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A microbiological evaluation of warm air hand driers with respect to hand hygiene and the washroom environment

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J.H. TAYLOR, K.L. BROWN, J. TOIVENEN AND J.T. HOLAH. 2000. A finger rinse technique for counting micro-organisms on hands showed no significant difference in the level of recovered micro-organisms following hand drying using either warm air or paper towels. Contact plate results appeared to reflect the degree of dampness of hands after drying rather than the actual numbers of micro-organisms on the hands. In laboratory tests, a reduction in airborne count of *Pseudomonas aeruginosa* and *Staphylococcus aureus* of between 40 and 75% was achieved from 600 readings comparing inlets and outlets of warm air hand driers. In washroom trials, the number of airborne micro-organisms was reduced by between 30 and 75%. Air emitted from the outlet of the driers contained significantly fewer micro-organisms than air entering the driers. Drying of hands with hand driers was no more likely to generate airborne micro-organisms than drying with paper towels. Levels of micro-organisms on external surfaces of hand driers were not significantly different to those on other washroom surfaces. This work shows that warm air hand driers, of the type used in this study, are a hygienic method of drying hands and therefore appropriate for use in both the healthcare and food industry.

INTRODUCTION

The importance of hand hygiene in controlling infection in both hospitals and the food industry is well understood since Semmelweis's observations in 1847 that the implementation of hand washing brought about a reduction in the deaths of women from puerperal fever (Semmelweis 1847).

There is evidence, primarily from the health care sector but also from the food industry, to show that transient micro-organisms are transferred to the hands in the process of handling food such as meat and poultry (and occasionally through poor personal hygiene after visiting the lavatory), resulting in the hands being heavily contaminated with enteric pathogens (Pether and Gilbert 1971; De Wit 1985; Kerr *et al.* 1993). Cross-contamination via the hands may be direct by handling food or patients, or indirect through poor practices and control of equipment. Such cross-contamination continues to be a major issue in both the medical and food industry, although much of the research focuses on the hospital environment (Lowbury *et al.* 1970; Larson 1981).

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Hand hygiene is concerned with removing the transient micro-organisms and usually involves washing the hands with water and a bactericidal soap, followed by drying and, in the food industry, finishing with an alcohol based hand rub. The choice of method for hand drying includes linen or paper towels and warm air hand driers. The choice of drying may depend upon a number of factors, which may be practical, economic or perception (i.e., the belief that one method is superior to another). Recent research provides evidence to show that the efficiency of drying is important in the prevention of translocation of micro-organisms (Patrick *et al.* 1997). Other researchers have evaluated the different methods, but differing results and conclusions have been presented as to which method is the most efficient and least likely to be a microbiological hazard. This means that managers within the food industry may have difficulty in deciding which system is the most appropriate for their particular application.

This work was undertaken with the aim of comprehensively and independently evaluating the performance of warm air hand driers, in comparison with paper towels, to examine a number of issues. First, the ability of warm air driers to dry hands hygienically was evaluated by measuring the number of micro-organisms on hands after washing and drying with warm air hand driers and comparing the

results with the same protocol but drying with paper towels. Secondly, to evaluate whether warm air driers do in fact change the level of air-borne micro-organisms in the washroom environment; there has been a report that they increase the levels (Knights *et al*. 1993). Finally, the surfaces of warm air driers and other washroom areas were evaluated for total viable counts to ascertain whether there were any differences attributable to the use of warm air driers.

MATERIALS AND METHODS

Assessment of the number of micro-organisms on hands after washing and drying

Experimental set-up. These experiments were undertaken using the containment cabinet (Fig. 1). Fifteen volunteers were asked to wash and dry their hands using warm air hand driers; the following day the same people were asked to use paper towels. The hand drier was situated outside the cabinet with an extension tube on the nozzle passing through a porthole into the centre of the cabinet. The air inlet of the drier was open to the laboratory. The opposite port was used for subjects to place their hands for drying, and the adjacent port was used to take air samples from the cabinet during the drying procedure. After each subject, the cabinet was purged with filtered air for 4 min. Hand drying with paper towels was also done in the cabinet and after drying, the towel was retained for microbiological testing.

