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Research Article

Microbiological Assessment of the Different Hand Drying Methods and Washroom Environment Cross-Contamination

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Proper hand drying is a fundamental part of the hand hygiene process looking at optimizing the elimination of potentially pathogenic microbes. This research compared the effectiveness of three different hand drying methods—paper towels, the use of warm air dryers in stationary hands position, and the use of air drying while hand rubbing—and their potential for cross-contamination of other users and the surrounding environment. One hundred sixty samples were collected from finger pads and palms, before and after drying. The outlet of the air dryers, air current emitted from the air dryers, and washroom environment air were also tested. The study reported that paper towels were more successful in eliminating bacteria and lead to less contamination to the washroom environment compared to the air dryers. The average number of bacteria obtained from volunteers using hand air dryer while hand rubbing was significantly higher than drying with air dryer while holding hands stationary. Plates exposed to the turned-off dryer for 5 minutes gave an average of only 25 colonies/plate, while plates exposed to the air outlet of the turned-on warm air dryers provided 292 colonies/plate. Placing Petri dishes at least one meter away from the dryer in the washroom for 30 minutes gave 72.5 colonies/plate. The current research also documented frequent contamination of public washroom environments and showed dissemination of potential pathogens, including *Escherichia coli* (*E. coli*), *Klebsiella* species, *Bacillus cereus* (*B. cereus*), *Staphylococcus aureus* (*S. aureus*), and coagulase-negative Staphylococci. Over 70.0% of Staphylococci were resistant to at least three antibiotics and 50.0% revealed coresistance to at least four antibiotics including penicillin, erythromycin, clindamycin, and co-trimoxazole. The method of hand drying may serve as a risk factor of cross-contamination from users to the environment and subsequent users and as reservoirs of drug-resistant bacteria in public washrooms.

1. Introduction

Hand hygiene has been documented as the easiest and the most efficient method existing in a number of settings to minimize the risk of infection transmission, including healthcare settings, food industry, schools, and other public locations [1–3]. Indeed, wet hands have shown higher probability both of getting microorganisms from polluted objects and of transmitting them to uncontaminated matters [4, 5]; hence, proper hand drying after washing is an important aspect of the process. Given that, it has become noticeable that hand drying is vitally important for preventing diseases transmission, since bacteria more likely multiply in humid environments and water is easily transferred between objects [6, 7]. As hand washing does not eliminate all microorganisms, the drying method can affect the number of microbial dispersals from washed hand to the surrounding environment but knowledge about which drying methods contribute least to users and environmental contamination is scarce. A small number of studies comparing the efficiency of warm air dryers to paper towels were carried out focusing generally on the number of microorganisms left on the hands after drying [8–13]. These findings have revealed that the number of bacteria left on the hands depends primary on the type of microbe, the time and the method of drying (rubbing amount), and the portion of the hand examined. The majority of these studies have shown that any method has its benefits and limitations but that, with any drying process, satisfactory results can be obtained if the hands are fully dried by the technique. Paper towels

and hot air dryers are still the most widely used methods of hand drying in public washrooms. Some researchers suggested an increase in bacteria by drying with paper towels in comparison to drying with a hot air dryer [14]. Meanwhile, a study conducted by Gustafson et al. [9] revealed no statistically significant differences in the effectiveness of the hand drying methods including paper towels and warm air dryers for eliminating bacteria from washed hands. Redway and Fawder [15] attributed the decrease in the number of bacteria when using paper towels compared to warm air dryers to the ability of the paper towels to dry hands more efficiently. It has been reported that even though air dryers effectively dry the hands as paper towels, the bacterial growth on the hands still increased. Furthermore, there is conflicting evidence about whether the hand drying methods differ in their tendency to aerosolize and spread microbes. Several studies have indicated that drying hands with warm air dryers can enhance the aerosolization of microorganisms [16], although others have shown that the tendency of drying methods to aerosolize microorganisms is limited [10]. Additionally, some studies demonstrated the risk of potential aerosolization of microorganisms from trash cans as they were often uncovered and placed directly below the hand dryers [17]. A recent study conducted by researchers at Connecticut University and Quinnipiac University has shown that warm air hand dryers in public toilets may suck bacteria from the air and dump them into the washed hands of users [17]. They stated that most of the hand dryers' bacterial growth had originated from air in the washroom because the number of microbes in the plates exposed to hand dryer's air had dropped by 75% after using particulate air (HEPA) filters to the dryers.

