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A comparative study of four different hand drying methods: paper towel, continuous roller towel, warm air dryer, jet air dryer.

Prepared by

Keith Redway & Shameem Fawdar,
School of Life Sciences,
University of Westminster,
London.

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Prepared by

Keith Redway & Shameem Fawdar,
School of Life Sciences,
University of Westminster,
115 New Cavendish Street,
London W1W 6UW

Tel: +44 (0)20 7911 5000 Ext. 3686
E-mail: redwayk@westminster.ac.uk
Web: www.westminster.ac.uk/~redwayk

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Part B (extended): Changes in the number of different types of bacteria on the hands before and after drying using paper towel, continuous roller towel, warm air dryer and jet air dryer.

Introduction

Following Semmelweis's observations on the effect of hand washing on the incidence of puerperal fever in a maternity ward in the 19th Century, good hand hygiene has been recognized as an important factor in controlling the spread of infectious disease and, more recently, antibiotic-resistant bacteria in hospitals and in the community. Meticillin-resistant ***Staphylococcus aureus*** (MRSA), ***Clostridium difficile***, ***Enterococcus faecalis*** and other agents causing hospital-acquired infections can be transmitted to patients by the hands of medical staff. Similarly, food-poisoning organisms can be transmitted to food by dirty hands and subsequently cause illness to those eating it.

There have been many studies on the benefits of hand washing and on the efficacy of different hand washing agents but relatively few on the contribution of hand drying to hand hygiene. However, there is increasing awareness of its importance in the overall hand hygiene debate.

Disregarding the types of textile towel where users dry their hands on the same area of material as previous users and which have been condemned on hygiene grounds for many years, the three main hand drying methods available in public washrooms have until fairly recently been: paper towels, continuous roller towels (where a fresh area of towel is available for each user) and warm air dryers. In recent years manufacturers such as Dyson, Mitsubishi and Veltia have introduced new types of electric hand dryer (jet air dryers) where users insert their hands into a slot whilst unheated air is emitted at high speed and removes water from the hands by scraping. In this study, a jet air dryer with the highest claimed velocity of air movement was tested.

Blackmore (1989) showed that in normal use warm air dryers increase the number of bacteria that can be isolated from the fingerpads after drying. She also recorded decreases in the bacterial numbers on fingerpads when paper towels and continuous roller towels were used for hand drying. Two previous studies carried out by the University of Westminster (Knights ***et al***., 1993; Redway ***et al***., 1994) showed similar results in that on average warm air dryers substantially increase the number of bacteria on the hands of users. Compared to the number present on subjects' hands before washing and drying, the first study found the mean percentage increase in the number of bacteria on the fingerpads after using a warm air dryer was 504%. The second study found mean percentage increases in different types of bacteria on the fingerpads of subjects after using a warm air dryer ranging from 169% to 438%. Conversely, both studies showed that paper towels and continuous roller towels decrease the mean number of all types of bacteria on the fingerpads of users.

Since these studies all other investigations by the University of Westminster have consistently shown that towels, both continuous roller towels and paper, perform significantly better than warm air dryers in terms of speed, drying efficiency, hand hygiene and bacterial contamination. However, until 2008 and this present extension of that study (Redway & Fawdar, 2008), the performance of a jet air dryer had not been investigated by the University nor compared to

other hand drying methods.

This study is an extensor of Part B of the original ETS 2008 study. The main aims of this extended study were to assess any changes in the numbers of different types of bacteria on the fingerpads and palms of 20 subjects (10 male, 10 female) before and after washing and drying their hands using four different hand drying methods: paper towel, continuous roller towel, warm air dryer, jet air dryer.

Part B (extended): Changes in the number of different types of bacteria on the hands before and after drying using paper towel, continuous roller towel, warm air dryer and jet air dryer.

Introduction

Previous studies (Blackmore,1989; Knights ***et al***., 1993; Redway ***et al***., 1994) have used the 'contact plate' method to assess changes in the number of bacteria present on the hands before and after washing and drying. The method involves pressing the fingerpads onto nutritive agar plates, growing any transferred bacteria at 37^{o}C overnight and then counting the number of colony-forming units (cfu's) present. This method has been shown to be relatively quick and sufficiently accurate for this type of study (Sanderson & Weissler, 1992). In addition to contact plates, this present study also used swab sampling of an area of the palm of the hand before and after the use of paper towel, continuous roller towel, warm air dryer or jet air dryer.

The hand drying times used in this part of the study for the paper towels and the continuous roller towel (10 seconds) and the warm air dryer (20 seconds) were based on observations (Redway ***et al***., 1997) in public washrooms of the average times used by members of the public. However, because it is relatively new, no such observations were available for the jet air dryer and the manufacturer's recommended time of 10 seconds was used.

Methods and materials

1. 20 subjects (10 male and 10 female) were recruited covering an age range 18 to 60 years.

2. Subjects were asked to visit a public washroom in a normal fashion and return to the laboratory without washing their hands. No instructions were given by the investigator as to how they should use the washroom or what they should do in it.

3. Three different agar growth media were used to sample the dominant hand of subjects before washing and drying (BD) and after washing and drying (AD). The media used and in this order were:

Nutrient Agar [NA] (Oxoid)

NA is a non-selective, general purpose growth medium which would be expected to grow most non-fastidious types of bacteria, including skin and gut bacteria.

Cystine-Lactose-Electrolyte-Deficient Medium [CLED] (Oxoid)

CLED medium supports the growth of potential pathogens from the gut giving good colonial differentiation and clear diagnostic characteristics for ***Escherichia coli***, ***Salmonella*** species, ***Enterococcus*** species, ***etc***.
Escherichia coli produces large yellow colonies due to fermentation of the lactose, ***Salmonella*** species produces flat blue colonies and ***Enterococcus*** species produce small yellow colonies. Other types of bacteria produce different colonial morphologies.

Mannitol-Salt Agar [MSA] (Oxoid)

MSA is a selective growth medium used for the isolation of staphylococci; most other bacteria are inhibited by the high salt content. Presumptive pathogenic, coagulase-positive ***Staphylococcus aureus*** colonies are surrounded by yellow zones (due to acid production from the fermentation of mannitol) whilst non-coagulase-positive staphylococci produce colonies with reddish purple zones.