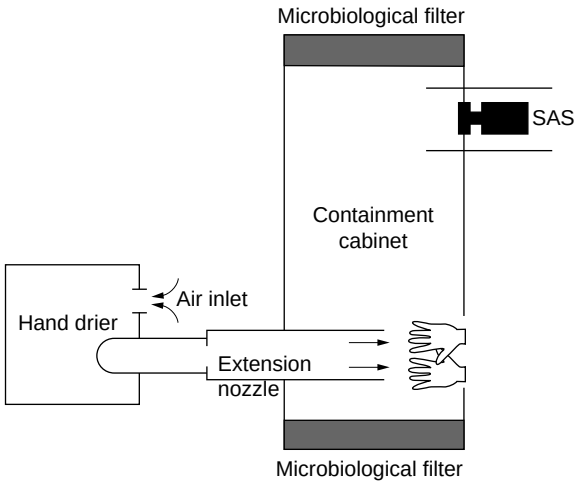

Fig. 1 Schematic diagram to show experimental set-up for hand wash experiments

Experimental procedure.. The cabinet was purged with filtered air for 4 min while the subject had samples of initial bacterial levels on their hands taken by finger rinse and contact plate methods. For finger rinses, the finger pads were gently rubbed on the base of Petri dishes containing 10 ml Maximum Recovery Diluent (MRD; bacteriological peptone $1{\cdot}0\,g\,l^{-1}$ and sodium chloride $8{\cdot}5\,g\,l^{-1}$ adjusted to pH 7·0) with inactivator (0·3% w/v lecithin, 3·0% v/v polysorbate 80, 0·5% w/v sodium thiosulphate, 0·1% w/v L-histidine, 3·0% w/v saponin, 1% v/v phosphate buffer (0·25 N)) for 1 min. Contact plates were taken by pressing contact plates containing Nutrient Agar (NA; Oxoid) against the palm and giving a slight twist before removing from the palm. For both methods, both left and right hand were sampled. The subjects then washed their hands in a standard way by wetting the hands, applying a measure of Century liquid soap (Kernick, Cardiff, UK) and rubbing according to the method in BS EN 1499 (Anon. 1994) for a total of 1 min followed by a rinse lasting approximately 10–20 s to remove all soap. The subjects then placed their hands in the porthole of the cabinet near to the extended drier nozzle, and dried their hands until they felt dry. During this time, the air in the cabinet was sampled (120 l) using the SAS Super 90 Air Sampler (Cherwell Laboratories, Bicester, UK) containing NA at the adjacent port. After drying, finger rinse and palm contact plates were undertaken to give post-wash values. The same procedure was carried out for the paper towels on the next day. After use, the paper towels were placed in a stomacher bag, 100 ml MRD added and the bags stomached for 30 s. The resuspension fluid was analysed for total viable counts by serial decimal dilution and duplicate pour-plating with NA. Finger rinse results were expressed as cfu $hand^{-1}$ (left and right), air sample results as cfu m^{-3}, towel results as cfu $towel^{-1}$ and contact plates as cfu $plate^{-1}$.

The effect of different drying times

The hand washing experiment was repeated with four different volunteers using warm air to dry hands; bacterial assessment was undertaken by palm contact plates. The experiment was undertaken with different drying times from 10 to 45 s.

Change in levels of air-borne micro-organisms: laboratory studies

Using a cabinet designed to contain microbial aerosols (Bassaire Ltd, Southampton, UK), the experiments were set up according to the diagram shown in Fig. 2.

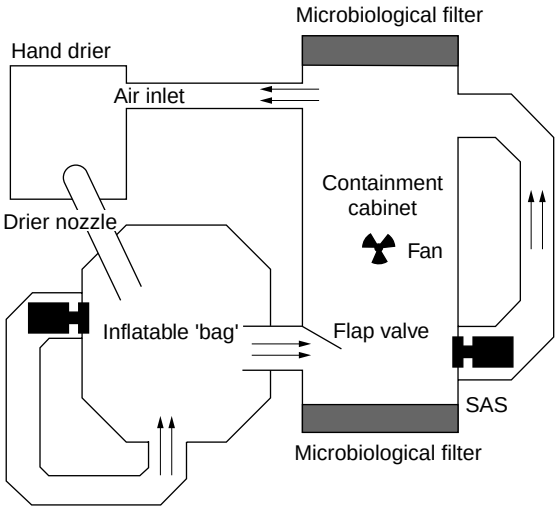

Fig. 2 Schematic diagram to show the experimental set-up to evaluate the change in air-borne micro-organisms passing through a hand drier

Experimental set-up. The experiments involved creating a bacterial aerosol of *Pseudomonas aeruginosa* or *Staphylococcus aureus* of different concentrations in the cabinet which had been previously purged of any micro-organisms using the microbiological filters at each end of the cabinet (one filtering air into the cabinet and one filtering air leaving the cabinet) for 4 min. The air inlet on the drier was connected to the cabinet containing the generated aerosol. Connected to the nozzle of the drier was an adapter leading into a large inflatable plastic 'bag' (to reduce the air velocity for sampling) from which air samples could be taken from a sampling tube set up to allow the exhaust air from the air sampler to be returned to the inflatable 'bag' and hence, back into the cabinet through a porthole. The porthole had a flap valve to prevent the back-flow of air into the inflatable bag. The sampling arrangement was checked using a smoke generator (Colt 4, Concept Engineering, Maidenhead, UK) to ensure that airflow into the samplers was not compromised by airflow through the hand driers.