As countless people belief that using hand washing and drying facilities in public washrooms is safe, those facilities may also be possible sources for pathogenic microorganisms to be transmitted due to their environments suitable for the survival of many pathogenic bacteria such as *E. coli, S. aureus*, *B. cereus*, and *Pseudomonas aeruginosa* (*P. aeruginosa*) [7]. In addition to the scarcity of research evaluating the different hand drying methods and the environment's air in the public washrooms in the Kingdom of Saudi Arabia (KSA), this study, however, aimed to assess the different methods of hand drying and their role in contaminating washroom's environment and antibiotic susceptibilities of isolated bacteria.

2. Materials and Methods

2.1. Sample Collection. This study was conducted in the different academic institutions' washrooms in the KSA to evaluate the efficacy of hand drying methods. The study involved 20 adult volunteers who agreed to participate in this research. Persons with any skin or nail lesions were excluded. The samples obtained after hands were washed with nonantibiotic soap and after drying with different methods. These methods include (1) drying with a paper towel, (2) drying with air dryer while keeping the hands steady, and (3) drying with air dryer while hand rubbing.

2.2. Evaluation of the Number of Microorganisms on Hands after Washing and Drying. Participants were instructed to wash their hands and dry them in warm air hand dryers; the following day, the same subjects were requested to use paper towels. The hands were dried in random sequence to eliminate any confusing effect. The subject washed for 30 seconds in running water with a nonantibacterial soap and then rinsed for 10–20 seconds to remove all soap. Each subject, after washing and rinsing, dried the hand with paper towels or the warm air hand dryer. For drying with the paper towels, fifteen seconds was used, and a single 30-second cycle of the warm air hand dryer was used. After washing and drying, samples were taken from the fingers and palms. The finger and palm samples were taken by contact plate methods, and the finger pads and the palms were pressed on Petri dishes containing nutrient agar. The plates were then incubated at 37°C for 48 hours and bacterial total counts were estimated after incubation.

2.3. Potential Contamination of Other Users and the Washroom Environment Using Hand Air Dryers. The surrounding environment was assessed for the contamination of bacteria by warm air dryers in the washrooms of four colleges with three different methods including (1) plates exposure to the air outlet of the turned-on warm air dryers, (2) placing the plates in front of the turned-off dryer for 3 minutes (min), and (3) placing Petri dishes at least one meter away from the dryer in the washroom for 30 min. Additionally, the inner surface of air dryers' nozzles was swabbed with sterile swabs moisturized in normal saline to collect samples. The samples were collected at several locations at the university. The plates were incubated for 48 hours at 37°C and bacterial total counts were estimated after incubation. The bacterial isolates were identified by the conventional methods such as morphological and cultural characteristics and biochemical characteristics.

2.4. Antibiotic Sensitivity Assay. Antibiotic sensitivity was tested on sixteen bacterial isolates obtained from the samples of the washroom's environment following Laboratory Standards Guidelines for antimicrobial susceptibility assay [7, 18, 19]. The resistance to antimicrobials was tested using disc diffusion assay (Kirby and Bauer, 1966). Bacterial suspensions prepared in sterilized saline were evenly spread with sterile swabs on Muller Hinton Agar with turbidity equal to that of the 0.5 McFarland standard. The following antibiotics were used: penicillin G (10 units), erythromycin (15 μg), ampicillin (10 μg), cephalothin (30 μg), clindamycin (2 μg), and co-trimoxazole (25 μg). The plates were incubated overnight at 35–37°C; then the inhibition zones around the antibiotic disks were measured.