4. Areas of hand sampled were: fingerpads (by direct contact with the agar plate surface) and the palm (by swabbing and inoculation of agar plates).

   a) For sampling fingerpads, subjects were asked to firmly press the fingerpads of their ring, middle and index fingers onto the surface of 3 agar plates in turn (NA, CLED, MSA). A sterile swab moistened with ¼ strength Ringers solution was then used to swab the entire surface of each agar plate so as to spread and disperse any potential colonies and enable them to be counted more easily.

   b) For sampling palms, a sterile metal former with a circular hole in it (diameter 4.2 cm) was placed on the palm of subjects and a sterile swab moistened with sterile ¼ strength Ringers solution was then used to swab half the area. The cotton bud of the swab was then aseptically removed to 3 ml of ¼ strength Ringers solution and vortexed for 10 seconds. 0.1 ml of this suspension was then dispensed onto the surface of 3 agar plates (NA, CLED, MSA) and spread using a sterile glass spreader.

5. Subjects were then asked to wash and rinse their hands for a total of 10 seconds using one squirt (0.83 ml) of a commonly available liquid soap (Johnson Diversy "***Soft Care***" hand washing cream) from a dispenser which was operated by the researcher and running tap water. Subjects were then requested to dry them using one of the following 5 hand drying

methods and for the times indicated:

i) Paper towel 1 (PT 1): 2-ply 100% recycled. Art. 217010 (Wepa). 10 seconds

ii) Paper towel 3 (PT 3): 2-ply through-air dried (TAD). 50% virgin - 50% recycled. Art. 6769 (Kimberly-Clark). 10 seconds.

iii) Continuous roller towel (CRT): single-use, textile towel dispensed from a cabinet (Cannon Hygiene). 10 seconds

iv) Warm air dryer (WAD): Electric-Aire™, model LE48 (World Dryer Corporation). 20 seconds.

v) Jet air dryer (JAD): Airblade™, model AB01 (Dyson). 10 seconds.

Subjects were not given any instructions as to how to dry their hands and were allowed to take as many paper towels as they wished (mean = 2.5) but only within 10 seconds. Similarly, subjects were not instructed as to how they should use the CRT, WAD or JAD devices but were stopped after 10, 20 and 10 seconds respectively. However, subjects were given a demonstration of the JAD in case they had not encountered this type of hand dryer previously.

6. The sampling technique as in Stage 4 was repeated after washing and drying (AD), ***viz***. fingerpad and palm inoculation of the three different agar growth media in turn. For palm sampling, the half of the circular area not swabbed previously for the BD sample was used.

7. All agar plates were incubated at 37^{o}C and examined after 1 and 2 days for bacterial growth. The number of colonies on each plate was recorded and, where appropriate, differentiation made between different types of colony, ***e.g***. yellow zones around colonies on MSA indicating mannitol fermentation and presumptive identification as ***Staphylococcus aureus***. Counts on plates which showed too many colonies to count were scored as 200, which is considered the upper limit for accurate counting.

8. All 20 subjects were re-tested exactly as in Stages 2 - 6 above but on a different days when they were required to a different hand drying method each day.

9. The order that subjects were required to use the four different hand drying methods was randomised between subjects to minimize any external effects such as variation in temperature or humidity on different days.

10. Results were recorded, tabulated and statistically analysed. The percentage (%) changes in bacterial numbers (as colony-forming units) on the hands were calculated as follows:

$$\frac{\text{number after drying} - \text{number before drying}}{\text{number before drying}} \times 100$$

The paired t-test was used to establish if there were any significant differences between the mean number of different types of bacteria on the hands of subjects before washing and drying their hands (BD) and after washing and drying their hands (AD) using the four different hand drying methods. The analysis was applied to all bacterial types that grow on nutrient agar, plus potential skin pathogens on MSA and gut bacteria on CLED. The 4 different drying methods were also statistically compared by t-tests on the AD counts of subjects after using them.

11. Controls: Plates of all 3 agar growth media were used at regular intervals to test samples of the paper towels, the continuous roller towel, the air flow of the warm air dryer, the air flow of the jet air dryer, the liquid soap and the tap water for the presence of bacteria. For the paper towels and the continuous roller towel bacterial contamination was tested by using the end of a sterile glass beaker to press a set area (15.90 cm^2) of towel onto an agar plate. Similarly, the liquid soap and the tap water were tested for the presence of bacteria by plating out 0.1 ml aliquots onto agar plates and spreading with a sterile glass spreader. The warm air dryer's airflow was tested by holding agar plates beneath it at a distance of 10 cm for 20 seconds. The jet air dryer's airflow was tested by holding agar plates in the air flow emitted from the sides of the device for 10 seconds. Control plates were incubated at 37^oC and examined after 1 and 2 days for the presence of bacterial colonies.

12. Measurements were taken using an environmental meter (CEM DT-8820) at regular intervals of the laboratory ambient temperature, tap water temperature, air flow temperature from the two dryers, the relative humidity in the laboratory and the noise levels when the dryers were running. The power consumption of the 2 electric dryers was also recorded.

Results

Table 1
Mean counts and percentage changes in bacterial numbers (CFUs) on fingerpads before and after washing and drying hands using different hand drying methods.