The level of micro-organisms entering the air inlet on the drier was measured by sampling air from the cabinet (exhaust air from the sampler was returned to the cabinet). The system was therefore contained with respect to the test micro-organisms, and enabled precise measurements of levels of organisms entering and leaving the hand drier under test.

Experimental procedure.. Overnight cultures of bacterial suspensions of *Ps. aeruginosa* (NCIMB 10421) and *Staph. aureus* (NCTC 10788) were grown in 150 ml Nutrient Broth (Oxoid) at 25 °C. The cultures were harvested by centrifugation at 3600 *g* for 10 min and resuspended in 100 ml phosphate buffer (3·4%w/v) adjusted to pH 7·2. The optical density (O.D.) of the suspension was measured in a spectrophotometer S104 (WPA, Cambridge, UK) at 420 nm to determine the cell concentration from previous calibrations of O.D. against viable counts. Further bacterial suspensions were obtained by serial decimal dilution to give an overall range of concentrations of 10^6-10^9 cfu ml^{-1}.

Five driers in total, including both manual and automatic models, were used in this part of the study and placed in turn into the containment system. The cabinet was purged of micro-organisms by switching on the filters for 4 min. Contact plates containing NA (previously filled with a dispenser to ensure a consistent level) were fitted into the SAS air samplers and isolated from the experimental circuit until required for sampling.

The bacterial aerosol (0·2 ml min^{-1}) was created in the cabinet using a Collison nebuliser (Birral, Bristol, UK) and compressed air at 68 kN m^{-2} for 1 min. A small axial fan in the ceiling of the cabinet allowed even distribution of the aerosol. The warm air drier was switched on for one drying cycle and the SAS samplers initiated sampling 45 l of air.

The agar plates were removed from the samplers and the cabinet purged of micro-organisms ready for the next test.

The agar plates were incubated at 30 °C for 48 h, and the number of positive results corresponding to holes in the SAS sampler head were counted and adjusted to give the probable count (from the table in the SAS manual) to compensate for the fact that more than one micro-organism may enter the holes on the air sampler head.

For each of the five driers, 30 repeats were carried out using the range of suspension concentrations described. The results were calculated and expressed as cfu m^{-3}. For statistical analysis, the paired results for the inlet and outlet were calculated to give individual recoveries. The $\log_{10}$ recoveries for the driers with the heaters in place were compared with the recoveries for the controls (drier with no heating element in place).

Change in air-borne levels of micro-organisms: washroom studies

This part of the study was undertaken in washrooms at Campden & Chorleywood Food Research Association (CCFRA) and, for practical reasons, only the five female washrooms serving about 200 people were used.

The study was designed to measure the levels of micro-organisms entering the drier (including manual and automatic) through the air inlet and from the nozzle outlet in a normal operating washroom environment and, in addition, to identify some of the types of micro-organisms using selective media.

Using the adapter from the laboratory studies, it was possible to sample air from the inlet separately from the nozzle outlet. The adapter was placed in the nozzle leading into the inflatable 'bag' and then exiting through a 25 cm diameter pipe. The flexibility of the adapter meant that it could be positioned away from the air inlet so that local recirculation of air in and out of the drier was unlikely, thus providing a clearer measure of the levels of micro-organisms entering and leaving the drier.

Experimental procedure. Air (120 l) was sampled from both the air inlet and the nozzle outlet of the drier (the drier was switched on for the duration of sampling) using each of the following media: Violet Red Bile Glucose Agar (VRBGA; Oxoid) for presumptive Enterobacteriaceae spp.; Nutrient Agar (NA) for viable counts; *Pseudomonas* Agar Base (PSAB; Oxoid) with CFC selective supplement (SR103) for presumptive *Pseudomonas* species; and Baird Parker Agar (BP; Oxoid) for presumptive *Staphylococcus* species.

After the appropriate incubation times and temperatures (NA; 30 °C for 48 h; BP 37 °C for 48 h; VRBGA 37 °C for 24 h; PSAB 25 °C for 48 h), the colonies were counted and adjusted for most probable count. The results were calculated and expressed as cfu m^{-3}. For each agar type, the paired results for the nozzle outlet were compared with those for the air inlet.

Surface contamination of warm air driers compared with other washroom areas

Experimental procedure. Swabs were taken from selected sites in the washrooms described previously using cotton wool tipped-swabs moistened in 10 ml MRD containing inactivator. Where possible, the swab area was approximately 25 cm^2. Total viable counts were undertaken by vortex mixing of the swab in MRD for 30 s to resuspend the bacteria, followed by serial decimal dilution and pour-plating 1 ml duplicates with Nutrient Agar. The plates were incubated at 30 °C for 48 h and the colonies counted. The results were expressed as cfu $swab^{-1}$ for each swab site. A total of 10 swab sites were evaluated, which included inside the outlet nozzle of the drier, the air inlet of the drier, the outside of the outlet nozzle of the drier, the sensor/switch of the drier, the enamel top of the drier, the wall below the drier, the tap on the washroom sink, the door handle (washroom), the floor of the washroom, and the wall away from the drier.

