Original Article

Effects of 4 Hand-Drying Methods for Removing Bacteria From Washed Hands: A Randomized Trial

DANIEL R. GUSTAFSON, MT(ASCP); EMILY A. VETTER, BA; DIRK R. LARSON, MS; DUANE M. ILSTRUP, MS; MYRON D. MAKER, BS; RODNEY L. THOMPSON, MD; AND FRANKLIN R. COCKERILL III, MD

• *Objective*: **To evaluate the effects of 4 different drying methods to remove bacteria from washed hands.**

• *Subjects and Methods*: **One hundred adult volunteers participated in this randomized prospective study. All bacterial counts were determined using a modified glove-juice sampling procedure. The difference was determined between the amounts of bacteria on hands artificially contaminated with the bacterium Micrococcus luteus before washing with a nonantibacterial soap and after drying by 4 different methods (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). The results were analyzed using a nonparametric analysis (the Friedman test). By this method, changes in bacterial colony-forming unit values for each drying method were ranked for each subject.**

• *Results*: **The results for 99 subjects were evaluable. No statistically significant differences were noted in the numbers of colony-forming units for each drying method (P=.72).**

• *Conclusion*: **These data demonstrate no statistically significant differences in the efficiency of 4 different hand-drying methods for removing bacteria from washed hands.**

Mayo Clin Proc. **2000;705-708**

CFU = colony-forming unit

Hand washing is the single most important procedure in hospital infection control. Many studies reported in the medical literature have shown that disease-causing bacteria are carried on the hands of health care workers.[1-9] Good hand-washing techniques can prevent the spread of these bacteria to patients.[3-8] Many studies have also demonstrated the usefulness of antibacterial soaps and the physical washing of the hands to remove bacteria.[10-19] Fewer studies have been reported that evaluated the effect that drying the hands has on removing bacteria.[20-22] The purpose of the present study was to determine the difference between the amount of bacteria on the hand before washing and after drying with 4 different hand-drying methods: 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 evaporation. We hypothesized that no significant difference in bacterial reduction occurs among any of these hand-drying methods.

SUBJECTS AND METHODS

Study Subjects and Sample Size

The study was approved by the Mayo Clinic Institutional Review Board and was conducted from October 7, 1996, through January 21, 1997. Potential recruits for the study were excluded if they had acute or chronic nail or skin disorders, including eczema, or were considered by an examining physician to have compromised immunity. One hundred healthy adults older than 18 years were ultimately enrolled in the study after formal consent was obtained. This number was chosen following the results of a pilot study.

For the pilot study, the hands of volunteers were artificially contaminated with the bacterium Micrococcus luteus (the hand contamination procedure is described below). The SD of the difference in colony-forming units (CFUs) among 4 hand-drying methods in the prewash to postdry changes was estimated to be 5.27×10^7. Based on these results, it was determined that a sample size of 100 subjects would provide at least 90% power to detect a mean difference in the change in CFUs between any 2 of the 4 drying methods that is greater than or equal to 1.7×10^7 CFUs (α=.05; β=.10). This is equivalent to an effect size of 0.32, which is considered to be between a small and medium effect size.[23] Alternatively, in the case of nongaussian data where the analysis would not involve a comparison of the means, 100 subjects would provide at least 90% power to detect a difference in the proportion of subjects having a

 ©2000 Mayo Foundation for Medical Education and Research

higher change in CFUs that is equal to 0.16 (relative to a null value of 0.50). This is considered to be approximately a medium effect size.[23]

Allocation of Study Participants

Each subject was tested under 4 methods of hand drying: paper towel, cloth towel, warm forced air, and evaporation. To eliminate any confounding effect due to test order or residual bacteria, the treatments were administered to the subjects in a balanced design created by randomly assigning the 4 drying methods to the letters of a 4 x 4 Latin square. First the rows, then the columns of this square were randomly permuted. This process of pemuting the rows and columns of the Latin square was repeated 25 times, resulting in 100 treatment allocation sequences. The effects of this design were that each drying method was applied first, second, third, and fourth an equal number of times and that each method was followed by each other method equally often. Also, with use of the 4 x 4 Latin square, after every 4 subjects the design was balanced. Each subject was required to wait a minimum of 3 complete days before participating in the next drying method.

Artificial Contamination of Hands With Bacteria

A modified glove-juice method was used for bacterial contamination of hands and performance of prewash and postdry bacterial counts. One of the subject's hands was artificially contaminated with approximately 1×10^7 bacterial cells of *M luteus*. The bacterial inoculum was prepared by seeding 500 mL of tryptic soy broth with *M luteus* and incubating the flask overnight at 35°C in room air on a shaker incubator. Ten milliliters of inoculum were pipetted into a sterile, quart-size resealable plastic bag. One hand of the subject was placed into the bag and wetted with the *M luteus* broth culture. The subject then dried the hand using a warm air hand dryer (Model A, World Dryer, Berkeley, Ill) until the hand did not appear visibly moist.