HAND DRYING METHOD	GROWTH MEDIUM	COLONY TYPE	MEAN BEFORE DRY COUNT (BD)	MEAN AFTER DRY COUNT (AD)	MEAN CHANGE (%)	T-TEST (p)
PT 1	NA	ALL	73.9	41.0	-44.6	0.0980
PT 3	NA	ALL	64.8	15.0	-76.9	0.0020
CRT	NA	ALL	105.1	34.2	-67.5	0.0001
WAD	NA	ALL	38.2	109.3	+186.4	0.0002
JAD	NA	ALL	63.2	96.6	+52.8	0.0310
PT 1	CLED	ALL	53.4	24.9	-53.4	0.1700
PT 3	CLED	ALL	39.0	11.5	-70.5	0.0170
CRT	CLED	ALL	109.8	27.6	-74.9	0.0010
WAD	CLED	ALL	40.4	123.0	+204.3	0.0002
JAD	CLED	ALL	64.6	82.7	+28.0	0.2890
PT 1	MSA	MAN +	25.4	10.6	-58.5	0.2760
PT 3	MSA	MAN +	26.0	2.2	-91.5	0.0700
CRT	MSA	MAN+	22.1	6.6	-70.1	0.0100
WAD	MSA	MAN +	11.4	58.6	+414.0	0.0100
JAD	MSA	MAN +	14.9	43.6	+193.3	0.0120
PT 1	MSA	MAN -	42.7	18.6	-56.6	0.0360
PT 3	MSA	MAN -	40.4	12.8	-68.3	0.0370
CRT	MSA	MAN-	59.5	20.0	-66.4	0.0197
WAD	MSA	MAN -	33.1	70.8	+114.1	0.0200
JAD	MSA	MAN -	40.4	37.0	-8.4	0.8200
PT 1	MSA	ALL	68.1	29.1	-57.3	0.0320
PT 3	MSA	ALL	66.4	15.0	-77.4	0.0240
CRT	MSA	ALL	81.6	26.6	-67.4	0.0023
WAD	MSA	ALL	44.5	129.4	+191.0	0.0001
JAD	MSA	ALL	55.2	80.5	+45.8	0.0700
PT 1	TOTAL	ALL	195.4	95.0	-51.4	0.0660
PT 3	TOTAL	ALL	170.1	41.5	-75.6	0.0050
CRT	TOTAL	ALL	296.5	88.4	-70.2	0.0002
WAD	TOTAL	ALL	123.0	361.6	+193.9	0.0001
JAD	TOTAL	ALL	183.0	259.8	+42.0	0.0650

(N = 20)

Key to *Tables 1 – 4* and *Figures 1 - 4*:
PT = paper towel (1 or 3); CRT = continuous roller towel; WAD = warm air dryer; JAD = jet air dryer.
CFU = colony-forming unit; NA = nutrient agar; CLED = cystine-lactose-electrolyte-deficient medium; MSA = mannitol salt agar; MAN + = acid from mannitol positive; MAN - = acid from mannitol negative; ALL = total number of CFUs (all types of colony); TOTAL = total number of colonies on all three media (NA, CLED, and MSA).
↓ = decrease in bacterial count after washing and drying;
↑ = increase in bacterial count after washing and drying.
Change statistically significant at the limit of probability as follows:

* p < 0.1; ** p < 0.05; *** p < 0.01; **** p < 0.001.
The result shown in ***Table 1*** are summarized in ***Table 2*** and represented graphically in ***Figures 1 – 4***.

Table 2
Summary of mean percentage changes in bacterial numbers on fingerpads before and after washing and drying hands using different hand drying methods.

GROWTH MEDIUM	COLONY TYPE	PAPER TOWEL 1 (PT 1)	PAPER TOWEL 3 (PT 3)	CONTINUOUS ROLLER TOWEL (CRT)	WARM AIR DRYER (WAD)	JET AIR DRYER (JAD)
NA	ALL	-44.6 ↓ *	-76.9 ↓ ***	-67.5↓ ****	+186.4 ↑ ****	+52.8 ↑ **
CLED	ALL	-53.4 ↓	-70.5 ↓ **	-74.9↓ ***	+204.3 ↑ ****	+28.0 ↑
MSA	MAN +	-58.5 ↓	-91.5 ↓ *	-70.1↓ **	+414.0 ↑ ***	+193.3 ↑ **
MSA	MAN -	-56.6 ↓ **	-68.3 ↓ **	-66.4↓ **	+114.1 ↑ **	-8.4 ↓
MSA	ALL	-57.3 ↓ **	-77.4 ↓ **	-67.4↓ ***	+191.0 ↑ ****	+45.8 ↑ *
TOTAL	ALL	-51.4 ↓ *	-75.6 ↓ ***	-70.2↓ ****	+193.9 ↑ ****	+42.0 ↑ *

Table 3
Mean counts and percentage changes in bacterial numbers (CFUs per cm^2) on palms before and after washing and drying hands using different hand drying methods.

HAND DRYING METHOD	GROWTH MEDIUM	COLONY TYPE	MEAN BEFORE DRY COUNT (BD)	MEAN AFTER DRY COUNT (AD)	MEAN CHANGE (%)	T-TEST (p)
PT 1	NA	ALL	129.7	50.0	-61.4	0.046
PT 3	NA	ALL	105.0	23.2	-77.9	0.063
CRT	NA	ALL	25.3	9.1	-64.1	0.014
WAD	NA	ALL	79.0	261.1	+230.4	0.005
JAD	NA	ALL	155.0	169.1	+9.1	0.773
PT 1	CLED	ALL	76.6	45.5	-40.7	0.352
PT 3	CLED	ALL	86.8	24.7	-71.6	0.132
CRT	CLED	ALL	38.3	19.5	-49.2	0.021
WAD	CLED	ALL	77.9	267.2	+242.8	0.021
JAD	CLED	ALL	126.2	143.5	+13.7	0.698
PT 1	MSA	MAN +	13.4	6.9	-48.4	0.193
PT 3	MSA	MAN +	16.2	6.3	-61.3	0.065
CRT	MSA	MAN+	3.5	1.3	-62.5	0.106
WAD	MSA	MAN +	14.3	82.7	+478.8	0.126
JAD	MSA	MAN +	82.1	72.7	-11.3	0.830
PT 1	MSA	MAN -	69.9	47.0	-32.8	0.146
PT 3	MSA	MAN -	70.4	10.4	-85.2	0.170
CRT	MSA	MAN-	62.4	18.6	-70.1	0.248
WAD	MSA	MAN -	43.7	151.1	+245.5	0.027
JAD	MSA	MAN -	47.4	86.4	+82.2	0.052
PT 1	MSA	ALL	83.4	53.9	-35.3	0.125
PT 3	MSA	ALL	86.6	16.7	-80.8	0.110
CRT	MSA	ALL	65.8	19.9	-69.7	0.236
WAD	MSA	ALL	58.0	233.8	+303.0	0.006
JAD	MSA	ALL	129.5	159.1	+22.9	0.545
PT 1	TOTAL	ALL	289.7	149.4	-48.4	0.083
PT 3	TOTAL	ALL	278.4	64.5	-76.8	0.093
CRT	TOTAL	ALL	129.5	48.5	-62.5	0.056
WAD	TOTAL	ALL	215.0	762.1	+254.5	0.004
JAD	TOTAL	ALL	410.7	471.8	+14.9	0.664

(N = 20)

The result shown in ***Table 3*** are summarized in ***Table 4*** and represented graphically in ***Figures 1 – 4***.