Statistical analysis

One way analysis of variance (MINITAB, Minitab, Inc, PA, USA) was carried out on the data using the 5% confidence level to determine significance.

RESULTS

Assessment of the number of micro-organisms on hands after washing and drying

The results are shown in Tables 1 and 2. Table 1 shows the results for the finger rinses for drying with the warm air driers and paper towels. In all but three subjects, there was an increase in the number of bacteria on the finger pads after drying with warm air. Table 1 also shows the finger rinses for paper towels and with the exception of three subjects (not the same ones), the mean numbers of bacteria also increased. This is because of the dispersal of resident colonies on the skin with this recovery method, which leads to an apparent increase in skin flora. However, the increases for both hand drying methods were generally less than one log order, and statistical analysis showed that the results for the driers were not significantly different when compared with the paper towels ($P = 0{\cdot}56$). Individual subject results show that there was considerable variation between subjects but consistency between left and right hands (two-way analysis of variance $P = 0{\cdot}219$) for rinses. In addition, the results on different days were generally of the same log order. This suggests that the experimental design and protocol were reliable.

The results for the contact plates of the palms are shown in Table 2. In most cases the counts were in excess of 300 colonies per plate after washing and drying with the hand drier, while the use of paper towels resulted in little differences. Statistical analysis showed that the differences between the drier and paper towels for the contact plates were significant ($P = 0{\cdot}00$). Analysis of variance showed good consistency between left and right hands ($P = 0{\cdot}96$). Microbiological testing of the paper towels showed that micro-organisms were transferred from the hand to the towels. The paper towels would be deposited in bins and therefore, could potentially act as a bacteriological reservoir if disposal was not managed correctly. The air results taken during hand drying using either the drier or paper towels are shown in Table 1, and analysis of variance showed that there were no differences ($P = 0{\cdot}64$) in counts of air-borne micro-organisms when drying hands with either warm air hand driers or paper towels.

Table 1 Handwash results for driers and paper towels using finger rinse method

Subject	Hand driers Pre-value cfu plate^{-1} Mean	Post-value cfu plate^{-1} Mean	Air sample cfu m^{-3}	Paper towels Pre-value cfu plate^{-1} Mean	Post-value cfu plate^{-1} Mean	Air sample cfu m^{-3}
1	$2{\cdot}73 \times 10^5$	$6{\cdot}88 \times 10^4$	0	$1{\cdot}08 \times 10^5$	$5{\cdot}78 \times 10^5$	25
2	$5{\cdot}68 \times 10^4$	$5{\cdot}74 \times 10^5$	33	$8{\cdot}50 \times 10^4$	$7{\cdot}13 \times 10^5$	66
3	$5{\cdot}85 \times 10^4$	$2{\cdot}80 \times 10^5$	33	$2{\cdot}20 \times 10^5$	$3{\cdot}20 \times 10^5$	30
4	$5{\cdot}58 \times 10^3$	$5{\cdot}61 \times 10^4$	17	$1{\cdot}88 \times 10^4$	$5{\cdot}20 \times 10^5$	58
5	$3{\cdot}76 \times 10^5$	$1{\cdot}06 \times 10^6$	33	$6{\cdot}13 \times 10^5$	$1{\cdot}91 \times 10^6$	25
6	$3{\cdot}06 \times 10^4$	$2{\cdot}43 \times 10^5$	17	$2{\cdot}86 \times 10^4$	$3{\cdot}96 \times 10^5$	50
7	$1{\cdot}93 \times 10^4$	$1{\cdot}43 \times 10^5$	17	$9{\cdot}58 \times 10^3$	$8{\cdot}75 \times 10^4$	17
8	$3{\cdot}32 \times 10^4$	$3{\cdot}15 \times 10^5$	50	$2{\cdot}06 \times 10^4$	$5{\cdot}08 \times 10^5$	25
9	$1{\cdot}10 \times 10^2$	$1{\cdot}23 \times 10^3$	42	$1{\cdot}08 \times 10^4$	$7{\cdot}83 \times 10^2$	8
10	$4{\cdot}02 \times 10^4$	$2{\cdot}68 \times 10^5$	33	$6{\cdot}15 \times 10^3$	$1{\cdot}26 \times 10^5$	25
11	$5{\cdot}34 \times 10^4$	$5{\cdot}05 \times 10^4$	50	$5{\cdot}44 \times 10^4$	$2{\cdot}98 \times 10^5$	42
12	$4{\cdot}21 \times 10^4$	$9{\cdot}15 \times 10^4$	17	$3{\cdot}23 \times 10^3$	$1{\cdot}79 \times 10^4$	17
13	$3{\cdot}98 \times 10^5$	$4{\cdot}00 \times 10^5$	50	$4{\cdot}58 \times 10^5$	$5{\cdot}18 \times 10^5$	33
14	$6{\cdot}35 \times 10^3$	$2{\cdot}91 \times 10^4$	133	$3{\cdot}05 \times 10^5$	$1{\cdot}35 \times 10^5$	33
15	$1{\cdot}64 \times 10^6$	$2{\cdot}34 \times 10^6$	33	$1{\cdot}17 \times 10^6$	$1{\cdot}84 \times 10^6$	42