Washing and Drying of Contaminated Hands

The contaminated hand was then placed into another sterile resealable bag to which 50 mL of Butterfield phosphate-buffered water was added. The hand was massaged externally for 1 minute to remove bacteria from the hand into the buffered water. The hand was removed from the bag, and the subject washed in warm running water with a nonantibacterial soap (Camay, Procter & Gamble, Cincinnati, Ohio) for 30 seconds and then rinsed for 10 seconds with cold running water.

After washing and rinsing, each subject, based on randomization schedules, dried the study hand with cloth towels accessed by the study subject from a roller dispenser, with paper towels from a stack on the handwashing sink, with warm forced air from a mechanical dryer that the study participant activated with the nonstudy hand, or by spontaneous room air evaporation. The same warm air hand dryer was used immediately following artificial bacterial contamination of hands and for this step. Fifteen seconds were used for drying with the cloth towel or paper towels, and a single 30-second cycle of the warm air hand dryer was used. For the spontaneous room air evaporation method, the hand was allowed to air dry until no visible moisture was present. The dried hand was then placed into another sterile plastic bag, and 50 mL of Butterfield buffered water was added. The hand was again massaged externally for 1 minute.

Processing of Samples

The buffered water samples obtained before washing and after drying were serially diluted (1:10,000 and 1:1000, respectively) with Butterfield buffered water, and 0.2 mL of each diluted sample was pipetted onto the surface of a Letheen agar plate, which was incubated for 72 hours at 30°C in room air.

Bacterial CFUs were determined on the dilutions, which appeared to have fewer than 100 colonies of *M luteus*. Counting of only the *M luteus* colonies was aided by their bright lemon-yellow appearance. Colonies without such pigment were not counted.

Statistical Analysis of Data

For each of the 4 hand-drying methods, the end point of interest was the change in the number of CFUs, defined as the difference between the prewash CFU count and the postdry CFU count. The prewash, postdry, and change in CFU counts were examined graphically and tested for normality. These values were found to be highly non-gaussian. Therefore, the analysis was carried out using the Friedman test, a nonparametric procedure for randomized complete block designs, and the associated rank sum multiple comparison procedure.[24,25] The experiment was conducted according to the O'Brien-Fleming rule.[26] That is, when the data for approximately half the subjects (n=52) were obtained, the results were analyzed and tested for statistical significance at α=.001. If the results had been found to be significant, the experiment would have been concluded. However, at that point, there was insufficient evidence to stop the study, and the experiment continued until all subjects were tested. The analysis was repeated on the complete data set, this time at α=.049.

RESULTS

Of the 100 people recruited to participate in the study, only 1 failed to complete the experiment under all 4 hand-drying conditions and hence was removed

Table 1. **Prewash Colony Count***

Method	Mean (SD)	Percentile 25th	50th [median] (95% CI)	75th
Warm air hand dryer	7.09 (9.58)	1.98	3.70 (2.62-5.00)	8.20
Cloth towel	5.56 (5.63)	1.50	3.10 (2.45-4.48)	8.00
Evaporation	5.87 (6.76)	1.70	3.40 (2.80-4.78)	7.90
Paper towel	5.73 (6.92)	1.90	3.80 (2.85-4.60)	7.30

*Data are based on results from 99 study participants. All values are reported as number of organisms × 10^3. CI = confidence interval.

from the data set, leaving 99 subjects available for analysis. In addition, 2 treatment sequences were inadvertently skipped during the latter part of the experiment. However, these omissions affected the balancing only slightly.

Tables 1 through 3 summarize the prewash and postdry numbers of CFUs and the changes in CFUs by method. No statistically significant difference in the change in the number of CFUs among the 4 hand-drying methods was identified (P=.72).

DISCUSSION

Most nosocomial infections result from the transmission of bacteria on the hands of health care workers.[1-9] Good handwashing technique involves both washing and drying of hands. Many studies reported in the medical literature have demonstrated the importance of proper hand washing for removing harmful microorganisms from the hands.[10-19] Fewer studies have evaluated the effects of different drying methods for removing microorganisms from the hands, and the reported results have been inconsistent.[20-22] Ansari et al[20] demonstrated that warm air hand dryers performed better than paper towels or cloth towels, whereas Blackmore[21] showed that either paper towels or cloth towels outperformed warm air hand dryers. In a third study, Davis et al[22] observed no difference among these 3 hand-drying methods.