Table 4
Summary of mean percentage changes in bacterial numbers on palms before and after washing and drying hands using different hand drying methods.

GROWTH MEDIUM	COLONY TYPE	PAPER TOWEL 1 (PT 1)	PAPER TOWEL 3 (PT 3)	CONTINUOUS ROLLER TOWEL (CRT)	WARM AIR DRYER (WAD)	JET AIR DRYER (JAD)
NA	ALL	-61.4 ↓ **	-77.9 ↓ *	-64.1↓ **	+230.4 ↑ ***	+9.1 ↑
CLED	ALL	-40.7 ↓	-71.6 ↓	-49.2↓ **	+242.8 ↑ **	+13.7 ↑
MSA	MAN +	-48.4 ↓	-61.3 ↓ *	-62.5↓	+478.8 ↑	-11.3 ↓
MSA	MAN -	-32.8 ↓	-85.2 ↓	-70.1↓	+245.5 ↑ **	+82.2 ↑ *
MSA	ALL	-35.3 ↓	-80.8 ↓	-69.7↓	+303.0 ↑ ***	+22.9 ↑
TOTAL	ALL	-48.4 ↓ *	-76.8 ↓ *	-62.5↓	+254.5 ↑ ***	+14.9 ↑

Figure 1

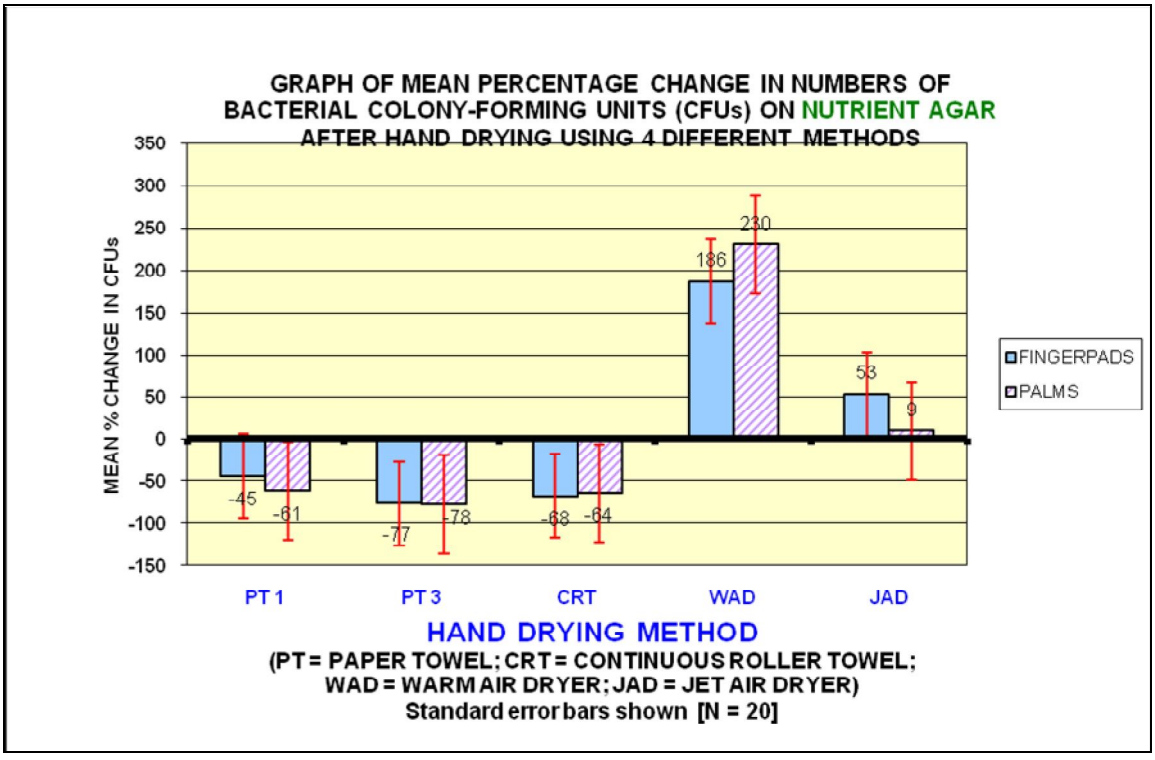

Figure 2

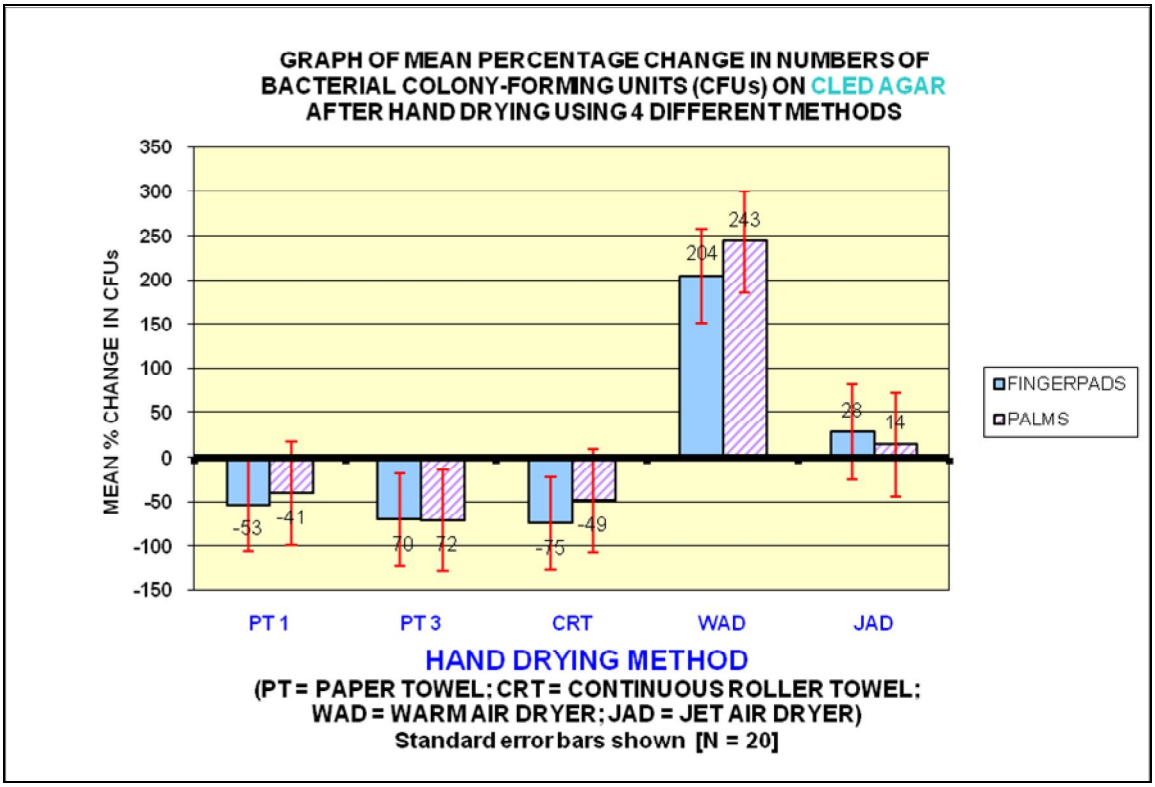

Figure 3

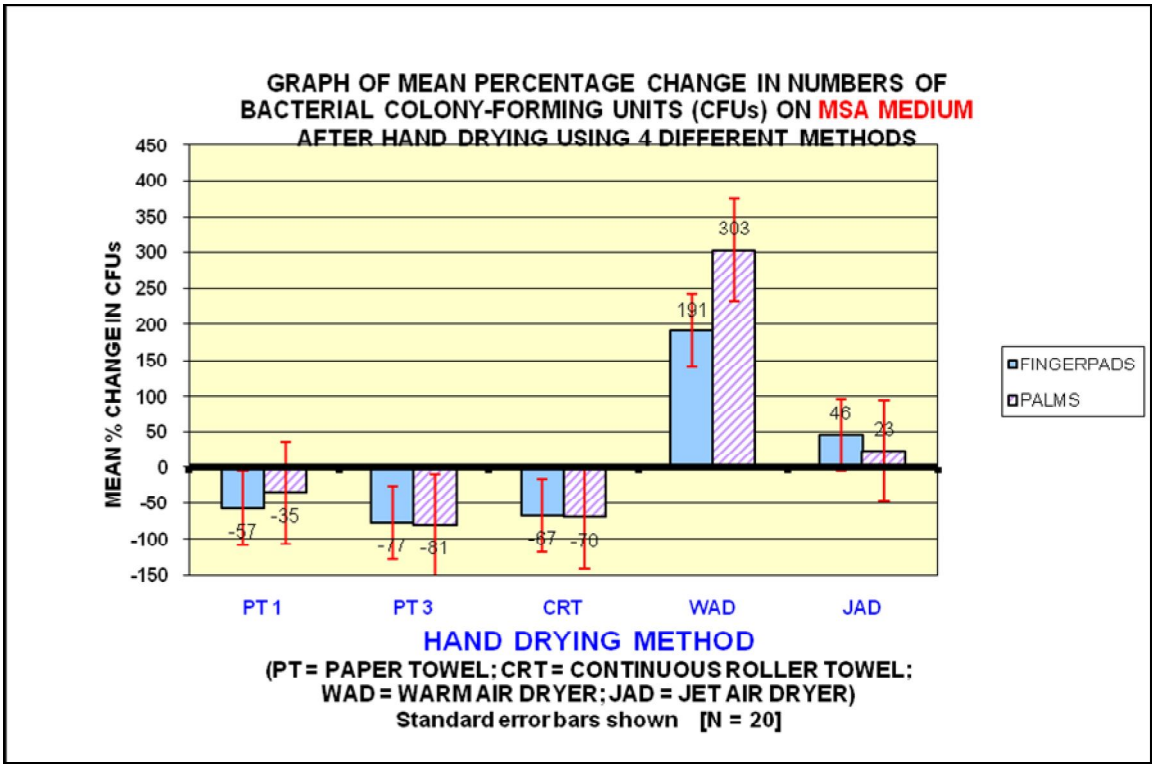

Figure 4

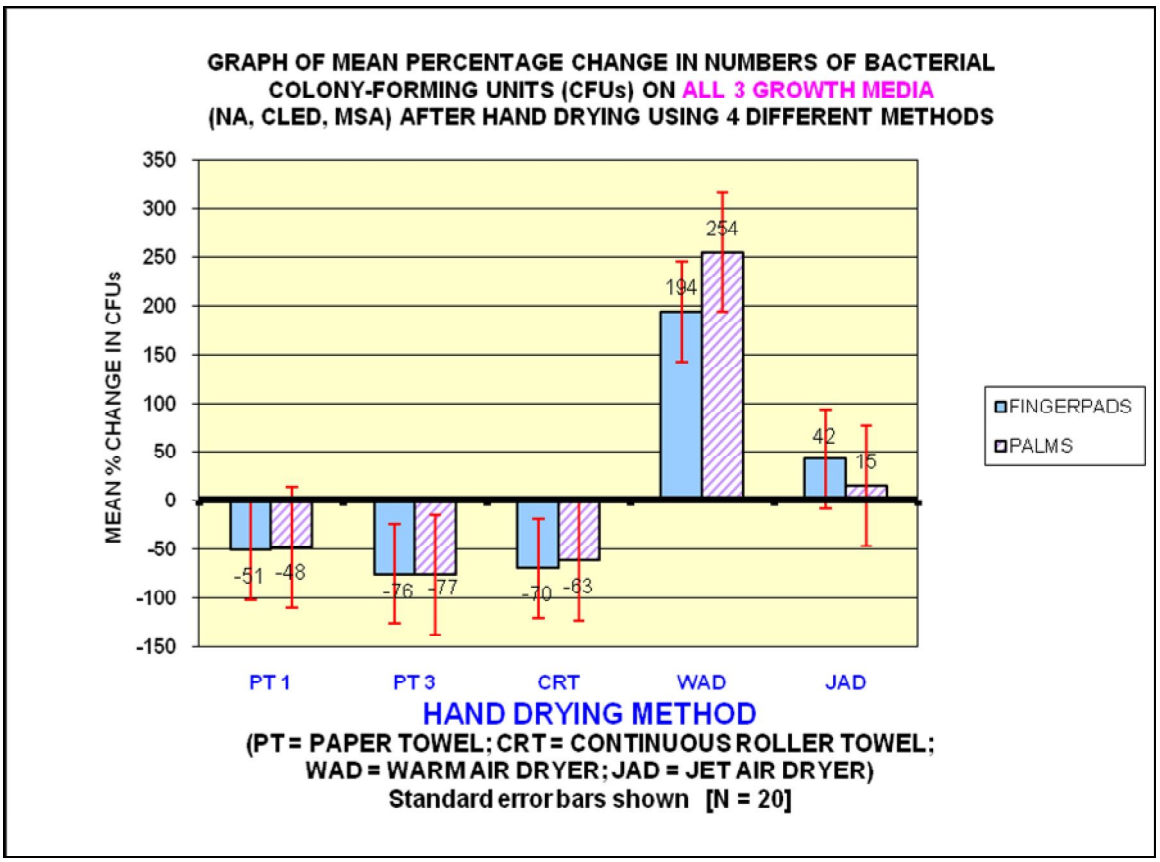

Table 5
T-test results (p values) comparing the bacterial after dry (AD) counts on subjects' hands after using different hand drying methods.

FINGERPADS				
	PT1	**PT3**	**CRT**	**WAD**
PT3	0.0733 *	NA	NA	NA
CRT	0.8403	0.0428 **	NA	NA
WAD	0.00003 ****	0.000001 ****	0.0002 ****	NA
JAD	0.0005 ****	0.00001 ****	0.0007 ****	0.037 **