2.5. Data Analysis. Data were analyzed using the Mann–Whitney test to assess significance where statistical significance was expressed as $p < 0.05$. Graphs were performed using GraphPad Prism version 8.4.3, San Diego, California, USA.

3. Results

3.1. Assessment of Microorganisms' Number on Hands after Washing and Drying. The air dryer increased the bacterial average numbers on both the palms and finger pads of subjects. In the current study, paper towel was found to be superior to the air dryer for hand palms and finger pads (Figure 1). The number of residual bacteria on the fingers was substantially increased in the participants who had dried their hands with the air dryer compared to the drying with paper towels. The result was significant at $p < 0.05$ for finger using paper towel (140.1) compared to drying with the air dryer (276.6). On hands dried with a paper towel, recovered bacteria were significantly lower compared to drying hands with the air dryer ($p < 0.05$). As shown, the number of bacteria obtained from participants with hand towels and an air dryer varied greatly (Standard Deviation (SD): 95.6 and 33.6, respectively).

3.2. Effect of Hand Movement during Hand Drying Using Warm Air Dryers. A significant raise in the number of bacteria was obtained from volunteers using hand air dryer while hand rubbing compared to drying with air dryer while holding hands stationary. The result is significant at $p < 0.05$for fingers (297.1, SD 3.7 and 146.8, SD 27.8, respectively) and palms (109.1 SD 19.3 and 69.9 SD 17.1, respectively) (Figure 2).

3.3. Potential Contamination of Other Users and the Washroom's Environment Using Hand Air Dryers. This part of study was done to assess the bacterial contamination of the washroom's environment caused by using the warm air dryers. Aiming to calculate the total viable counts, Petri dishes containing nutrient agar were exposed to outlet nozzle of the air dryers in the washrooms in different conditions. Bacterial isolates were recovered from the air emitted by the air flow from the outlet nozzle of the air dryers in the washrooms. During use, open agar plates were placed under air flow from the outlet nozzle of the hand drying device. Colonies that grew on the plates were counted. Analyses of microbial colonies recovered on agar plates showed that there is a significantly high number of bacteria (290.75, SD 15.1) in comparison with the plates exposed to the nozzle air with hand dryers off (25, SD 13.7). In the plates exposed to washroom air for 30 min at least one meter away from the air dryers, the mean number of bacteria on fingers and palms was 72.5 (SD 30.2) (Figure 3). Different types of bacteria were recovered, some of which are pathogenic bacteria including *E. coli, Klebsiella* spp., *Bacillus cereus, Staphylococcus aureus,* and coagulase-negative *Staphylococcus* spp. (Table 1).

Moreover, when swabs were taken from the nozzles to test if the bacteria are multiplying inside the hand dryers, the result found high bacterial numbers on the hand dryers' outlets (43 colonies).

