## Evaluation of three principal studies comparing the environmental contamination of paper towels with jet air dryers

Assessment of the environmental microbiological cross contamination following hand drying with paper hand towels or an air blade dryer (SCA Hygiene Products, 2013)

Evaluation of the potential for virus dispersal during hand drying: a comparison of three methods (European Tissue Symposium, 2016)

Environmental contamination by bacteria in hospital washrooms according to hand-drying method: a multi-centre study (European Tissue Symposium, 2018)

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#### **Executive Summary**

In this paper, three principal studies that were initiated and/or funded by the paper tissue industry (SCA Hygiene Products and the European Tissue Symposium) are evaluated.

The first study, which was carried out by SCA Hygiene Products AB (owner of the Tork brand) with Campden BRI in 2013, concluded that there is no significant increase in the microbial levels in the environment when comparing the use of paper towels with the use of jet air dryers after hands are washed.

The second study, which was initiated by the European Tissue Symposium (ETS) and lead by Keith Redway<sup>1</sup> in 2015, concluded that when artificially contaminated hands with a suspension of MS<sub>2</sub> bacteriophage with a mean count in the range of 10,000,000,000 plaque-forming units (PFU) per ml are "dried" with a jet air dryer there is greater and further dispersal of bacteriophage than when using paper towels.

While the use of contaminated gloves does lead to higher dispersal in an artificial context in which these gloves are not washed first, earlier research concludes there is no significant increase in the microbial levels in the environment between paper towels and jet air dryers when hands are washed.

The third study, dating back to 2018, was funded by the ETS and lead by Mark Wilcox<sup>1</sup>. It was done in a real-live setting in three hospitals in the UK, France and Italy, and compared paper towels with jet air dryers. The number of bacteria was measured on six locations: "Air", "Door", "Sink", "Dust", "Box" (hand dryer vs. paper towel dispenser) and "Floor" (directly beneath the hand dryer and paper towel dispenser).

The research shows there is no significant measurable difference in the "Air", disproving the allegation of the paper tissue industry that jet air dryers cause contamination in the air. Also, on the "Door" there was no significant difference. There was a slight measurable difference on the "Sink" and in the "Dust", but these differences were minor.

The only major significant difference was measured on the "Box" and on the "Floor". However, on the "Floor" in Italy, over the full six-week period, the average measurement is close to zero and this is identical for paper towels and jet air dryers. This implies the floor was (properly) cleaned during the research period in both the washrooms with jet air dryers and the ones with paper towels. The "Floor" in the UK and France showed significantly higher values for both paper towels and jet air dryers, suggesting the floor was not (properly) cleaned during the research period.

The same assumption applies to the "Box", i.e. the jet air dryer itself. This location also showed high measured values, however, these values were not higher than the ones measured in the "Dust" of washrooms with paper towels. Most likely, the jet air dryers were also not (properly) cleaned during the research period.

This implies that when the jet air dryer and the floor are properly cleaned, there is no difference between paper towels and jet air dryers. This also implies that when a jet air dryer that is integrated in the water tap is used, there will be no significant difference between the use of a jet air tap dryer and paper towels as water will disappear in the sink.

From these three studies initiated by the paper tissue industry, it can be concluded that, when comparing jet air dryers with paper towels under normal circumstances, there is no significant difference in microbial levels in the washroom.

<sup>&</sup>lt;sup>1</sup> It is publicly stated that Keith Redway and Mark Wilcox are paid for their services by the ETS

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Research title: Assessment of the environmental microbiological cross contamination following hand drying with paper hand towels or an air blade dryer (2013)
Funding sources: The funding for this research was provided by SCA Hygiene Products
Researchers: E. Margas, E. Maguire, C. R. Berland, F. Welander and J. T. Holah
Conflict of interest statement: C. R. Berland is an employee of SCA Hygiene Products AB
Method: One hundred volunteers for each method washed their hands and dried them using paper towels and an air blade dryer. Bacterial contamination of the surrounding environment was measured using settle plates placed on the floor in a grid pattern, air sampling and surface swabs.
Stated conclusion: The two drying methods led to different patterns of ballistic droplets and levels of microbial contamination under heavy use conditions. The increase in microbial levels in the

**Evaluation:** Even though some droplets of water are dispersed when using an air blade dryer, this has no significant impact on bacteria levels in washroom air compared to paper towels.

#### Assessment of the environmental microbiological cross contamination following hand drying with paper hand towels or an air blade dryer

E. Margas<sup>1</sup>, E. Maguire<sup>1</sup>, C. R. Berland<sup>2</sup>, F. Welander<sup>2</sup> and J. T. Holah<sup>1</sup>

Abstract

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#### Keywords

environment is not significant.

air blade, detection, electric dryer, enumeration, food safety, hand drying, hand hygiene, microbial contamination, paper towels, washroom contamination.

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#### Acknowledgements

The funding for this research was provided by SCA Hygiene Products, Göteborg, Sweden. We would like to thank the Members of Staff at Campden BRI for their participation in the trials. We would like to thank Dr Ulrika Husmark for helpful discussion during the planning and interpretation. Aims: This study compared the potential for cross contamination of the surrounding environment resulting from two different hand-drying methods: paper towels and the use of an air blade dryer.

Methods and results: One hundred volunteers for each method washed their hands and dried them using one of the two methods. Bacterial contamination of the surrounding environment was measured using settle plates placed on the floor in a grid pattern, air sampling and surface swabs. Both drying methods produced ballistic droplets in the immediate vicinity of the hand-drying process. The air blade dryer produced a larger number of droplets which were dispersed over a larger area. Settle plates showed increased microbial contamination in the grid squares which were affected by ballistic droplets. Using the settle plates counts, it was estimated that approx.  $1.7 \times 10^5$  cfu more micro-organisms were left on the laboratory floor (total area approx.  $17.15 \text{ m}^2$ ) after 100 volunteers used an air blade dryer compared to when paper towels were used.