PALMS				
	PT1	**PT3**	**CRT**	**WAD**
PT3	0.090 *	NA	NA	NA
CRT	0.068 *	0.423	NA	NA
WAD	0.005 ***	0.003 ***	0.0025 ***	NA
JAD	0.012 **	0.006 ***	0.0041 ***	0.185

Key to *Table 5*:
PT = paper towel (1 or 3); CRT = continuous roller towel; WAD = warm air dryer; JAD = jet air dryer; NA = not applicable (redundant comparison).

* p < 0.1; ** p < 0.05; *** p < 0.01; **** p < 0.001.

Control results

Table 6
Means of bacterial colony counts for controls on different growth media after incubation at 37°C for 2 days.

CONTROL ITEM	NA	CLED	MSA
PT 1 (per cm^2)	0.13	0.06	0.06
PT 3 (per cm^2)	0.00	0.00	0.00
CRT (per cm^2)	0.13	0.25	0.06
WAD (20 sec.)	1.40	0.00	0.40
JAD (10 sec.)	1.00	0.00	0.20
Sterile Ringer's solution (per ml)	0.00	0.00	0.00
Tap water (per ml)	0.00	0.00	0.00
Liquid soap (per ml)	0.00	0.00	0.00

(N = 5)

Key to *Table 6*:
PT = paper towel (1 or 3); CRT = continuous roller towel; WAD = warm air dryer; JAD = jet air dryer; NA = nutrient agar; CLED = cystine-lactose-electrolyte-deficient medium; MSA = mannitol salt agar.

Measurements

Table 7
Measurements in the laboratory and a public washroom.

