al. (1985)	Natural flora	Determine whether rings impede the efficacy of a hand wash	Ring wearing
Larson et al. (1988)	Natural flora	Determine the efficacy of washing with soap containing CHG, PCMX, triclosan, or no antimicrobial agent 6 and 18 times a day	Antimicrobial soap CHG soap Regular soap
Larson et al. (1986)	Natural flora	Determine the efficacy of various alcohol-based hand rinses (with and without CHG) on reducing natural flora, in a frequent-use situation (15 washes/day for 5 days)	Alcohol sanitizer Initial count on hands Regular soap
Larson et al. (1998)	Natural flora	Determine if there is a difference in microbial counts on damaged and undamaged skin	Initial count on hands
Miller et al. (1994)	Natural flora	Compare regular soap, antimicrobial soap, E2 soap, and instant hand sanitizers	Antimicrobial soap Regular soap Alcohol sanitizer
Paulson (1994a)	*Serratia marcescens*	Determine the effect of antimicrobial soap, E2 soap, alcohol gel sanitizer, regular soap with sanitizer, and antimicrobial soap with sanitizer over a sequence of 10 washes	Alcohol sanitizer Antimicrobial soap Regular soap
Paulson (1994b)	Natural flora	Determine the immediate, persistent, and residual antimicrobial effect of 4% CHG, 2% CHG, PVP-I, PCMX, and alcohol	Alcohol sanitizer Antimicrobial soap CHG soap
Redway et al. (1994)	Natural flora	Determine the effect of hot air drying and paper towel drying; determine the effect of hot air drying on air quality	Hot air drying Towel drying
Salisbury et al. (1998)	Natural flora	Determine whether rings impede the efficacy of a hand wash	Ring wearing
Sheena and Stiles (1983b)	Natural flora	Compare a variety of hand soaps including antimicrobial agents such as CHG, PCMX, and iodophor	Antimicrobial soap CHG soap
Sheena and Stiles (1983a)	*Escherichia coli* *Pseudomonas fluorescens*	Compare efficacy of CHG, iodophor, PCMX, and regular soaps as well as hand sanitizing solutions	Antimicrobial soap CHG soap

sart, 1997; Fendler et al., 1998; Rose and Slifko, 1999). Proper hand washing has been recognized as one of the most effective measures to control the spread of pathogens, especially when considered along with the restriction of ill workers, and the controversial recommendation of no-bare-hand contact with ready-to-eat foods (Adler, 1999; Montville et al., 2001).

What constitutes "proper hand washing" in a given situation requires an objective and systematic evaluation of available scientific data. The Codex Alimentarius Commission, which sets international standards for foods, has recommended risk assessment as part of an approach to facilitate informed decision making and control food safety hazards (Anonymous, 1995). A large number of studies have determined the efficiency of hand washing using different techniques (Table 1). However, published data on hand washing represent fragmented pieces of the picture, and the risk associated with different hand washing techniques has not been systematically evaluated. While there were numerous articles on the efficacy of soaps, there were few articles on cross contamination via faucet handles, microbial contamination levels on the hands of ill workers, or the effect of gloves on microbial transfer.

This study was undertaken in an attempt to systematically increase the level of understanding of the various factors that influence hand washing efficacy in the home and foodservice establishments. Relevant data were collected from the scientific literature and from laboratory experiments. Both literature and experimental data were used to develop a quantitative risk assessment model to assess the risk [expressed as logarithm of colony forming units (log CFU) on hands at the end of the hand washing process] associated with different hand washing techniques. Experimental data were also collected to validate the efficacy of some hand washing procedures. This manuscript is an extended version of an oral presentation given at the 3rd International Conference on Predictive Modelling in Foods (Schaffner et al., 2000).

2. Materials and methods

Literature data were collected by searching medical and biological databases for documents related to hand washing. A summary of the relevant literature can found in Table 1. Relevant graphs and tables were collected for bacterial counts on the hand (de Wit, 1985; Larson et al., 1986, 1998) and water faucet spigots (Josephson et al., 1997). Data describing initial bacterial count on hands were taken from foodservice workers, healthcare workers, and employees of a research institution. The effectiveness of various hand washing procedures was measured in log CFU change as effected by soap type (Sheena and Stiles, 1983a,b; Larson, 1984; Larson et al., 1986, 1988; Bartzokas et al., 1987; Miller et al., 1994; Paulson, 1994a,b; Hobson et al., 1998), sanitizing solution (Larson et al., 1986; Ayliffe et al., 1988; Rotter, 1988; Miller et al., 1994; Paulson, 1994a,b; Dyer et al., 1998), drying method (Blackmore and Prisk, 1984; Blackmore, 1989; Redway et al., 1994), and wearing rings (Jacobson et al., 1985; Salisbury et al., 1998).