**Conclusions:** The two drying methods led to different patterns of ballistic droplets and levels of microbial contamination under heavy use conditions. Whilst the increase in microbial levels in the environment is not significant if only

nonpathogenic micro-organisms are spread, it may increase the risk of pathogen contamination of the environment when pathogens are occasionally present on people's hands.

Significance and Impact of the Study: The study suggests that the risk of cross contamination from the washroom users to the environment and subsequent users should be considered when choosing a hand-drying method. The data could potentially give guidance following the selection of drying methods on implementing measures to minimise the risk of cross contamination.

## 2. Evaluation of "Evaluation of the potential for virus dispersal during hand drying: a comparison of three methods (2016)"

**Research title:** Evaluation of the potential for virus dispersal during hand drying: a comparison of three methods (2016)

Researchers: P.T. Kimmitt and K.F. Redway

**Conflict of interest statement:** Keith Redway has received honoraria from the European Tissue Symposium (ETS)

**Method:** Participants washed their gloved hands with a suspension of MS<sub>2</sub> bacteriophage with a mean count in the range of 10,000,000 plaque-forming units (PFU) per ml and hands were "dried" with one of the three hand-drying devices without washing them first.

**Stated conclusion:** Use of the JAD (jet air dryer) lead to significantly greater and further dispersal of MS<sub>2</sub> bacteriophage from artificially contaminated hands when compared to the WAD (warm air dryer) and PT (paper towels).

**Evaluation:** Gloved hands were coated with unrealistically high numbers of viruses; similar studies have used 100,000 times less. The actual number of viruses aerosolized and transmitted is approximately 0.000008% of the amount originally applied to the gloved hands. While the use of artificially contaminated hands does lead to higher dispersal when hands are not washed, earlier research concludes there is no significant difference in environmental contamination between paper towels and jet air dryers when hands are washed.

## Evaluation of the potential for virus dispersal during hand drying: a comparison of three methods

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#### Keywords

aerosolization, cross-contamination, dispersal, hand drying, hand hygiene, MS2 bacteriophage, virus.

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#### Conflict of Interest

This study was independently funded in full from a University of Westminster research reserve account. Keith Redway has received honoraria from the European Tissue Symposium for microbiological advice and travel expenses to attend meetings and conferences.

#### Abstract

Aims: To use a MS2 bacteriophage model to compare three hand-drying methods, paper towels (PT), a warm air dryer (WAD) and a jet air dryer (JAD), for their potential to disperse viruses and contaminate the immediate environment during use.

Methods and Results: Participants washed their gloved hands with a suspension of MS2 bacteriophage and hands were dried with one of the three hand-drying devices. The quantity of MS2 present in the areas around each device was determined using a plaque assay. Samples were collected from plates containing the indicator strain, placed at varying heights and distances and also from the air. Over a height range of 0·15–1·65 m, the JAD dispersed an average of >60 and >1300-fold more plaque-forming units (PFU) compared to the WAD and PT (P < 0.0001), respectively. The JAD dispersed an average of >20 and >190-fold more PFU in total compared to WAD and PT at all distances tested up to 3 m (P < 0.01) respectively. Air samples collected around each device 15 min after use indicated that the JAD dispersed an average of >50 and >100-fold more PFU compared to the WAD and PT (P < 0.001), respectively.

**Conclusions:** Use of the JAD lead to significantly greater and further dispersal of MS2 bacteriophage from artificially contaminated hands when compared to the WAD and PT.

Significance and Impact of Study: The choice of hand-drying device should be considered carefully in areas where infection prevention concerns are paramount, such as healthcare settings and the food industry.

#### Evaluation of "Environmental contamination by bacteria in hospital washrooms according to hand-drying method: a multi-centre study (2018)"

**Research title:** Environmental contamination by bacteria in hospital washrooms according to hand-drying method: a multi-centre study (2018)

Funding sources: The ETS funded the project

**Researchers:** E. Best, P. Parnell, J. Couturier b, F. Barbut, A. Le Bozec, L. Arnoldo, A. Madia, S. Brusaferro , M.H. Wilcox

**Conflict of interest statement:** Mark .H. Wilcox has received honoraria from the European Tissue Symposium (ETS)

**Method:** A total of 120 sampling sessions occurred over 12 weeks in each of three hospitals (UK, France, Italy). Bacteria were cultured from air, multiple surfaces, and dust.

**Stated conclusion:** Multiple examples of significant differences in surface bacterial contamination, including by faecal and antibiotic-resistant bacteria, were observed, with higher levels in JAD versus PT washrooms. Hand-drying method affects the risk of (airborne) dissemination of bacteria in real-world settings.

**Evaluation:** The results of the median total aerobic bacteria (cfu) recovered between the six sampling locations show significant differences. The lowest value is o cfu, measured in washrooms with jet air dryers in Italy in the "Air" and on the "Door". The highest value is 300 cfu, measured in washrooms in France for the "Dust" in the washroom with paper towels and in the "Dust" and on the "Box" of washrooms equipped with jet air dryers.