MEASUREMENT	MINIMUM	MAXIMUM	MEAN (N = 10)
Laboratory ambient temperature (°C)	22.9	26.7	24.3
Washroom ambient temperature (°C)	21.8	26.9	23.2
Laboratory tap water temperature (°C)	21.3	24.9	22.7
WAD air flow temperature (°C) [20-second run]	50.5	59.1	55.6
JAD air flow temperature (°C) [10-second run]	36.6	40.7	39.2
Laboratory relative humidity (%)	33.6	51.6	47.0
Washroom relative humidity (%)	36.6	49.2	44.6
Background laboratory noise level (dB)	51.2	52.7	51.8
Noise level (dB) with laboratory JAD on at 0.5 m distance	94.7	93.7	94.1
Noise level (dB) with laboratory JAD on at 1.0 m distance	85.1	89.3	87.4
Noise level (dB) with laboratory JAD on at 2.0 m distance	85.4	87.6	86.3
Background washroom noise level (dB)	55.5	58.7	57.8
Noise level (dB) with one washroom JAD on at 2.0 m distance	ND	ND	83.6
Noise level (dB) with one washroom JAD on at 10.0 m distance	ND	ND	77.9
Noise level (dB) with two washroom JADs on at 2.0 m distance	ND	ND	92.0
Power consumption of WAD (W)	ND	1400-1600	N/A
Power consumption of JAD (W)	1 (standby)	1600	N/A

Key to *Table 7*:
WAD = warm air dryer; JAD = jet air dryer; dB = decibel: ND = no data;
W = watts; N/A = not applicable.