Data that were included on the effectiveness of soap type included six references where total bacterial count was considered (Sheena and Stiles, 1983b; Larson, 1984; Larson et al., 1986, 1988; Miller et al., 1994; Hobson et al., 1998), one where resident organisms were targeted specifically (Paulson, 1994b), and one with foodservice workers naturally contaminated in their work environment (Miller et al., 1994). In addition, data were included describing hands artificially contaminated with *Escherichia coli* and *Pseudomonas fluorescens* from ground beef (Sheena and Stiles, 1983a). The data on sanitizers included three sets using natural contamination (Ansari et al., 1989; Miller et al., 1994; Paulson, 1994b), two sets using *Serratia marcescens* (Paulson, 1994a; Dyer et al., 1998), and two sets using *E. coli* (Ayliffe et al., 1988; Rotter, 1988). Ungragh software (Biosoft, Ferguson, MO) was used to convert graphical data to numerical form. Numerical data were combined wherever appropriate (i.e. where data had approximately the same range and peak). For example, log reduction due to single-use paper towel and cotton towel drying both ranged between 0.10 and 2.0 log CFU and showed a peak around 0.75 log CFU; so these data were combined to create one distribution for towel drying.

A nalidixic acid-resistant *Enterobacter aerogenes*, with attachment characteristics similar to *Salmonella* (Zhao et al., 1998) was used for laboratory experi-

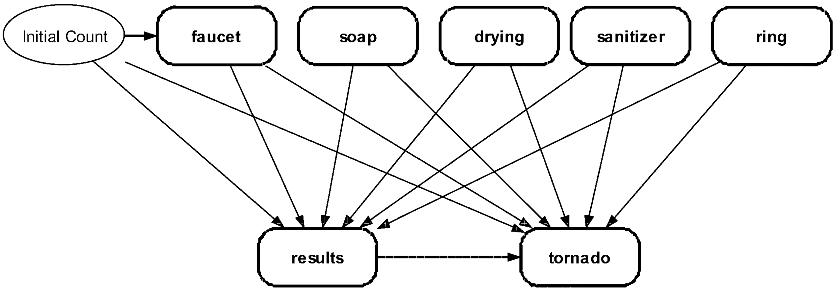

Fig. 1. Flow diagram for hand washing quantitative risk assessment simulation created to quantify the risk (expressed in log CFU bacteria) associated with different hand washing techniques.

ments. The details of methodology are reported elsewhere (Chen et al., 2001). Approximately 30 different volunteers were recruited to generate data for each bacterial transfer rate: from hand to faucet spigot, from faucet spigot to hand, and hand washing efficacy following the FDA food code (i.e. soaping for 20 s and rinsing thoroughly) followed by drying with a paper towel (Anonymous, 1997).

Data were translated into appropriate discrete or probability distribution functions. Numerical data were log transformed using Excel (Microsoft, Redmond, WA) and histograms were generated for both literature and experimental data. The appropriate statistical distribution for each set of numerical data was determined using BestFit software (Palisade, Newfield, NY).

Table 2
Factors considered as input variables in the hand washing QRA model[a]

Variable	Factor	Distribution	K-S ranking
Initial count	Initial count	Beta (2.82, 2.32, 5.0, 7.5)	1
Faucet type	Touch free	0[b]	–
	Spigot, clean	Definition[c]	–
	Spigot, with baseline level	Definition[d]	–
Spigot contamination	Baseline level on spigot	Triangular (2.18, 6.42, 7.54)	1
	Hand-to-spigot transfer rate	Normal (– 0.8, 1.09)	2
	Spigot-to-hand transfer rate	Normal (0.36, 0.9)	6
Soap	Regular soap	Beta (3.01, 1.91, – 3, 0.6)	2
	Antimicrobial soap	Beta (4.19, 2.99, – 4.5, 1.5)	1
	Soap with chlorohexidine gluconate (CHG)	Triangular (– 4.75, – 1, 0)	2
Drying	Hot air dryer	Beta (3.52, 1.92, – 0.2, 1)	1
	Paper towel	Triangular (– 2.25, – 0.75, 0)	1
Sanitizer	No sanitizer	0	–
	Alcohol sanitizer	Gamma (1.23, 4.42) – 5.8	1
	Alcohol-free sanitizer	Gamma (2.22, 5.38) – 5	1
Ring	No ring	0	–
	Ring	Beta (8.55, 23.35, 0.1, 0.45)	1