Washrooms	Mean footfall	an footfall Mean temperature (°C) eople/h)	Median total aerobic bacteria (cfu) recovered a,b						
	(people/h)		Air	Door	Floor	Box	Sink	Dust	
Paper towel (	(N = 60)		1101	100				00000	
UK	93	21.9	5	1	40	9	85	115	
France	9	23.4	5	12	24	9	37	300	
Italy	10	27	5	<1	<1	<1	<1	75	
Jet air dryer	(N = 60)								
UK	86	22.1	6	15	200	200	63	145	
France	7	23.2	1	5	190	300	132	300	
Italy	10	27	0	0	<1	100	<1	20	

<sup>a</sup> Volume of air sampled was 1500 L, equivalent to 20 L per agar plate. Approximate surface area sampled was 10 × 10 cm per site, equivalent to 0.2 cm<sup>2</sup> per agar plate.

<sup>b</sup> Significant differences highlighted in text.

- Air: The study shows there is no significant measurable difference in the "Air", disproving the allegation from the paper tissue industry that jet air dryers cause contamination in the air. The unweighted average for paper towel is 5 (5,5,5) and for jet air dryer is 2.3 (6,1,0), which indicates that the air in the washrooms equipped with jet air dryers is less contaminated than the air in the washrooms with paper towels. However, the relative difference is <1% (2.7/300).
- **Door:** On the "Door", there is no significant measurable difference either (<1%). The unweighted average for paper towel is 4.3 (1,12,<1) and for jet air dryer 6.7 (15,5,0).
- Floor: A significant difference is measured on the "Floor", with an unweighted average for paper towel of 21 (40,24,<1) and for jet air dryer of 130 (200,190,<1). It is noteworthy, however, that on the "Floor" in Italian washrooms, the average measurement is close to zero and the exact same for both paper towels and jet air dryers. This implies that the floor was (properly) cleaned during the research period in both the washrooms with jet air dryers and the ones with paper towels. The "Floor" in the UK and France show significantly higher values both for paper towels and jet air dryers, suggesting the floor was not (properly) cleaned during the research period.

- **Box:** A significant difference is also measured on the "Box" (paper towel dispenser vs. jet air dryer), with an unweighted average for paper towel of 6 (9,9,<1) and 200 (200,300,100). As for the "Floor" in the UK and France: the assumption is that the jet air dryers were not (properly) cleaned either during the research period.
- Sink: A minor difference is measured on the "Sink", with an unweighted average of 40.7 (85,37,<1) for paper towels and 65.0 (63,132,<1) for jet air dryers, with a relative difference of 8.1% in favour of paper towels.
- **Dust:** A minor difference is measured on the "Dust", with an unweighted average of 163.3 (115,300,75) for paper towels and 155.0 (145,300,20), with a relative difference of 2.8% in favour of jet air dryers.

As can be concluded from the overview, in the washrooms in Italy there was no significant difference in measurements in the "Air", on the "Door", on the "Floor" and on the "Sink", qualifying all these surfaces as "clean". This implies that the washrooms were properly cleaned, as opposed to the situation in the washrooms in the UK and France. Only the "Box" shows more bacteria recovered in the jet dryer washrooms, whereas the "Dust" shows more bacteria recovered in paper towel washrooms.

This implies that, if washrooms and jet air dryers are properly cleaned, there will be no significant differences measured between paper towels and jet air dryers. This corroborates what can be expected based on other studies. Finally, this also implies that, when a jet air dryer integrated in the water tap is used, there will be no significant difference between the use of a jet air tap dryer and paper towels.

## Environmental contamination by bacteria in hospital washrooms according to hand-drying method: a multi-centre study

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ARTICLEINFO

#### SUMMARY

Article history: Received 23 May 2018 Accepted 4 July 2018	<b>Background:</b> Hand hygiene is a fundamental component of infection prevention, but few studies have examined whether hand-drying method affects the risk of dissemination of potential pathogens. <b>Aim:</b> To perform a multi-centre, internal-crossover study comparing bacterial contami-
<i>Keywords:</i> Hand hygiene Aerosol	nation levels in washrooms with hand-drying by either paper towels (PT) or jet air dryer (JAD; Dyson). <i>Methods</i> : A total of 120 sampling sessions occurred over 12 weeks in each of three hospitals (IK France Italy) Bacteria were cultured from air multiple surfaces and dust
Transmission	Washroom footfall (patients/visitors/staff) was monitored externally. <b>Findings:</b> Footfall was nine times higher in UK washrooms. Bacterial contamination was lower in PT versus JAD washrooms; contamination was similar in France and the UK, but markedly lower in Italian washrooms. Total bacterial recovery was significantly greater from JAD versus PT dispenser surfaces at all sites (median: 100–300 vs 0–10 cfu; all P < 0.0001). In the UK and France, significantly more bacteria were recovered from JAD washroom floors (median: 24 vs 191 cfu, $P < 0.00001$ ). UK meticillin-susceptible Staphy- lococcus aureus recovery was three times more frequent and six-fold higher for JAD vs PT surfaces (both $P < 0.0001$ ). UK meticillin-resistant S. aureus recovery was three times more frequent (21 vs 7 cfu) from JAD versus PT surfaces or floors. Significantly more
Conflict of interest statement M.H.W. has received honoraria from the European Tissue Symposium (ETS) for microbiological advice and lectures, and travel expenses to attend meetings. F.B. has received honoraria from ETS for microbiological advice and travel expenses to attend meetings.	enterococci and extended-spectrum $\beta$ -lactamase (ESBL)-producing bacteria were recovered from UK JAD versus PT washroom floors ( $P < 0.0001$ ). In France, ESBL-producing bacteria were recovered from dust twice as often during JAD versus PT use. <b>Conclusion:</b> Multiple examples of significant differences in surface bacterial contamina-
Funding sources The ETS funded the project; conception, design, results analysis, and manuscript preparation were carried out by the authors.	tion, including by faecal and antibiotic-resistant bacteria, were observed, with higher levels in JAD versus PT washrooms. Hand-drying method affects the risk of (airborne) dissemination of bacteria in real-world settings.