Conclusions and discussion

The experimental protocol used in this study attempted to reproduce the public's usual hand washing and drying practices as closely as possible. The times used for washing and drying the hands were based on those shown by a previous study (Knights ***et al***., 1993) to be the averages for men and women using paper towels (10 seconds) and warm air dryers (20 seconds) in real public washrooms, ***i.e***. under 'normal', non-laboratory conditions. The average time that men use warm air dryers was found to be 20 seconds whilst for women it was 25 seconds. By comparison, Patrick ***et al.*** (1997) found that the average time for men using warm air dryers was 17.0 seconds and 13.3 seconds for women. However, the study by Knights ***et al***. (1997) involving 292 subjects showed that men used warm air dryers for 15.4 seconds on average and women for 17.7 seconds. A survey on the "***Country Doctor***" website (2006) gives the average time for men using a warm air dryer as 20 seconds and for women as 16 seconds. Therefore, the drying time of 20 seconds for both sexes used in the present study is likely to be longer than the actual average time that the public uses warm air dryers and would favour them compared to towels so that any poor results from dryers cannot be explained by the drying time used in this study being too low. The drying time of 10 seconds used for the jet air dryer was not based on observations of the public but on the manufacturer's recommendation as given on the dryer itself.

Using the three different growth media it was hoped to count most of the bacteria present on the subjects' hands before and after washing and drying. In addition, it was also hoped that information would be obtained about the incidence of the following types of bacteria in particular:

- ***Escherichia coli***, a bacterium found in the human gut and a good indicator of faecal contamination. Some strains are pathogenic and cause disease, sometimes severe, ***e.g***. O157. This bacterium produces large yellow colonies on Cystine-Lactose-Electrolyte-Deficient Medium (CLED).
- Other coliforms also grow on CLED. Distinction between normal commensals and pathogens would require further tests which were not done in this part of the study but any presence of coliforms is indicative of faecal contamination and poor hygiene.
- Acid from mannitol negative staphylococci and micrococci. The former can sometimes be pathogenic and cause disease. These bacteria grow on mannitol salt agar and are normal commensal inhabitants of human skin and nostrils.
- Acid from mannitol positive staphylococci. These were differentiated on mannitol salt agar by the production of yellow zones around colonies due to acid production and presumptively identified as ***Staphylococcus aureus***. This organism can be found on the skin and in the nostrils of healthy people but it is a common potential pathogen causing a toxigenic food poisoning, abscesses, boils and other problems. However, pathogenicity and antibiotic resistance vary greatly between different strains, which include meticillin-(methicillin-) resistant ***Staphylococcus aureus*** (MRSA), a common hospital-acquired infection. The presence of any type of

Staphylococcus aureus on the hands of a worker in the food industry or medical field should be taken seriously as should any increase in its numbers caused by particular hand drying methods.

The issue of warm air dryer hygiene is controversial. Some studies (Blackmore, 1989; Blackmore & Prisk, 1984; Gould, 1994; Knights ***et al***., 1993; Knights ***et al***., 1997; Ngeow ***et al***., 1989; Redway ***et al***., 1994; Redway ***et al***., 1995: Redway & Fawdar, 2008) have shown that warm air dryers are hygienically inferior to towels and actually increase the number of bacteria on the hands after use. Other studies (Davis ***et al***., 1969; Gustafson ***et al***., 2000; Matthew & Newsom, 1987; Meers & Leong, 1989; Patrick ***et al***., 1997; Taylor ***et al***., 2000) have shown that there is little significant difference between the three hand drying methods. Only a few studies (Ansari ***et al***.,1991) have shown warm air dryers to be generally hygienically superior to paper towels. Yamamoto ***et al***. (2005) found warm air dryers reduced bacterial numbers if subjects held their hands stationary in the airflow rather than rubbing them which caused an increase but this method is likely to take longer to dry the hands. They also found that paper towels reduced the bacterial numbers on the fingertips more than warm air dryers; a result which agrees with the present study. However, their observation that paper towels did not reduce bacterial numbers on the palms is not in agreement with the results of other studies or the present one but may be explained by a different sampling method. Snelling ***et al***. (2010) also found that rubbing the hands during the use of a warm air dryer increased the number of bacteria released from the surface of the skin.

The large discrepancy between the results of different studies can invariably be explained by differences in the experimental protocols used, such as abnormally long drying times of up to 1 minute (when the average time used by the public is less than 20 seconds) and by the use of new dryers in laboratories, rather than regularly-used, and often contaminated, dryers in public washrooms. Used electric dryers are commonly contaminated and emit bacteria in their air flow (Redway ***et al***., 1994: Redway & Fawdar, 2008). It should be noted that a new warm air dryer and new jet air dryer were used in a laboratory in this part of the study and that regular tests showed no significant numbers of bacteria in their air flows. Therefore, any increases in bacterial numbers after use of dryers in this part of the study must have been due to factors other than bacterial contamination of the dryers themselves.

It is generally accepted that the transmission of bacteria and other microorganisms is more likely to occur from wet skin than from dry skin (Gould 1994). This happens partly because of the ease of water transfer from one surface to another and partly because microorganisms prefer a damp environment and, therefore, may be in a better physiological state to colonize touched surfaces. The amount of residual water left on the hands of users after drying is directly related to the number of bacteria that are transferred by contact, the greater the amount, the more bacteria (Patrick ***et al***., 1997). Knights ***et al***. (1993) showed that warm air dryers in normal use do not dry the hands as thoroughly as either type of towel. Warm air dryers in normal use achieved only 55% dryness of the hands of men and 68% of the hands of women. In contrast,

both types of towel in normal use achieved 93% or more dryness of the hands of both sexes. Similar results were also found in a later study (Redway & Fawdar, 2008).

It is highly likely that the significantly poorer hygiene performance of warm air dryers compared to towels shown in this study is mainly due to the low drying efficiency of warm air dryers and the consequent greater amount of water remaining on the fingerpads and palms of the hand after their use. However, there must be other factors operating on the bacterial load on the hands of users because although the jet air dryer showed a similar drying efficiency to paper towels (see Part A of this study), its hygiene performance, although better than the warm air dryer, was significantly worse than the two types of paper towel and the continuous roller towel tested in this study. The superior performance of towels over the two types of electric dryer in reducing the numbers of bacteria was shown with both the fingerpads and the palms of subjects. It is possible that towels work better because they frictionally remove dirt, grease, bacteria and skin squames from the hands whereas the jet air dryer, like the warm air dryer, does not.