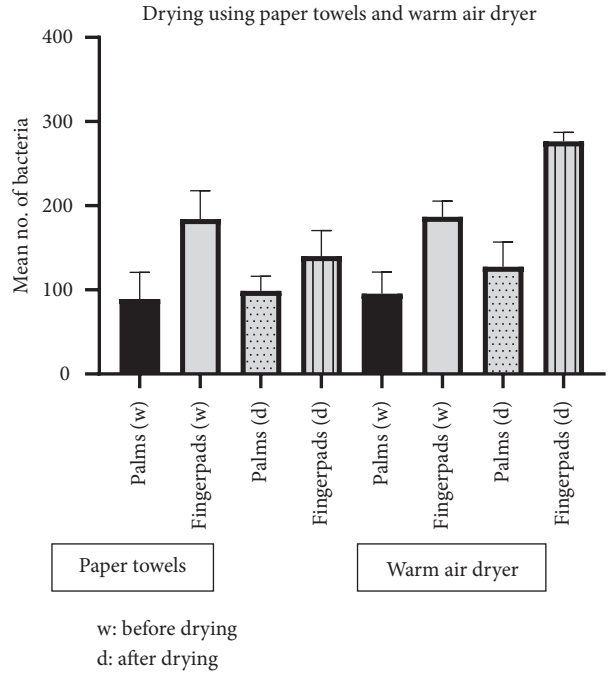

Figure 1: The mean number of bacteria obtained from the participants' hands upon washing and drying using paper towels and warm air dryer.

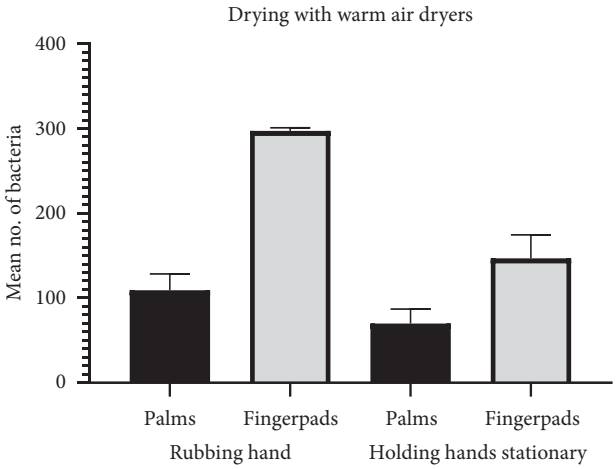

Figure 2: The mean number of bacteria obtained from the participants' hands upon washing and drying with air dryer while holding stationary hands and drying with air dryer during hand rubbing.

3.4. Antibiotic Sensitivity Assay. The antibiotic sensitivity test was performed by using penicillin G (PG) 10 units, erythromycin (15 μg), ampicillin (10 μg), cephalothin (30 μg), clindamycin (2 μg), and co-trimoxazole (25 μg) for the bacterial isolates recovered from the plates that were exposed to the washroom's air. Result displayed that over 18.25 percent (%) of bacterial isolates showed resistance to all tested antibiotics, and 50 percent of isolates demonstrated resistance to at least three antimicrobials, including

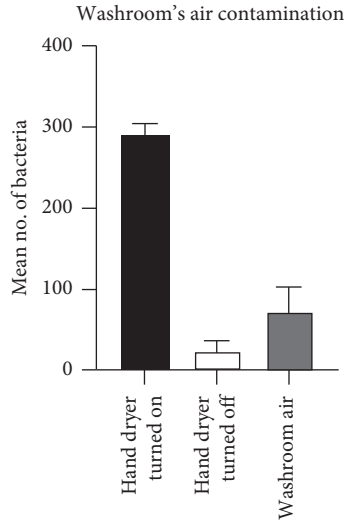

Figure 3: The impact on microbial contamination of the washroom environments by using hand air dryers.

Table 1: Antibiotic resistance of bacterial species.

Bacterial isolates	Total number of isolates	% resistance (number of isolates)						Resistance to at least 3 antibiotics (%)	Resistance to at least 4 antibiotics
		Penicillin G	Erythromycin	Ampicillin	Cephalothin	Clindamycin	Co-trimoxazole		
E. coli	3	33.3% (1)	33.3%	66.7% (2)	33.3% (1)	33.3% (1)	66.7% (2)	33.3	—
Klebsiella spp.	1	100% (1)	100% (1)	100% (1)	0% (0)	0% (0)	0% (0)	100	—
Staphylococcus aureus	3	100% (3)	66.7% (2)	100% (3)	66.7% (2)	66.7% (2)	66.7% (2)	66.7	66.7%
CoNS	7	85.7 (6)	71.4 (5)	85.7 (6)	42.8% (3)	57.1% (4)	42.8% (3)	71.4	42.8%
Bacillus cereus	2	100% (1)	50.0% (1)	100% (1)	100% (1)	0% (0)	0% (0)	50.0	—