Appendix 1: Assessment of the environmental microbiological cross contamination following hand drying with paper hand towels or an air blade dryer (2013)

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#### ORIGINAL ARTICLE

#### Assessment of the environmental microbiological cross contamination following hand drying with paper hand towels or an air blade dryer

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#### Keywords

air blade, detection, electric dryer, enumeration, food safety, hand drying, hand hygiene, microbial contamination, paper towels, washroom contamination.

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#### Abstract

Aims: This study compared the potential for cross contamination of the surrounding environment resulting from two different hand-drying methods: paper towels and the use of an air blade dryer.

Methods and results: One hundred volunteers for each method washed their hands and dried them using one of the two methods. Bacterial contamination of the surrounding environment was measured using settle plates placed on the floor in a grid pattern, air sampling and surface swabs. Both drying methods produced ballistic droplets in the immediate vicinity of the hand-drying process. The air blade dryer produced a larger number of droplets which were dispersed over a larger area. Settle plates showed increased microbial contamination in the grid squares which were affected by ballistic droplets. Using the settle plates counts, it was estimated that approx.  $1.7 \times 10^5$  cfu more micro-organisms were left on the laboratory floor (total area approx.  $17.15 \text{ m}^2$ ) after 100 volunteers used an air blade dryer compared to when paper towels were used.

**Conclusions:** The two drying methods led to different patterns of ballistic droplets and levels of microbial contamination under heavy use conditions. Whilst the increase in microbial levels in the environment is not significant if only

nonpathogenic micro-organisms are spread, it may increase the risk of pathogen contamination of the environment when pathogens are occasionally present on people's hands.

Significance and Impact of the Study: The study suggests that the risk of cross contamination from the washroom users to the environment and subsequent users should be considered when choosing a hand-drying method. The data could potentially give guidance following the selection of drying methods on implementing measures to minimise the risk of cross contamination.

#### Introduction

In both healthcare and community settings, the rise in prevalence of infections with multiresistant bacteria has highlighted the importance of fighting infection by preventing transmission rather than by treating with antibiotics (Desai *et al.* 2011; Gagliotti *et al.* 2011). Similarly, large outbreaks of food poisoning have highlighted the need for better hygiene in the food industry, where hands

have been recognised as a major vector of food contamination during food-handling activities (Todd *et al.* 2010a, b,c). Hand hygiene has long been recognised as one of the simplest and most effective tools available to reduce the risk of transmission of infection in a variety of settings, including food service and health care (Griffin 2007).

Because hand hygiene plays such a crucial role in many areas, the subject of the best method for performing hand hygiene has been a very active area of research (Ayliffe *et al.* 1988; Boscart *et al.* 2009; Magiorakos *et al.* 2010). Much of this research has been focused on finding the most effective washing and disinfection methods (Boyce and Pittet 2002).

However, it has become increasingly apparent that proper drying of hands after washing is of vital importance for best infection control results. In particular, it has been demonstrated that damp hands are more likely both to acquire microbes from a contaminated object and to transfer microbes to a clean object (Patrick *et al.* 1997; Merry *et al.* 2001).

A small number of comparative studies comparing the efficacy of paper or cloth towels to warm air dryers have been performed (Gustafson *et al.* 2000; Yamamoto *et al.* 2005; Snelling *et al.* 2011) and have focused primarily on the amount of bacteria or virus remaining on the hands after drying.

These studies have shown that the amount of bacteria remaining on the hands is highly dependent on the type of microbe (normal flora versus laboratory-applied contaminant), drying procedure (amount of rubbing), the portion of the hand examined and the drying time. Most studies indicate that each method has its strengths and weaknesses, but that satisfactory results can be achieved with any drying method if the hands are completely dried by the procedure.

This study differs from previous comparisons of paper towels and air dryers in that it focuses on the effect a drying method has on the surrounding environment (Gustafson et al. 2000; Yamamoto et al. 2005, Snelling et al. 2011). The hands are almost certainly the most important vehicle for transferring microbes between surfaces; however, several recent studies have demonstrated that contaminated objects in the environment can serve as reservoirs of infection (Bright et al. 2010; Weber et al. 2010). Furthermore, airborne micro-organisms are a major route for product spoilage and also pose a risk of pathogenic contamination (Todd et al. 2010b). Because the hands are never free of micro-organisms after washing, there is the potential that the choice of drying method will affect the amount of microbial contamination from the wet hands to the surrounding environment during the drying process. In the described studies, two drying methods were investigated: paper towels and an air blade electric hand dryer.

#### Materials and methods

#### Experimental set-up

Hand-drying systems were placed alternatively in the centre of the back wall of a  $4.90 \times 3.50$  m controlled

atmosphere test room. The surrounding floor was covered with brown parcel paper with a grid of  $50 \times 50 \text{ cm}^2$  drawn onto it. The squares were grouped into zones (see Fig. 1). Zone 1 included the grid the apparatus was in and the immediate grids surrounding this grid (six 50  $\times$  50 cm<sup>2</sup> in total). Zone 2 included the squares immediately neighbouring those in zone 1 (nine squares in total). Zone 3 incorporated the next outer layer of squares (thirteen squares in total) and zone 4 included one further outer layer (seventeen squares in total). The air blade electric hand dryer (Air blade hand dryer) was mounted on a portable metal plate, at the height suggested by the manufacturer (female washroom mounting; back screw: 915 mm from the floor). This was thought to be an average common height as 70% of the participants were female. In the trials using paper towels, the paper towel dispenser (Tork ABS-MABS) containing paper towels (Tork Premium hand interfold, H2 xpress) was mounted on the wall 120 cm from the floor. The accompanying open mouth bin (Tork Elevation 50-l bin, B1 system) was placed directly below the dispenser (all provided by SCA Global Hygiene Category, Göteborg, Sweden). Before each experiment, all surfaces were cleaned and disinfected with alcohol wipes (Spectrum SP160 disinfectant wipes; Johnson and Johnson medical), air was extracted from the room and the HEPA filtered air supply was turned on to flush the room with clean air.