[a] All values for distribution parameters are on a log scale. For example, hand-to-spigot transfer rate of normal (– 0.80, 1.09) corresponds to a mean of 0.16%.

[b] Where a distribution is 0 (zero), no change in microbial population occurs.

[c] The amount transferred from a single hand contact minus the amount transferred back to the hand.

[d] The amount transferred from a single hand contact minus the amount transferred back to the hand, calculated from a baseline level of contamination.

A quantitative risk assessment model was created using Analytica software 2.0 (Lumina Decision Systems, Los Gatos, CA). The overall structure of the model is shown in Fig. 1, while the details of the statistical distribution are shown in Table 2. Table 2 also describes the calculations used to determine the effect of using a water faucet with a clean or contaminated spigot and distributions for the baseline bacterial density on the spigot and bacterial transfer rates between hand and spigot upon contact.

The final log count of bacteria on the hand was calculated as the sum of the initial levels on the hands, level transferred from faucet spigot to hand, and the resulting log changes as influenced by soap, drying, sanitizer, and rings.

$$\text{Final log CFU} = \log_{10}(10^{\text{initial CFU}} + 10^{\text{faucet CFU}}) + \text{soap} + \text{drying} + \text{sanitizer} + \text{ring} \quad (1)$$

The indexing of input variables allowed the selection of any combination of factors for a total of 108 distributions for final log counts on hands. Results for simulated input distributions as well as final log counts were obtained by running 1000 simulations. Tornado analysis was conducted to determine the relative significance of the input variables. The effect of each factor in the simulation on the final log CFU on the hands at the end of the hand washing process was calculated. Each factor was set to its 5th and 95th percentile values, while the other variables were held at their nominal values, and the end result was determined.

3. Results

3.1. Input distributions

Analysis of literature and experimental data indicated that various distributions described the available data on the factors influencing hand washing efficiency (Table 2). The triangular distribution was chosen to describe data sets with known upper and lower limits and a mean value. Beta and gamma distributions are usually more flexible than normal distributions, and provide better fits of skewed data (Evans et al., 1993).

The initial distribution for total bacterial count on hands, as well as the distributions for log change effected by regular soap, antimicrobial soap, hot air dryer, and ring wearing were described by beta distributions. Ring wearing was found to decrease the efficacy of hand washing since the log change described by the beta distribution was usually greater than zero (data not shown). A triangular distribution described the available data on baseline bacterial density on a faucet spigot, and the effect of chlorhexidine gluconate (CHG) soap and paper towel drying. A gamma distribution appropriately described the literature data for alcohol sanitizer and alcohol-free sanitizer.

Laboratory experiments using *E. aerogenes* showed that bacterial transfer rates varied by five orders of magnitude (Chen et al., 2001). A normal distribution described the rate distributions from hand to spigot and spigot to hand. The values were, in log percentage transfer rate: hand to spigot (− 0.80, 1.09) and spigot to hand (0.36, 0.90). Fig. 2 shows data collected for antimicrobial soaps fitted to a beta distribution. The bars represent the number of times each reduction was observed in the literature. The light gray bars represent data from soaps containing triclosan, black bars represent soaps containing *para*-chloro-*meta*-xylenol (PCMX), white bars represent soaps containing iodophors, and dark gray represents