The room temperature, the tap water temperature and the relative humidity varied in the laboratory from day to day (see ***Table 7***) but any effect that these factors may have had on the results were minimized by randomising the order of hand drying method tested and subjects used.

In this study both types of paper towel (PT 1 and PT 3) tested reduced the mean numbers of all types of bacteria tested on the fingerpads and the palms of subjects. The percentage mean reductions ranged from –44.6% to –91.5% for fingerpads and from –32.8 to –85.2% for palms. Reductions were shown with all types of bacteria on all 3 growth media. The majority of these reductions were significant suggesting that they were not due to chance alone but to the action of the towels.

Similarly, the continuous roller textile towel reduced the mean numbers of all types of bacteria tested on the fingerpads and the palms of subjects. The percentage mean reductions ranged from –66.4% to –74.9% for fingerpads and from –49.2% to –70.1% for palms. As with the paper towels, reductions were shown with all types of bacteria on all 3 growth media and again the majority of these reductions were significant suggesting that they were not due to chance alone but to the action of the towels.

The warm air dryer increased the mean numbers of all types of bacteria tested on the fingerpads and the palms of subjects. The percentage mean increases ranged from +114.1% to +414% for fingerpads and from +230.4% to +478.8% for palms. Increases were shown with all types of bacteria on all 3 growth media. The majority of these increases were significant, some highly so, suggesting that they were not due to chance alone but to the action of the warm air dryer.

The jet air dryer increased the mean numbers of most types of bacteria tested on the fingerpads and the palms of subjects. The percentage mean increases

ranged from +28.0% to +193.3% for fingerpads and from +9.1% to +82.2% for palms. Increases were shown with most types of bacteria on all 3 growth media, the only exceptions being reductions on the fingerpads of mannitol-negative bacteria and reductions on the palms of mannitol-positive bacteria. However, neither of these decreases was significant, whereas some of the increases were.

Comparisons of the after dry bacterial counts on the fingerpads of subjects using the paper towels or the continuous roller towel with the warm air dryer and with the jet air dryer showed that there were highly significant differences between the towels and both types of dryer, ***i.e***. the superior performance of the towels in reducing bacterial numbers was confirmed. Both types of dryer caused mean increases in the bacterial counts on the fingerpads of subjects but the jet air dryer performed better than the warm air dryer in that the increases were not as great. Differences between the two types of dryer were less significant than for the towels compared to either dryer.

Results for the palms were similar. Comparisons of the after dry bacterial counts on the palms of subjects using the towels with the warm air dryer and with the jet air dryer showed that there were significant differences (although not as great as for the fingerpads) between the towels and both types of dryer. Again, the superior performance of the towels in reducing bacterial numbers was confirmed. As for the fingerpads, the jet air dryer performed better than the warm air dryer in not increasing mean bacterial count on the palms as much but this difference was not significant.

Therefore, the manufacturer's claim that the tested JAD is the "***most hygienic hand dryer***" is confirmed, especially for fingerpads and assuming that the term "***hand dryer***" refers to electric devices only because its performance in terms of the numbers of all types of bacteria remaining on the hands of users compared to towels was significantly worse.

The study by Snelling ***et al.*** (2010) compared an 'ultra-rapid' jet air dryer with warm air dryers and showed superior hygiene performance in terms of the numbers of bacteria transferred from contaminated hands after drying. They also showed that rubbing when using an electric dryer increased the transference of bacteria. However, they did not directly compare the performance of either paper or textile towels with electric dryers using all the tests used in the study although acknowledged that "***paper towels consistently outperformed all the other drying techniques, especially with regard to bacteria left on the palms and fingertips***".

The fact that paper and textile towels performed similarly in this study is probably due to the fact that they cleanse and dry the hands in the same way, ***i.e***. by friction and absorption, which is different from the mode of drying action of either warm air dryers or jet air dryers. Snelling ***et al***. (2010) also suggested that paper towels physically removed bacteria re-populating the skin during the rubbing process.

Both the paper and the textile towel used in this study showed some evidence of bacterial contamination before use. However, the bacteria isolated from the

unused paper towels were in small numbers and evidently harmless environmental organisms such as non-pathogenic ***Bacillus*** species whilst the bacteria isolated from the textile towel included presumptively identified ***Staphylococcus aureus,*** a known pathogen, albeit in small numbers. It is likely that such organisms contaminate textile towels in use and are not all removed in the laundering process. This effect may be exacerbated by the increased use of lower washing temperatures for laundering textile towels and to save energy. If so, textile towels could present greater hygiene risk than paper towels in that the hands of a user could be contaminated by the bacterial flora of a previous user. The risk is probably low and would vary with the towel batch but may be significant in a hospital environment.

The results of all parts of this study suggest that towels should be used in locations where hygiene is paramount, such as hospitals, clinics, schools, nurseries, care homes, kitchens and other food preparation areas. Warm air dryers and jet air dryers should be carefully considered for these types of location because of their poorer hygiene performance and the increased likelihood of transmission of bacteria, including potentially pathogenic types, via the fingerpads and palms of the hand and their air flows. The performance of both the warm air dryer and the jet air dryer was inferior to towels in all respects (drying efficiency, bacterial numbers on the hands, bacterial contamination of the air flow and surfaces of the devices, and transmission of bacteria in the washroom) with the one exception that the jet air dryer is equal in drying efficiency. The jet air dryer was shown to be superior to the warm air dryer in all respects except for similar bacterial contamination and greater transmission potential. Although representing a considerable improvement over warm air dryers in speed, the jet air dryer's overall performance, with the exception of drying efficiency, was significantly poorer than that of towels in all other respects tested in this study.

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Note: this study has not yet been peer reviewed but it is intended that the test methods described in this document are provided in sufficient detail to allow replication by those who wish to confirm the results.