#### Ballistic water droplet distribution during hand drying

A preliminary trial was required to determine the areas of highest water droplet distribution on the floor when using paper towels or an air blade electric dryer to dry hands. Fifteen volunteers were used, for each drying apparatus, to gain quantitative data on the ballistic spread of water droplets whilst drying hands in a regular fashion. Each volunteer was asked to wet their hands in a portable basin held by a researcher without dripping excess water from their arms onto the floor. The volunteer was then asked to remove wet hands and give one flick into the basin, as they would at a normal sink, then continue to dry hands in their normal fashion. Once hands had been dipped and flicked once into the basin, the basin was removed immediately so as to not hinder droplet dispersion results in that area. The droplets generated on the floor (covered with brown paper) after each person dried their hands were marked each time and the totals were recorded. Neither the size of the droplets nor the volume of water deposited on the floor was measured due to the fast evaporation of water from the paper. The amount of micro-organisms spread via droplets, however, was investigated by using settle plates. The results obtained from settle plates were related to the amount of water droplets



which were generated when using each method on the basis of the greater the number of droplets, the larger the microbial contamination.

#### Microbial distribution during hand drying

The trial required the participation of 100 volunteers to pass through a hand washing and drying procedure in a controlled laboratory within 1 h. The number of volunteers and the timing of the study were chosen to simulate conditions in a high-traffic washroom. Volunteers were healthy adult employees of Campden BRI between the ages of 17 and 65. The male to female ratio was approx. 30:70. Volunteers were previously familiar with both hand-drying methods used in the study. Hand drying involved the use of a paper towel dispenser with accompanying disposal bin or the use of an air blade electric hand dryer. Bacterial sampling of the environment was undertaken by using swabs (to measure any contamination on the surfaces arising from water droplets spread from hands), settle plates (to measure contamination spread by water droplets and aerosols) and air impaction samplers (to measure contamination of the air) following hand drying.

#### Movement of participants

Participants were advised to wash and dry their hand in their usual fashion. However, they were directed as to whether or not to use soap (Tork Premium soap liquid, S1 system) according to the experimental schedule (soap use was changed every 25 people). In total, that there were not more than two participants in the room at one time and no queue built-up to the handdrying apparatus. All participants were provided with protective booties to cover their own shoes. They were asked to enter the room (using a door on the left hand side, see Fig. 1), wash their hands in a knee-operated sink (basin: length 56.5 cm, width 40 cm, height 19.5 cm; distance from the top to the bottom of the basin 49.5 cm; distance from the top edge of the basin to the floor 87.5 cm) using only water (2.9 l min<sup>-1</sup> flow at 40.5°C) or water and soap, then walk to the drying equipment, dry their hands and walk out of the room using a different door (opposite the drying equipment). The spread of contamination from paper towels and the air blade was evaluated twice on separate days. In total, over 150 volunteers took part over the 4-day trial period.

during each experiment, 50 people did use soap and 50 people did not. The flow of people was controlled so

#### Swabs

Swabs (Copan Italia S.p.A, plain swab, sterile wooden applicator cotton tipped) from the hand-drying equipment, walls, sink and soap dispenser were taken before the experiment, and after 50 people and after 100 had washed and dried their hands. Swabs were taken from the sink (from the panel between the tap and the basin), the soap dispenser and the front and back of the push button (Tork elevation, dispenser soap liquid). The wall close to (approx. 50 cm right, 105 cm high) and far (approx. 230 cm left, 124 cm high) from the drying apparatus was also swabbed. For both drying apparatus, the most likely areas of contact with the users were swabbed. The areas of swabbing for the paper towel drying method were on the bin accompanying the dispenser (around the edge of the bin) and the dispenser itself (around the area where towels were dispensed). In the case of the air blade electric hand dryer, the front and back panels were swabbed (on the inside of the top edge, where hands enter the equipment).

An area of approx.  $5 \times 5$  cm was swabbed by rotating the swab and going across the surface in two directions, covering the area a minimum of four times. For some larger swabbing positions (walls and sink), four  $5 \times 5$  cm areas were swabbed and swabs from these areas were broken into the same container (four times  $5 \times 5$  cm square, giving total of 100 cm<sup>2</sup> area swabbed) in order to get some countable results for the purpose of the trial. Swabs were prewetted and then resuspended in a neutralising solution consisting of 1 ml of standard disinfectant neutraliser (3 g lecithin, 30 ml polysorbate 80, 5 g sodium thiosulphate, 1 g L-histidine, 30 g saponin, 10 ml 0.25 mol l<sup>-1</sup> phosphate diluent; made up in 1000 ml deionised water) added to 9 ml MRD (MRD, Lab M 116893). Each swab was vortexed for 30 s, before performing 10-fold dilutions prior to incubation and enumeration.

Swabs were analysed for coliforms and total viable counts (TVC). For the enumeration of TVC, samples were incubated in plate count agar (PCA, Oxoid) at  $30 \pm 1^{\circ}$ C for  $48 \pm 4$  h. For enumerating coliforms, samples were poured with violet red bile agar plates (VRBA, Lab M 109720/153), and once each plate had solidified, samples were over-poured with approxi. 4 ml of molten-tempered VRBA. Plates were incubated at  $37 \pm 1^{\circ}$ C for  $24 \pm 2$  h. Following incubation, each plate containing not more than 300 colonies was enumerated.