The protocols for each of these studies differed considerably. Ansari et al[20] artificially contaminated fingerpads with known quantities of Escherichia coli or rotavirus. Reduction in the numbers of these organisms was then assessed following the use of different handwashing agents and different drying methods. Organism counts were determined by manually scraping the area of the inoculated fingerpad on the inside rim of a vial containing broth. The total drying time for all methods averaged 10 seconds. Blackmore[21] assessed reduction in indigenous bacterial flora by directly contacting fingertips to a Petri dish containing nutrient agar. Drying time was only controlled for the forced warm air method and varied from 30 to 55 seconds. Davis et al[22] also assessed reductions in indigenous flora. After drying, the entire hand was then immersed and rubbed in Ringer lactate solution for 30 seconds. Drying times for all methods approximated 10 seconds.

For the current study, we artificially contaminated the hands of study subjects with a known inoculum of the bacterium *M luteus.* We also used a modified glove-juice method for assessing bacterial counts. Our pilot studies demonstrated that this method produced more consistent results than inoculating fingertips onto the surface of nutrient agar contained in Petri dishes. Theoretically, the glove-juice method should permit sampling of interdigital areas, which is not possible with imprinting techniques and therefore should provide a more comprehensive sampling of skin bacteria. Interdigital areas may not be dried as efficiently as palmar or volar surfaces of the hands,and fewer organisms may be removed by the drying process. This method has been recommended by the Food and Drug Administration as the preferred method for assessing the effectiveness of anti-septics for removing microorganisms from hands.[27]

The drying time for the warm air hand dryer in our study was equal to 1 cycle of the machine (approxi-

Table 2. **Postdry Colony Count***

Method	Mean (SD)	Percentile 25th	50th [median] (95% CI)	75th
Warm air hand dryer	0.06 (0.08)	0.008	0.02 (0.01-0.03)	0.08
Cloth towel	0.03 (0.05)	0.005	0.01 (0.01-0.02)	0.03
Evaporation	0.05 (0.10)	0.006	0.02 (0.01-0.02)	0.04
Paper towel	0.02 (0.03)	0.006	0.01 (0.009-0.02)	0.03

*See footnote to Table 1 for explanation of data.

Table 3. **Change in Colony Count (Prewash – Postdry)***

Method	Mean (SD)	Percentile		
		25th	50th [median] (95% CI)	75th
Warm air hand dryer	7.03 (9.53)	1.92	3.61 (2.61-4.95)	8.02
Cloth towel	5.53 (5.60)	1.49	3.09 (2.44-4.47)	7.98
Evaporation	5.82 (6.67)	1.69	3.39 (2.79-4.76)	7.87
Paper towel	5.71 (6.91)	1.89	3.79 (2.82-4.57)	7.24

*See footnote to Table 1 for explanation of data.

mately 30 seconds). We are unaware of any studies that have assessed how many people dry their hands the length of 1 drying cycle for a mechanical dryer. This time period approximated the air dryer time used by Blackmore[21] (30 seconds) but was considerably longer than that used by Ansari et al[20] (10 seconds) or Davis et al[22] (10 seconds).

The results of the current study showed that there was no statistically significant difference between prewash and postdry absolute counts of bacteria (CFUs) when any 2 hand-drying methods were compared (Tables 1-3). For this analysis, the warm air drying method had the highest average numeric rank. This ranking means that the change in the number of CFUs for this method compared with other methods from prewash to postdry was greatest. Although this difference seems to favor the forced warm air method as the best method for removing bacteria from the washed hand, the difference was not statistically significant. Of interest, the prewash CFU counts for the warm air hand dryer tended to be higher (although not statistically significantly) than those of the other 3 methods (Table 1). We have no explanation for this. What, if any, impact these higher counts had on corresponding postdry counts is also unknown.

In conclusion, the results of the current study suggest that there are no differences in the efficiencies of removing bacteria from washed hands when hands are dried using paper towels, cloth towels, warm forced air, or spontaneous evaporation.