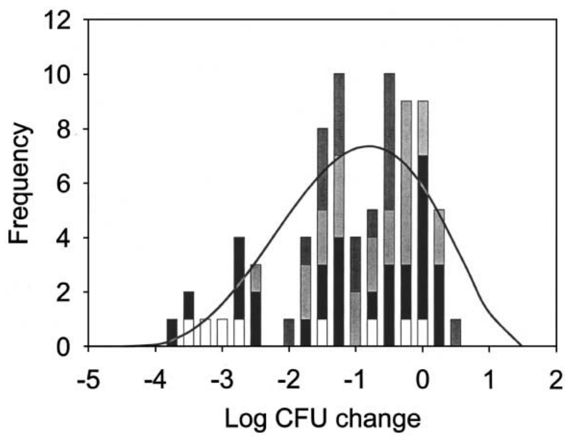

Fig. 2. Analysis of literature data using antimicrobial soap as an example. (A) Frequency of log change results from the use of soap containing triclosan (light gray), PCMX (black), iodophor (white), and other antimicrobial compounds (dark gray). (B) Beta distribution (solid line) fit to the combined data (bars).

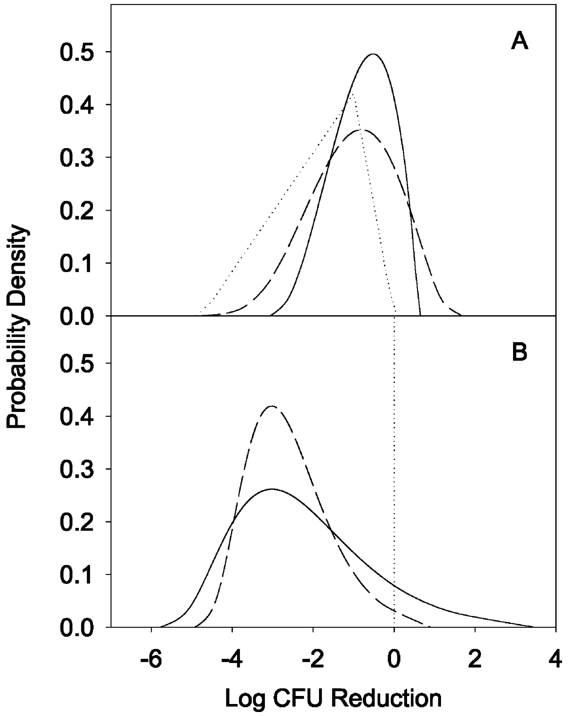

Fig. 3. Input distributions for soaps and sanitizers. (A) Effect of regular soap (solid line), antimicrobial soap (dashed line), and CHG soap (dotted line). (B) Effect of alcohol sanitizer (solid line), alcohol-free sanitizer (dashed line), and no sanitizer use (dotted line).

soaps containing other antimicrobial agents (excluding CHG). Visual inspection of these data indicates that combining them into a single distribution would be appropriate. The beta distribution shown was ranked first by the Kolmogorov–Smirnov test (Massey, 1951). The log change distributions for soap (Fig. 3A) and sanitizer types (Fig. 3B) based on literature data are shown in Fig. 3. Soaping or using a sanitizer after hand washing resulted in various degrees of log CFU change in the bacterial count on hands. The distributions also quantify the probability of an increase, albeit small, of bacterial count on hands, which is shown as log change values greater than zero (Fig. 3A and B).

3.2. Final log counts

Fig. 4 shows 3 of the 108 possible distributions by the simulation. All other factors being equal, Fig. 4A indicates that choosing a paper towel (dotted line) as a drying method shows a better log CFU reduction vs. using a hot air dryer (solid line). The final log CFU distribution was shifted to the left, indicating better overall hand washing efficiency for the paper towel method as opposed to a hot air dryer. Experimental data (Chen et al., 2001) on hand washing efficiency are shown in Fig. 4B. The distribution for the experimental data overlapped with the distribution predicted by the model for hand washing efficiency under a similar set of conditions, based on literature data collected from different studies. The similarity of the real and simulated data indicates a good agreement between the distributions used to characterize the literature data and the experimental data collected in our lab.