#### Settle plates

Within the control room, each  $50 \times 50$  cm square was labelled and contained 90-mm agar Petri dishes (settle plates) specific for sampling before the trials (controls) and during the trials. Squares which were used as a path for volunteers or which had the equipment placed on them did not contain any plates. In total, there were 33 squares used in the first set of experiments for both methods (days 1 and 2) and 41 in the second set of experiments (days 3 and 4). However, some plates, which were contacted or damaged by the washroom users, were not included in subsequent calculations. Tryptic soy agar (TSA, Oxoid 1098982) settle plates were placed on the floor and opened for 1 h and collected prior to starting each trial to check the TVC level in the room before any hand washing/drying activity took place (controls). During each trial, each  $50 \times 50 \text{ cm}^2$  had a VRGA plate specific for the detection and enumeration of coliform bacteria; these plates were exposed during the whole trial (approx. 1 h). A TSA plate was also present in each square throughout the trial for approx. 1 h (long-term exposure plates). A third plate, also TSA, was present at the start of the trial and replaced three times during the trial (after the first, second and third set of 25 people), approx. every 15 min (short-term exposure plates). All TSA settle plates were incubated at  $30 \pm 1^{\circ}$ C for  $48 \pm 4$  h. VRBA plates were over-poured after the trial with a layer of VRBA and incubated at  $37 \pm 1^{\circ}$ C for  $24 \pm 2$  h.

#### Air impaction samples

Total viable counts in the air were also measured before and during the trial using two large volume air impaction samplers (M.A.Q.S., Oxoid 030217). They were fitted with open TSA agar set to sample 200 l of air. Air samples were taken close to the drying apparatus (50 cm to the right and at a height of 61 cm) and far away (230 cm to the left and at a height of 61 cm). Background counts were taken before the experiments on each day to gain information on micro-organism levels before any hand washing/drying activity started. Throughout the trial, the air samplers were running constantly; as soon as each 200 l sample was finished (approx. 102 s sampling time), the next plate was fitted, and the samplers were started again (See Fig. 1 for room set-up).

#### Results

#### Ballistic water droplet distribution during hand drying

The range of total droplets in each grid, after 15 volunteers washed and dried their hands, using either paper towels or an air blade dryer, is shown in Fig. 2. It was observed that the highest concentration of droplets occurred for the paper towel dispenser directly under the dispenser and the immediate neighbouring squares (referred to as zone 1). The results for the air blade electric hand dryer were slightly more widespread and occurred more to the sides of the hand dryer. There was a lot of variation between participants as to the direction of the dispersion, size and concentration of droplets on floor. Essentially, both hand-drying techniques produced droplets when hands were dried, particularly close to the hand-drying operation, with the air blade dryer spreading more droplets to the sides. The air blade dryer produced a higher number of droplets (total of 1747) than the paper towel method (total of 1310), over a greater number of grids, suggesting that ballistic droplet travel was further than with paper towels. The maximum distance that droplets were found from the air blade electric hand dryer to the sides, diagonally and to the front, was 2.24, 2.44 and 1.50 m, respectively; that from the paper towel dispenser was 1.74, 2.00 and 1.50 m, respectively.

#### Microbial distribution during hand drying

#### *Air and surface contamination – settle plates*

The settle plates which were used to evaluate total viable counts were divided to three groups: controls (exposed before the start of the trial for 1 h to check the background count), long-time exposure plates (left opened during the complete 1 h trial) and short-time exposure plates (replaced approx. every 15 min stages during the trial; four stages in total).

Control and long-time exposure plates had the same sampling time; therefore, they provide an indication of the contamination level before and after each trial and also point out how the contamination differed between the two drying methods. Plates from the four 15 min stages (stage 1, stage 2, stage 3 and stage 4) were compared with each other to investigate the micro-organism build-up in the room environment during one hour of use.

The average settle plate results from controls and longterm exposure plates during each day for each method are expressed as box plots in Fig. 3. Control values were very low (average 6.45 CFU per plate) and were found to be not significantly different for each hand-drying method (P = 0.734). This emphasised the relative cleanliness of the laboratory prior to commencement of the trial. It was clear that the contamination level was significantly higher for plates exposed during each trial than for the controls. The mean plate count for settle plates exposed during the use of the air blade hand, dryer was 184.8 CFU per plate (n = 67); during the use of paper towels, it was 123.9 cfu per plate (n = 71). Approximately 61 more colonies were found on each settle plate exposed when using the air blade dryer, and the results from both methods were significantly different (P < 0.001). Because of the difference in the n number, the total area sampled for each method was slightly different. The surface area of each settle plate was 0.0063 m<sup>2</sup>; therefore, 0.447 m<sup>2</sup> and 0.422 m<sup>2</sup> total areas were sampled for the paper towels and the air blade dryer, respectively. To effectively compare the differences between the methods, the number of micro-organisms per m<sup>2</sup> or per total area of the room (17.15 m<sup>2</sup>) needs to be calculated. It can be estimated that, on average, there was approx.  $9.7 \times 10^3$  cfu m<sup>-2</sup>, or  $1.7 \times 10^5$  cfu per whole laboratory floor, more micro-organisms deposited following air blade hand drying than when using paper towels.