REFERENCES

1. Horan T, Culver D, Jarvis W, et al. Pathogens causing nosocomial infections: preliminary data from the Nosocomial Infections Surveillance System. *Antimicrob Newslett.* 1988;5:65-67.
2. Bauer TM,Ofner E, Just HM, Just H, Daschner FD. An epidemiological study assessing the relative importance of airborne and direct contact transmission of microorganisms in a medical intensive care unit. *J Hosp Infect.* 1990;15:301-309. [Medline Link]
3. Slaughter FG. Immortal Magyar: *Semmelweis, Conqueror of Childbed Fever.* New York, NY: Schuman; 1950:3.
4. Frappier-Davignon L, Frappier A,St-Pierre J. Staphylococcal infection in hospital nurseries: influence of three different nursing techniques. *Can Med Assoc J.* 1959;81:531-536.
5. Mortimer EA Jr, Wolinsky E,Gonzaga AJ, Rammelkamp CH Jr. Role of airborne transmission in staphylococcal infections. *BMJ.* 1966;1:319-322.
6. Steere AC, Mallison GF. Handwashing practices for the prevention of nosocomial infections. *Ann Intern Med.* 1975;83:683-690. [Medline Link]
7. Black RE, Dykes AC,Anderson KE,et al. Handwashing to prevent diarrhea in day-care centers. *Am J Epidemiol.* 1981;113:445-451. [Medline Link]
8. Semmelweis IF. *The Etiology, Concept, and Prophylaxis of Childbed Fever.* Carter KC, trans-ed. Madison: University of Wisconsin Press; 1983.
9. Larson E. A causal link between hand washing and risk of infection? examination of the evidence. *Infect Control.* 1988;9:28-36. [Medline Link] [CINAHL Link]
10. Ojajarvi J. Effectiveness of hand washing and disinfection methods in removing transient bacteria after patient nursing. *J Hyg (Lond).* 1980;85:193-203. [Medline Link]
11. Morrison AJ Jr, Gratz J, Cabezudo I, Wenzel RP. The efficacy of several new handwashing agents for removing non-transient bacterial flora from hands. *Infect Control.* 1986;7:268-272. [Medline Link] [CINAHL Link]
12. Rotter ML. Hygienic hand disinfection. *Infect Control.* 1984;5:18-22. [Medline Link] [CINAHL Link]
13. Larson EL, Eke PI, Laughon BE. Efficacy of alcohol-based hand rinses under frequent-use conditions. *Antimicrob Agents Chemother.* 1986;30:542-544. [Medline Link]
14. Reybrouck G. Handwashing and hand disinfection. *J Hosp Infect.* 1986;8:5-23. [Medline Link] [CINAHL Link]
15. Ayliffe GA,Babb JR,Davies JG, Lilly HA. Hand disinfection:a comparison of various agents in laboratory and ward studies. *J Hosp Infect.* 1988;11:226-243. [Medline Link]
16. Daschner FD. How cost-effective is the present use of antiseptics? *J Hosp Infect.* 1988;11(suppl A):227-235. [Medline Link]
17. Larson E. Guideline for use of topical antimicrobial agents [published correction appears in *Am J Infect Control.* 1991;19:59]. *Am J Infect Control* 1988;16:253-266. [Medline Link] [CINAHL Link]
18. Larson E,Rotter ML. Handwashing:are experimental models a substitute for clinical trials? two viewpoints. I*nfect Control Hosp Epidemiol.* 1990;11:63-66. [Medline Link] [CINAHL Link]
19. Doebbeling BN, Stanley GL,Sheetz CT, et al. Comparative efficacy of alternative hand-washing agents in reducing nosocomial infections in intensive care units. *N Engl J Med.* 1992;327:88-93. [Medline Link]
20. Ansari SA, Springthorpe VS, Sattar SA, Tostowaryk W, Wells GA. Comparison of cloth, paper, and warm air drying in eliminating viruses and bacteria from washed hands. *Am J Infect Control.* 1991;19:243-249. [Medline Link] [CINAHL Link]
21. Blackmore MA. A comparison of hand drying methods. *Catering Health.* 1989;1:189-198.
22. Davis JG, Blake JR, White DS, Woodall CM. The types and numbers of bacteria left on hands after normal washing and drying by various methods. *Med Officer.* 1969;116:235-238.
23. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* Rev ed. New York, NY: Academic Press; 1977:19-74.
24. Hollander M, Wolfe DA. *Nonparametric Statistical Methods.* New York, NY: John Wiley & Sons; 1973:183-184.
25. Ipe D. Performing the Friedman test and the associated multiple comparison test using PROC GLM. In: *Proceedings of the Twelfth Annual SAS Users Group International Conference*; Dallas, Tex; February 8-11,1987.
26. O'Brien PC,Fleming TR. A multiple testing procedure for clinical trials. *Biometrics.* 1979;35:549-556. [Medline Link]
27. Bruch MK. Methods of testing antiseptics: antimicrobials used topically in humans and procedures for hand scrubs. In:Block SS, ed. *Disinfection, Sterilization, and Preservation.* 4th ed. Philadelphia, Pa: Lea & Febiger; 1991:1028-1046.