The model predictions for final bacterial counts were influenced by the various hand washing regimens (Fig. 5). Comparing the cumulative distributions, the progressive shift of the distributions to the right indicated a progressively lower degree of hand

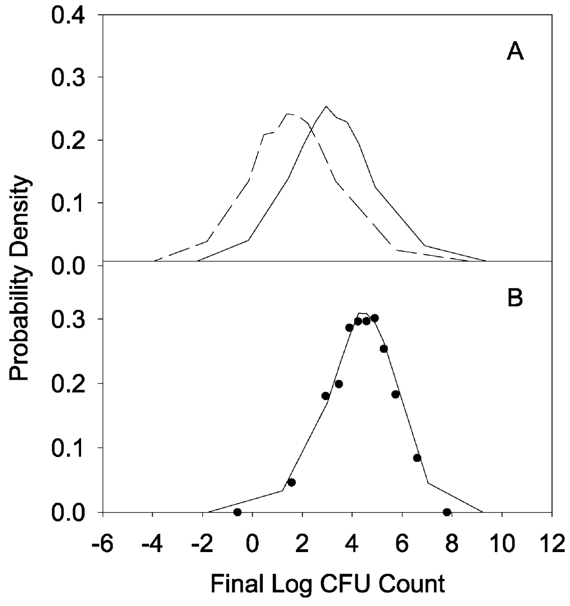

Fig. 4. Final bacterial counts on hand (log_{10} CFU). (A) Hand washing with chlorohexidine gluconate soap, alcohol-free sanitizer, and no rings using conventional faucet. Dotted and solid lines represent hot air dryer and paper towel, respectively. (B) Experimental data (closed circles) and model predictions (solid line) for the following scenario: antimicrobial soap, no sanitizer, paper towel drying, and no rings, touch free.

washing efficacy. For all three sets of scenarios, that is, "best case" (Fig. 5A), "average" (Fig. 5B), and "worst case" (Fig. 5C), choosing a clean, single-use paper towel as the drying method resulted in better hand washing efficiency. The drying method was one of the top three most significant factors in the model.

3.3. Tornado analysis

Fig. 6 shows the results of tornado analysis. Longer bars indicate greater variability associated with a factor. Both the overall effect of a factor (e.g. the range of reductions produced by all types of drying) and the choice of a factor (e.g. hot air vs. towel drying) were considered. The analysis revealed that the primary factors influencing the final bacterial counts on the hand were (a) sanitizer use, (b) soap use, and (c) drying method. Fig. 6 also indicates that whether or not a variable was chosen as an input in the model also effected model outcomes. Factors having relatively small influence on final log CFU on hands were the (i) ring effect, (j) faucet choice, and (k) ring choice.

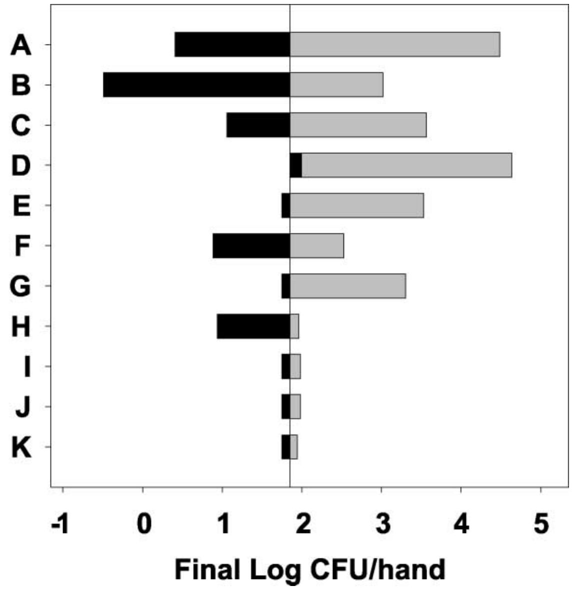

Fig. 6. Relative significance of input variables from top to bottom: (A) sanitizer effect, (B) soap effect, (C) drying effect, (D) sanitizer choice, (E) faucet effect, (F) initial count, (G) drying choice, (H) soap choice, (I) ring effect, (J) faucet choice, and (K) ring choice. Solid and hatched bars represent low 5% and high 95% fractile inputs of the variables, respectively.