CoNS: coagulase-negative Staphylococci.

penicillin, erythromycin, and ampicillin. Over 71.4% of coagulase-negative Staphylococci were resistant to at least three antibiotics and 42.8% revealed coresistance to at least four antibiotics including penicillin, erythromycin, clindamycin, and co-trimoxazole, while all tested *S. aureus* proved coresistance to at least three antimicrobial agents, with 66.7% of isolates being resistant to at least four antibiotics (Table 1).

4. Discussion

The necessity of hand washing for optimizing the elimination of potential pathogenic microbes is well documented [20]. Though insufficient studies have assessed the efficiency of various drying methods to eradicate microorganisms from the washed hands, there have also been contradictory reports from different studies. Some studies have shown that electric air dryers remain less successful in matters of hygiene [14], whereas some have a strong opinion that they are safe and efficient way to dry hands [10]. The current study is in agreement with the results supporting the low efficacy of warm air dryers and their potential in contaminating the environment and users. This study reported that there were higher bacterial numbers recovered from volunteers using a warm air dryer compared to those using hand towels. Similarly, Redway and Fawdar [14] have noted an apparent rise in microorganisms if electric air dryers were used in comparison with paper towels because of the ineffectiveness of electric air dryer in drying washed hands as paper towel. Although previous research did not show any considerable variation in the number of bacteria obtained after hands drying using either paper towel or air dryer [10], the research has shown that drying hands using warm air dryer is suitable in food industries and healthcare settings. However, Best et al. [21] reported that the bacterial counts near hand drying were 27-fold higher compared with use of paper towel. The variations in the sum of bacteria after drying by using paper towel and warm air dryer may be attributed to several other aspects instead of dryness alone [15]. Over both hand washing and drying, erosion can remove bacteria from the surface of the skin, rendering erosion the most significant factor in drying hands, since the bactericidal effect of antimicrobials in soap is not advantageous due to the limited skin contact time. Drying hand with paper towel is superior to the warm air dryer as it expels microbes from the washed hand while warm air dryer cannot [22, 23]. The examination of paper towels after using showed that many microorganisms had been transmitted from hands to paper towels