The contamination level within each zone (see Fig. 1 for zone locations) was compared and is represented in

(a)	A0	A1	A2	A3	A4 ***	A5	A6	A7	A8	A9
	B0	B1	B2	B3	B4	B5	B6	B7	B8	B9
	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9
	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9

(b)	A0	A1	A2	A3	***	A5	A6	A7	A8	A9
	B0	B1	B2	B3	B4	B5	B6	B7	B8	B9
	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9
	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9

Figure 2 Location and frequency of water droplets created after 15 people dried their hands: (a) air blade dryer and (b) paper hand towel. ( $\blacksquare$ ) >200; ( $\blacksquare$ ) 100–199; ( $\blacksquare$ ) 60–99; ( $\blacksquare$ ) 30–59; ( $\blacksquare$ ) 10–29; ( $\blacksquare$ ) 1–9; ( $\blacksquare$ ) 0, (\*\*\*) Drying apparatus.



**Figure 3** Box plot of settle plate results (cfu per plate), exposed for 1 h before the trial (controls) and during the trial (long-term exposure plates) for each drying method [(■) air blade dryer; (□) paper towels] during each day.

Fig. 4. The average micro-organism level in zone 1 (immediate surroundings of the drying apparatus) was 161.6 and 221.17 cfu per plate for the paper towel and air blade drying method, respectively. ANOVA analysis was undertaken for the overall counts for each drying method and for each zone. There was a statistically significant difference (*P*-value = 0.042) between drying methods within each zone. The air blade showed significantly higher counts in zones 2, 3 and 4 (175.38, 173.74 and 177.91 cfu per plate, respectively) than the paper towel (96.5, 119.70 and 115.44 cfu per plate, respectively) and not significantly higher counts in zone 1 (P = 0.179).

Figure 5 shows the interval plot of mean cfu per plate from the short-term exposure settle plates (15-min stages) during the different drying methods, for each of the stages. It can be observed that for each stage, the average counts on the air blade trial plates were higher than on the paper towel trial plates, though the variation between trial days was greater than that for the results from the long-term exposure plates. This was not unexpected given the extra sampling time of the long-term exposure plates. In essence, however, the short-term exposure plates indicate the same pattern as the results for the long-term exposure plates. The average microbial counts from all the 15-min stages during the hand-drying trials were 38-83 and 62-65 cfu per plate for the paper towels and air blade method, respectively. However, the contamination level was the lowest after the first 15 min, 29-49 cfu per plate for paper towels and 41-00 cfu per plate for the air blade hand dryer.

For the short-term exposure plates, ANOVA analysis on rank of 'cfu per plate' was performed and showed statistically significant evidence (*P*-value < 0.001) of 'day' effect. There was also statistically significant evidence (*P*-value = 0.017) of differences between each 15 min stage (1st, 2nd, 3rd and 4th), which illustrates the buildup of micro-organism levels in the room during each trial. There was statistically significant evidence (*P*value = 0.042) of differences between drying methods within each zone and stage (*P*-value = 0.039), with the air blade drying method having higher settle plate counts.

The effect of days cannot be overcome because each day people may have a different level of contamination on their skin and clothing. The high amount of volunteers (100) should be sufficient to include people with different levels of micro-organisms during each drying method.

#### Air contamination – air impaction samples

The individual results for each drying method (CFU  $m^{-3}$ ) during the trial for both the close and far air sampler posi-



Figure 4 Mean cfu per plate results  $\pm$  one standard error in each zone, for both drying methods during each day.



The mean surface sampling results for the different drying methods, after 0, 50 and 100 people washed and dried their hands, are shown in Table 1. All the results were expressed as mean log cfu per 25 cm<sup>2</sup>; however, some of the sampling points had 100 cm<sup>2</sup> as well as 25 cm<sup>2</sup> areas sampled (walls and sink; see Table 1); therefore, the limit of detection for this sampling points was lower (0.398 log cfu per 25 cm<sup>2</sup>) than for the sampling points where only 25 cm<sup>2</sup> areas were swabbed (0.699 log cfu per 25 cm<sup>2</sup>). The average results from the samples taken before the trial were close to the minimum detection levels, which indicates that all surfaces were clean before the experiment.

When analysing microbial levels on the sink and soap dispenser surfaces, the results showed an approx.  $0.8 \log$ increase in counts for the soap dispenser and approx. 1.8log increase for the sink, after 100 people. There was no statistical difference (*P*-value = 0.45) between drying methods, but there was a statistically significant effect (*P*-value < 0.001) of the number of people in the room. This indicates that micro-organism levels on the sink surfaces increased after people started using it. The increase in microbial level was the same for both drying methods, which indicates that microbial levels on people's hands during each day of the trial were similar.

The mean log cfu 25  $\text{cm}^{-2}$  values on the wall close to and far from the location of the hand-drying event are also shown in Table 1. When assessing microbial numbers in terms of their potential risk to a process or event, differences in microbial counts of greater than one log order are generally required to be considered of practical significance. The contamination level on the walls was found to be not of practical difference from control values prior to hand drying. It was found that when using the air blade hand dryer, however, on the wall close to the drying equipment, after 50 people had dried their hands, contamination levels in excess of one log order greater than control values were recorded (1.773 log cfu per 25 cm<sup>2</sup>). There was some evidence, therefore, to suggest that the contamination of the wall area close to the hand-drying event was greater than far from the drying equipment. From the trials undertaken, however, this contamination was not consistent and appeared not to be practically significant after 100 hand washes.