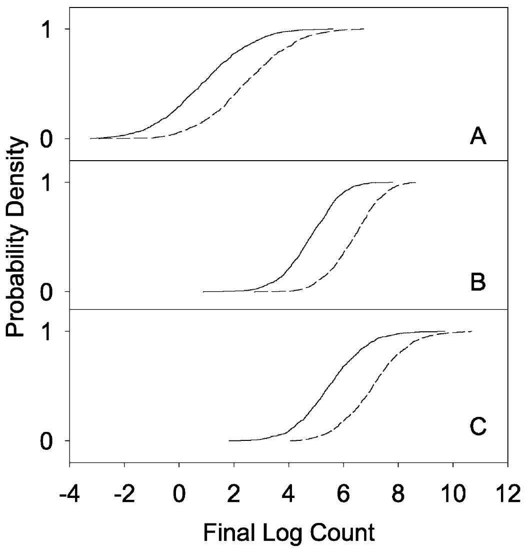

Fig. 5. Cumulative distributions obtained from 1000 Monte Carlo simulations. Dotted and solid lines represent hot air dryer and paper towel, respectively. (A) A best-case scenario: touch-free faucet, CHG soap, alcohol-free sanitizer, and no rings. (B) An average scenario: touch-free faucet, regular soap, and no sanitizer, with rings. (C) A worst-case scenario: contaminated faucet spigot with baseline density, regular soap, and no sanitizer with rings.

4. Discussion

The objective of this study was to provide a scientific basis for risk management strategies that minimize the levels of undesirable bacteria on the hands and, therefore, reduce the risk of cross contamination during food preparation. As an initial framework, this model considered only bacteria (not viruses) and studied only the influence of key variables. Several assumptions were made: (1) all bacteria (transient and resident) respond similarly to the factors; (2) these factors are independent; and (3) their effects are additive.

Soap with an antimicrobial agent was noted as being more effective than regular soap. Additionally, literature data show CHG to be more effective than other antimicrobial agents. There is some evidence that this is an experimental artifact due to the use of an incorrect antimicrobial quenching agent (Vashon, 1999, personal communication). Hot air drying had the capacity to increase bacterial contamination on hands, while paper towel drying caused a slight decrease in the level of contamination. There was little difference in the efficacy of alcohol and alcohol-free sanitizers. It is important to note that although sanitizers were shown to be very effective in the studies included here, they were primarily tested on relatively clean hands. It is likely that hand sanitizers would perform quite differently if used on dirty, greasy hands. Wearing rings caused a slight decrease in the efficacy of hand washing. The conventional hand washing system caused an increase in contamination on hands, as opposed to the touch-free system.

When factors are used in combination, final log CFU values range from less than -2 or greater than 9 (Fig. 5). Use of an antimicrobial soap, followed by use of a sanitizer, promotes a reduction, while hand contact with a contaminated faucet spigot, or use of a hot air dryer are to be avoided to improve hand washing efficacy. Previous research from our laboratory indicates that washed hands containing *E. aerogenes* at the level of about 5 log CFU/hand transferred the organism to lettuce during a simulated salad preparation task at the rate of about 1% (Chen et al., 2001). Given that the average transfer rates from hand to lettuce is equivalent to about a 2 log CFU reduction, a hand washing regimen resulting in 3 log CFU or less on hands may be desirable to minimize the risk for cross contamination. The simulation predictions (Fig. 5A) show that a hand washing regimen using CHG soap, paper towels, alcohol-free sanitizer, no rings, and a touch-free hand washing system would give ≤ 3 log CFU on hands about 92% of the time. A similar level of final log CFU can also be achieved by using other soap types or sanitizers. The choice of proper hand washing procedures for a foodservice establishment requires consideration of what is achievable and what is practical in the real world environment.

Although this study provided evidence to validate the combined effects of soaping followed by paper towel drying, the effects combining other factors requires further experimental validation. Some of the studies from which data were extracted for this simulation used a transient bacterium as a surrogate to evaluate the effect of various factors. Since foodborne pathogenic bacteria are transient in nature (with the exception of *S. aureus*), the model reflects hand washing efficacy with respect to the risk of bacterial contamination to a reasonable degree. Future work would also include expansion of the model to include assessment of risk associated with viruses, and the effect of a physical barrier such as gloves (Montville et al., 2001). Hand washing quantitative risk assessment simulation could provide a scientific base for the management of cross contamination via hand contacts in foodservice establishments when properly validated.

5. Conclusion

Systematic evaluation of the risk associated with different hand washing techniques indicates that, when done properly, hand washing can reduce the risk of bacterial contamination on hands. Quantitative risk assessment using literature and experimental data demonstrates that the primary factors influencing final bacteria counts on the hand were sanitizer use, soap use, and drying method. This research represents an initial framework from which sound policy can be promulgated.

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