[10, 11]. Most research, however, indicates that paper towel could efficiently dry hands, effectively eliminate microbes, and reduce contamination of the washroom environments. Thus, paper towels must be strongly suggested in places at which hygiene is crucial, such as healthcare facilities. Several studies have found that scrubbing hands when drying with warm air dryer to speed drying will result in higher concentrations of bacteria microbial spreading [12]. This result is in agreement with this work where there were a significantly increased number of bacteria recovered from volunteers using hand air dryer while hand rubbing compared to drying with warm air dryer when keeping hands fixed. Other studies have recorded the same result when comparing the hand drying methods by warm dryer in both conditions of drying. They demonstrated that drying hands while held fixed can eliminate more microbes than when rubbing hands [11, 13]. Rubbing hands could cause considerable raise in the number of microorganisms because the hand surface exposed to the hot air is reduced. Several studies have indicated the association between the increase of microorganism aerosolization and drying hands by warm air dryer, while others have stated there are no differences. A research by Gustafson et al. [9], for example, noticed no important difference in the efficiency of removal of microorganisms between hand drying methods, such as with warm air dryers and paper towels, whereas a study conducted by Alharbi et al. [24] to assess the bacterial contamination by 15 warm air dryers in the academic institution's washroom in the KSA inferred that warm air dryers may deposit pathogens on user's hands and bodies. Bacteria are spread into the washroom's environment while dryers are running and may be inhaled by users and bystanders. Several studies have confirmed the role of hand dryers in washroom in dispersing microbes from hands and deposing them on surfaces and newly washed hands. But less information is available about the dispersed microorganisms by hand dryers. The results of a previous study indicated that several species of bacteria and their spores including potential pathogens could be dumped on hands of washroom hand dryers' users. Also, spores can be spread in the buildings and dumped on washed hands by hand dryers [17]. The latter study tested whether, during drying, the air flow from the warm air dryer spread aerosolized bacteria on surfaces and if the hand dryer is a potential reservoir of bacteria. As known, public washrooms and toilet facilities are areas at serious rate of growing and transmitting of microbes including several species of fecal bacteria that could be pathogenic. Tiny aerosols containing potential pathogens could be sprayed into the washroom's environment each time a toilet is drained. The microorganism dispersal was shown to be over six-meter squares [25]. Redway and Fawdar [14] also stated that hand air dryers disperse contamination at a distance of approximately two meters. Such findings were in agreement with the current research reporting a considerable number of bacteria, some of which are potential pathogens in the washroom's environment when the air dryer was operating, in addition to its ability of absorbing microorganisms from air and disposing them on the hands of other users. It could also be a potential reservoir of bacteria as 43 colonies were recovered when the inner surface of the nozzle was swabbed. Relative to other drying methods, the poor hygienic efficiency of the warm air dryer may be attributed to its limiting drying capacity and therefore the larger amount of water left on the hands [13]. The effectiveness of the hand drying technique is not only the proportion of the hand's dryness but also the microbial elimination and the contamination prevention of the washed hands and washroom environment. In general, warm air dryers are mostly not preferred for use in locations at which hygiene is crucial including clinics and healthcare, food industry, and fitness locations since their efficiency is uncertain; in addition, they are slow. In contrast, the only adverse impact of using paper towels is related to the disposal of wastes and sustainability of environment [26]. As stated by Budisulistiorini [27], the amount of greenhouse gases (carbon dioxide) emitted when drying with paper towels is slightly higher than when drying with warm air dryers. This work suggests that hand dryer in public washrooms could serve as reservoirs of antibiotic resistant bacteria with 50% of isolates being resistant to at least three antibiotics. A study of Suen et al. [7] revealed that over 97% of the pathogenic *Staphylococcus* spp. isolated from washroom air were resistant to at least one first-line antibiotic, including penicillin, cefoxitin, erythromycin, co-trimoxazole, clindamycin, and gentamicin. They reported that over 20% of the isolates in their study displayed coresistance to at least two antibiotics. A research by Aiello et al. [28] reported that *Staphylococcus* spp. obtained from public washrooms in UK showed antibiotics resistance of 37.8 percent, with 67.7 percent of isolates being penicillin resistant and more than 20 percent of them exhibiting coresistance to at least two additional antibiotics.

There are some constraints to this study, as the number of obtained microbial colonies was high and the resources were limited; only certain isolated colonies were selected at random for identification. Therefore, not all isolates were identified and antibiotic susceptibility was not performed for all bacterial isolates. However, the results of this research can raise awareness among hand washing and hand drying facility users to the neglected aspect of public washrooms.

5. Conclusion

Appropriate drying of hands after washing is a fundamental part of hand hygiene. The present study supports the effectiveness of towel paper in the elimination of microorganisms from washed hands. Results of other studies are varying. Even then, many researches have indicated that paper towels can efficiently dry hands, effectively eradicate microorganisms, and reduce contamination of washroom environment. Other studies reported that the use of paper towels could have negative impacts concerning waste management and environmental sustainability. Further research is required to determine the effectiveness of different hand drying methods and the efficiency of the latest models of air dryers and to test the role of the hot air hand dryers in washrooms to absorb bacteria from the air and disposing them on the recently washed hands of other users.

In addition to investigating the types of pathogenic microorganisms dispersed by air dryers, the results of this study increase concerns about hand drying facilities in public washrooms to prevent contamination of washed hands and environments by pathogenic bacteria.

Data Availability

Data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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