Table 2 Handwash trials: contact plate results for hand driers, paper towels and microbiological results of paper towels

Subject	Hand driers Pre-value cfu plate^{-1} Mean	Post-value cfu plate^{-1} Mean	Paper towels Pre-value cfu plate^{-1} Mean	Post-value cfu plate^{-1} Mean	Paper towel cfu towel^{-1}
1	228	141	191	166	$2{\cdot}48 \times 10^5$
2	98	300	78	298	$5{\cdot}90 \times 10^4$
3	173	300	160	206	$1{\cdot}19 \times 10^5$
4	24	300	20	38	$5{\cdot}70 \times 10^4$
5	203	237	111	148	$8{\cdot}30 \times 10^5$
6	36	300	81	75	$1{\cdot}10 \times 10^5$
7	186	300	130	41	$5{\cdot}95 \times 10^4$
8	277	300	248	178	$3{\cdot}25 \times 10^4$
9	50	300	121	22	$2{\cdot}10 \times 10^3$
10	51	300	56	71	$9{\cdot}50 \times 10^5$
11	82	300	72	14	$8{\cdot}10 \times 10^4$
12	35	44	69	32	$2{\cdot}90 \times 10^3$
13	33	300	86	167	$1{\cdot}65 \times 10^5$
14	29	194	78	48	$6{\cdot}40 \times 10^4$
15	238	300	163	187	$7{\cdot}00 \times 10^5$
Control towel					
1					$5{\cdot}00 \times 10^1$
2					$7{\cdot}50 \times 10^2$
3					$2{\cdot}75 \times 10^4$
4					$4{\cdot}00 \times 10^2$
5					$5{\cdot}00 \times 10^2$

300 denotes counts that were too great to count.

Table 3 Hand-drying experiment: contact plate results

Subject	Pre-value cfu plate^{-1} Left	Right	Post-value cfu plate^{-1} Left	Right	Drying time (s)	Hand status
1	104	311	2325	2850	10	Wet
1	422	1128	1336	1288	20	Wet
1	466	467	218	197	40	Dry
2	12	16	312	14	10	Wet
2	81	12	100	94	20	Wet
2	74	67	144	108	45	Dry
3	144	116	68	91	10	Wet
3	200	9	451	512	20	Wet
3	292	58	268	257	30	Dry
4	209	90	832	1808	10	Wet
4	240	178	547	724	20	Wet
4	137	107	209	85	35	Dry

Table 3 shows the effect of drying time on the recovered viable counts using palm contact plates. After washing and drying (when the hands were visibly wet), the counts ranged from 14 to 2850 cfu plate^{-1}, which was an increase for three of the four subjects. When the hands were visually dry after washing (30–45 s drying time), the counts ranged from 85 to 257 cfu plate^{-1}. These results showed that the degree of hand wetness is an important factor to consider when assessing hand hygiene regimes.

Change in levels of air-borne micro-organisms: laboratory studies

The recovery rates for the experimental set-up (with no heater in place) are shown in Table 4 for the two organisms *Staph. aureus* and *Ps. aeruginosa*. They were 66% and 62·3%, respectively, and analysis of variance showed that the differences in the number of organisms leaving the drier compared with those entering were significant for both organisms ($P = 0{\cdot}00$). These results suggest that some of the micro-organisms were lost in the system, probably as a combination of adhesion to the surfaces of the drier, cabinet and other plastic surfaces, and death of air-borne cells through desiccation. The results for the driers with the heaters in place are shown in Tables 5 and 6. The mean recoveries for *Staph. aureus* and *Ps. aeruginosa* were 35·1% and 28·2%, respectively, and show that the recoveries are less than for the controls, demonstrating that the heater in the drier killed a proportion of the micro-organisms passing through. Analysis of variance showed that for both organisms, the differences were significant ($P = 0{\cdot}02$ and $P = 0{\cdot}00$ for *Staph. aureus* and *Ps. aeruginosa*, respectively). The reduction in recovery and hence, increased kill was greater for *Ps. aeruginosa* than *Staph. aureus*. This may reflect the fact that *Staph. aureus* is known to be more resistant to desiccation than *Ps. aeruginosa*.

The experimental set-up was designed to be controlled so that the counts for the air inlet and outlet were not affected by possible recirculation of air from outlet to inlet. However, separating the inlet from the outlet is unlikely to be a real situation and the experiment therefore represented a 'worst case' scenario. In a washroom situation, the air

Table 4 Laboratory trials: initial recoveries with the heater removed

Organism	Air sampled	*n*	Mean cfu m^{-3}	S.D.	Mean recovery %
Staphylococcus aureus	Inlet	40	$2{\cdot}67 \times 10^4$	$4{\cdot}83 \times 10^3$	66·0
	Outlet	40	$1{\cdot}76 \times 10^4$	$7{\cdot}45 \times 10^3$	
Pseudomonas aeruginosa	Inlet	29	$1{\cdot}91 \times 10^4$	$9{\cdot}15 \times 10^3$	62·3
	Outlet	29	$1{\cdot}19 \times 10^4$	$8{\cdot}90 \times 10^3$	

Table 5 Laboratory trials: *Pseudomonas aeruginosa*

Drier code	Air sampled	*n*	Mean cfu m^{-3}	S.D.	Recovery (%)
80	Inlet	30	$2{\cdot}57 \times 10^4$	$5{\cdot}60 \times 10^3$	25·4
	Outlet	30	$6{\cdot}52 \times 10^3$	$7{\cdot}72 \times 10^3$	
33	Inlet	30	$2{\cdot}57 \times 10^4$	$5{\cdot}99 \times 10^3$	34·1
	Outlet	30	$8{\cdot}76 \times 10^3$	$7{\cdot}67 \times 10^3$	
91	Inlet	30	$2{\cdot}12 \times 10^4$	$1{\cdot}16 \times 10^4$	26·6
	Outlet	30	$5{\cdot}95 \times 10^3$	$7{\cdot}03 \times 10^3$	
95	Inlet	30	$2{\cdot}39 \times 10^4$	$9{\cdot}16 \times 10^3$	29·1
	Outlet	30	$6{\cdot}95 \times 10^3$	$6{\cdot}66 \times 10^3$	
79	Inlet	29	$2{\cdot}05 \times 10^4$	$1{\cdot}10 \times 10^4$	25·6
	Outlet	29	$5{\cdot}24 \times 10^3$	$6{\cdot}64 \times 10^3$	

Table 6 Laboratory trials: *Staphylococcus aureus*

Drier code	Air sampled	*n*	Mean cfu m^{-3}	S.D.	Recovery (%)
80	Inlet	30	$2{\cdot}12 \times 10^4$	$1{\cdot}25 \times 10^4$	53·3
	Outlet	30	$1{\cdot}13 \times 10^4$	$9{\cdot}79 \times 10^3$	
33	Inlet	30	$1{\cdot}97 \times 10^4$	$1{\cdot}24 \times 10^4$	60·9
	Outlet	30	$1{\cdot}20 \times 10^3$	$1{\cdot}01 \times 10^4$	
91	Inlet	30	$2{\cdot}08 \times 10^4$	$1{\cdot}23 \times 10^4$	61·5
	Outlet	30	$1{\cdot}28 \times 10^4$	$1{\cdot}25 \times 10^4$	
95	Inlet	30	$1{\cdot}50 \times 10^4$	$1{\cdot}35 \times 10^4$	52·9
	Outlet	30	$7{\cdot}93 \times 10^3$	$8{\cdot}61 \times 10^3$	
79	Inlet	30	$2{\cdot}14 \times 10^4$	$1{\cdot}24 \times 10^4$	47·2
	Outlet	30	$1{\cdot}01 \times 10^4$	$9{\cdot}17 \times 10^3$	

from the outlet nozzle is likely to be drawn into the air inlet and recirculated. This means that the reduction of micro-organisms as air recirculates through the drier will have an enhanced effect on the overall bacterial count on air from the outlet nozzle with multiple passes through the drier.

Change in air-borne levels of micro-organisms: washroom studies

The results are given in Table 7 and show that for all the washrooms (PSAB and BP not shown), the mean number of bacteria passing through the driers and sampled from the nozzle was less than the mean number entering through the air inlet. The NA recoveries were 39% and the PSAB and BP recoveries were 24%. These were lower than the laboratory trials, which meant that the emission of micro-organisms through the drier nozzle was significantly lower than the level entering the drier; this was expected because of the recirculation of air. In addition, the different bacteria collected on the selective agars would have various sensitivities to heat and desiccation. There were very few counts on the VRBGA agar (recovery of 69%), which makes it difficult to draw conclusions.

Recoveries for *Pseudomonas* and Enterobacteriaceae spp. on selective agar, gave very few colonies, suggesting that with this study, *Pseudomonas* and Enterobacteriaceae species were not a problem in the washrooms and under these conditions, the hand driers did not disperse these particular pathogens into the washroom environments. The absence of these pathogens in the nozzle outflow would mean that any found on hands after washing and drying would be unlikely to have been derived from the warm air driers. It was therefore felt unnecessary to sample hands for pathogens after washing and drying. Sampling hands for different genera of pathogens would not provide information on

Table 7 Air samples from the washrooms

Agar medium			Washroom no. 1 cfu m^{-3}	2 cfu m^{-3}	3 cfu m^{-3}	4 cfu m^{-3}	5 cfu m^{-3}	Overall mean	Recovery (%)
Nutrient Agar	Inlet	Mean	282	139	103	101	95	144	
		S.D.	239·9	106·2	118·7	172	76		
	Outlet	Mean	74	79	15·4	37	37	49	
		S.D.	60·6	51·3	15·7	36·1	33·4		34
Baird Parker Agar	Inlet	Mean	162	60	34	35	24	63	
		S.D.	234	80	41	51·7	23·3		
	Outlet	Mean	32	24	5	9	7	15	
		S.D.	31·3	28·6	7·3	17·5	8·6		24

the origins of organisms and would therefore be of limited use in determining whether any pathogens on the hands had been deposited by the driers.

The results also show that the washrooms with high NA counts also had high counts on the BP agar, which is selective for *Staphylococcus* species, including coagulase negatives such as *Staph. epidermidis* and the pathogen coagulase-positive *Staph. aureus*. However, no attempt was made in this study to further differentiate the *Staphylococcus* species. Meers and Yeo (1978) found that the most numerous bacteria released as a result of hand washing were, in fact, coagulase-negative Staphylococci rather than the potentially pathogenic *Staph. aureus*.

Surface contamination of warm air driers compared with other washroom areas

The results are shown in Table 8 and vary widely for each swab site. The results were converted to $\log_{10}$ for statistical analysis. Two-way analysis of variance testing the effect of washroom, swab site and the swab site–washroom interaction showed that there was no significant difference between washrooms ($P = 0{\cdot}28$). Pooling all the drier swab results and comparing them with the pooled washroom sites demonstrated that there was no statistical difference ($P = 0{\cdot}003$) from other washroom surfaces. However, the wall below the drier had a slightly higher result because water droplets were shaken onto the wall in the process of drying the hands. There were visible signs of water droplets on the wall (which could enable micro-organisms to grow), and this demonstrates the importance of cleaning the surrounding wall. In this study, the driers were installed temporarily and as a result, the cleaning schedule did not detail cleaning the wall below the drier.

There was very little difference in the counts for the switch ($2{\cdot}19 \times 10^3$ cfu $swab^{-1}$) and the sensor ($1{\cdot}26 \times 10^3$ cfu $swab^{-1}$). Considering the sensor is not touched by the hands, it would be expected to have a much lower count. However, it is positioned such that it may be splashed by

Table 8 Washroom swab results

Site	Location	*n*	Mean cfu $swab^{-1}$	S.D. Range cfu $swab^{-1}$
1	Inside outlet nozzle of drier	30	$2{\cdot}52 \times 10^3$	$4{\cdot}92 \times 10^3$
2	Air inlet of drier	30	$1{\cdot}12 \times 10^3$	$1{\cdot}43 \times 10^3$
3	Outside outlet nozzle of drier	30	$3{\cdot}20 \times 10^2$	$4{\cdot}77 \times 10^2$
4	Sensor or switch of drier	30	$1{\cdot}38 \times 10^3$	$2{\cdot}74 \times 10^3$
5	Enamel top of drier	30	$2{\cdot}10 \times 10^2$	$2{\cdot}10 \times 10^2$
6	Wall below drier	30	$7{\cdot}03 \times 10^3$	$9{\cdot}30 \times 10^3$
7	Tap on washroom sink	30	$6{\cdot}70 \times 10^2$	$1{\cdot}16 \times 10^3$
8	Door handle (washroom)	30	$2{\cdot}05 \times 10^3$	$2{\cdot}75 \times 10^3$
9	Floor of washroom	29	$1{\cdot}63 \times 10^4$	$3{\cdot}42 \times 10^4$
10	Wall away from drier	28	$4{\cdot}00 \times 10^1$	$1{\cdot}09 \times 10^2$

water droplets and micro-organisms as users dry their hands.

DISCUSSION

Evaluation of the results from the hand-washing experiments requires an understanding of the complex nature of skin microflora. With the exception of the nail plate, the human skin is covered with a population of microflora as discussed by Noble (1983). The surface of the skin is composed of individual squames, non-viable, flat pavement-like cells, which are continually shed from the skin surface with their associated bacteria. The deeper skin layer continually reproduces and replaces the desquamated cells. The degree of hydration is most important in determining the microbiological flora. Increasing the quantity of water on the skin increases the number of bacteria detected. The microbiological flora of the skin can be divided into residents and transients; the residents are the normal population and are generally not a health hazard. The transients, which may include pathogenic organisms, are picked up onto the skin surface and transferred around the environment. Transients can be removed by normal hand washing whereas the residents, which are found throughout the skin and in hair follicles and skin glands, may be reduced but not removed by normal hand washing. It is most likely that the residents live in micro-colonies while the transients do not. There is a range of sampling techniques, including contact plates and rinse methods, and different results may be obtained depending on the method used. The contact methods measure the aggregates or micro-colonies of cells while scrub rinse methods measure the total viable cell population resulting from the dispersal of colonies.

This work and that of other workers has found that the results and hence, conclusions, for the different drying methods are greatly dependent on the method of bacterial assessment and the degree of skin hydration.

Davis *et al.* (1969), using whole hand rub/rinse methods, found no difference in the numbers of bacteria on hands after different drying methods, which is in agreement with the results presented here. Ansari *et al.* (1991) compared cloth, paper and warm air drying for eliminating viruses and bacteria from washed hands. The method involved inoculating finger pads and assessing bacterial numbers by eluting (rinsing without any physical rubbing). They found warm air to be the most effective in reducing bacterial numbers. They did not rub hands during any experimental procedure, which is therefore not representative of real life hand drying, and they only used one subject. Mathews and Newsom (1987) used whole hand impression on agar and found no difference between driers and towels with a drying time of 30 s. Blackmore and Prisk (1984) used contact plates and found the percentage removal of bacteria was greater with paper and cloth towels than with warm air drying (50 s).

The difference in reported results seems likely to be connected with the method of assessment, as already explained, and the duration of hand drying, especially for the warm air driers. Using any rinse method before and after drying (warm air or paper towels) means that the hands or fingers are wet during the assessment procedure and therefore, this important variable is controlled. In contrast, the contact methods are likely to be very susceptible to the degree of hydration and if the hands are not properly dried (by not using warm air for long enough or not using sufficient paper towels), then higher counts will ensue. The study by Knights *et al.* (1993) found higher counts after warm air drying using a contact method, and the drying time was only 25 s (less than the recommended cycle time of driers). Mathews and Newsom (1987) only dried for 30 s and found no difference between paper towels and warm air driers. Blackmore and Prisk (1984) found only a 9% reduction in bacteria on hands after using a warm air drier (50 s) compared with 68% and 55% for cotton and paper towels. In a later study, Blackmore (1989) dried for 30, 35 and 50 s, and using contact plates, found there was an increase in numbers on hands after using the driers compared with paper and cotton towels. In this study, subjects were asked to dry their hands until they felt dry and in fact, it was observed that at least one subject had damp hands. The additional hand drying experiment shows that the degree of skin hydration may explain the differences in results. The evidence suggested that the greatest drying times for the warm air driers gave a better performance with respect to the reduction in bacterial counts. However, it is clear that the number of variables in the different studies makes it difficult to derive conclusive comparisons.

It is clear that future hand wash studies need to control certain factors. They should include a standard hand wash and hand drying method (to control the degree of hydration), and an appropriate method of assessment, such that the only difference in the protocol is the method of drying. The implications of hand rinse and hand impression methods should also be understood.

This work shows that the warm air hand driers used in this study reduced the count of air-borne micro-organisms of *Ps. aeruginosa and Staph. aureus.* The reduction of counts was demonstrated in both laboratory (for a range of aerosol concentrations) and working washroom environments, and it is likely that other vegetative bacterial genera, including pathogens, would also be affected in the same way. Consequently, the installation of warm air hand driers in a working washroom could theoretically help to reduce the level of pathogens.

This work also shows that the external surfaces of the driers were contaminated with levels of viable counts simi-

lar to other washroom surfaces and therefore, unlikely to represent a greater microbiological risk than the other surfaces. It is important, however, for any washroom, regardless of hand drying method, to undertake a comprehensive cleaning programme, which should of course include any surfaces where hands touch (e.g. taps, switches) and where water droplets are dispersed. The cleaning frequency should be related to the frequency of use of the washrooms, and environmental swabbing of surfaces will indicate whether the cleaning programme is efficient.

With respect to the dissemination of bacteria from hands into the air, Meers and Leong (1989) used a Casella slit sampler to sample the air before, during and after drying with warm air driers (for 45 s) and found marginally more cfu released during and after drying than before drying. Meers and Yeo (1978) showed that skin squames and associated bacteria by air sampling were increased after washing and drying using paper towels. Mathews and Newsom (1987) examined the potential spread of air-borne bacteria from hand driers. Of four warm air driers, they found that the air-borne counts sampled during drying were on two occasions no different to the counts obtained while using a paper towel, and on the other two occasions, the air counts were significantly better (lower) than the counts for drying with paper towels.

In conclusion, provided that hands are properly dried, both warm air driers and paper towels gave acceptable results. Warm air driers did not increase the level of air-borne micro-organisms (and may actually decrease them) and the level of aerosols created by both methods were similar. Surfaces in washrooms, especially where water droplets may collect, should be properly cleaned, and the storage and disposal of used towels should be controlled.

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