It was noted that counts on the wall 230 cm away from the hand-drying event (wall far) were very low for both hand-drying methods, and only five individual swab counts were in excess of control values. There was no





**Figure 5** Interval plot of mean cfu per plate short-time exposure plate results within each day and stage, for both drying methods. [( $\bullet$ ) air blade dryer; ( $\oplus$ ) paper towels] during each day (95% CI for the mean).

tions are shown in Fig. 6. ANOVA analysis on control samples (taken before each trial) showed that there was no statistically significant difference (P = 0.966) between microbial numbers before the start of each trial for different drying methods, at different air sampler positions and for different days. The average number of micro-organisms for controls was 15.95 cfu m<sup>-3</sup>. This confirms the effectiveness of the air flushing of the room prior to commencement of the trial. It can be noted that, at each sampling position and throughout the trial, differences were seen between the drying methods in microbial counts; however, there was also a difference between days within each drying method. Therefore, ANOVA analysis was applied to determine any significant effect on the number of micro-organisms in the air when using different drying methods. The results showed that there was no statistically significant difference between the method of drying, and most of the variation in microbial count was due to the effect of the random factor, that is, day, people movement, etc. The results showed, however, how fast, after starting hand washing and drying activities, the microbial level in the washroom increased. After just 3 min, the counts reached 410 cfu m<sup>-3</sup> for the close position and 490 cfu  $m^{-3}$  for the far position of the sampling equipment. At the end of the trial, the maximum counts were 1435 cfu  $m^{-3} \mbox{ and } 1200 \mbox{ cfu } m^{-3} \mbox{ for the plates taken close to and }$ far from the hand-drying equipment, respectively.

#### Surfaces – swabs

The effect of the two drying methods on the contamination of surfaces surrounding the drying equipment (walls close to and far from the equipment) was investigated by taking swab samples. Also the contamination of the drying equipment itself (bin and paper dispenser, back and front panel of air blade dryer) was studied. The samples

	Drying method								
	Air blade			Paper towels					
	Mean log cfu 25	$\rm cm^{-2}$ (SD)		Mean log cfu 25 cm $^{-2}$ (SD)					
Location	0 people	50 people	100 people	0 people	50 people	100 people			
Soap dispenser	<0.699 (0.00)	1.256 (0.79)	1.659 (0.74)	<0.699 (0.00)	1.088 (0.55)	1.204 (0.60)			
Sink*	0.595 (0.41)	1.962 (1.14)	2.452 (1.11)	0.448 (0.40)	1.894 (0.52)	2.216 (0.65)			
Wall close*	<0.398 (0.33)	1.773 (1.73)	0.787 (0.44)	<0.398 (0.33)	0.514 (0.33)	<0.398 (0.33)			
Wall far*	0.731 (0.57)	0.477 (0.30)	<0.398 (0.33)	<0.398 (0.33)	<0.398 (0.33)	0.777 (0.43)			
Air blade back panel	0.879 (0.44)	3.272 (0.19)	2.781 (1.03)	_	_	_			
Air blade front panel	0.815 (0.29)	3.133 (0.60)	3.176 (0.25)	_	_	_			
Paper towel dispenser*	_	_	_	<0.699 (0.00)	1.104 (0.63)	1.224 (0.83)			
Paper towel bin	_	_	_	1.211 (0.49)	2.627 (0.80)	2.160 (0.85)			

**Table 1** Swab samples results expressed as log cfu per 25 cm<sup>2</sup> on all surfaces sampled over both hand-drying techniques, after various numbers of people. The data are presented as mean (standard deviation)

\*The areas sampled here were 25 and 100 cm<sup>2</sup>. The other locations had only 25 cm<sup>2</sup> areas swabbed.

indication, therefore, that for either hand-drying methods, there was any spread of contamination at a practically significant level to wall surfaces at distances away from the hand-drying event.

The hand-drying equipment was swabbed at two locations for each drying method. As each piece of drying equipment was only used for one drying method, it was not possible to directly compare the effect of contamination of the equipment. It was, however, possible to investigate separately, for each drying method, the effect on equipment contamination dependent of the number of people using the equipment.

The mean results of log cfu per 25 cm<sup>2</sup> on the bin and dispenser are also shown in Table 1. The results show that after people had dried their hands, the level of contamination on the bin, positioned to allow volunteers to dispose of the paper towels they had used, increased. The level of micro-organisms after 50 people washed their hands was 2.627 log cfu per  $25 \text{ cm}^2$  which was 1.416 log cfu per  $25 \text{ cm}^2$  in excess of control values. As the bin was positioned directly below the hand towel dispenser, it was not clear whether such contamination was derived from water splashes or hand contact with the bin during towel disposal. It may be possible to mitigate the increase in microbial count on the bin by positioning the bin further away from the hand-drying event (not directly below the dispenser).

The mean results of log (cfu per 25 cm<sup>2</sup>) on the paper dispenser after 0, 50 and 100 people washed and dried their hands are shown in Table 1. On four occasions, contamination on the paper towel dispenser was in excess of control values, though on average, all microbial counts following hand-drying events were less than one log order above such control values (0.405 log cfu per 25 cm<sup>2</sup> and

0.525 log cfu per 25 cm<sup>2</sup> in excess of the control values after 50 and 100 people, respectively). It is unlikely, therefore, that the paper towel dispenser would routinely act as a cross-contamination vector to users.

The mean results of log cfu per 25 cm<sup>2</sup> on the front and back panel of the air blade dryer are shown in Table 1. On all sampling occasions following 50 and 100 hand-drying events, the level of micro-organisms on the front panel of the air blade dryer was greater than control values (on average 2.318 and 2.361 log cfu per 25 cm<sup>2</sup> in excess of control values after 50 and 100 people, respectively) by more than one log order.

Similarly, on all sampling occasions following 50 and 100 hand-drying events, the level of micro-organisms on the back panel of the air blade dryer was greater than control values (in average, 2.393 and 1.902 log cfu per 25 cm<sup>2</sup> in excess of control values after 50 and 100 people, respectively) by more than one log order.

For both the front and back panel, however, the relationship between the number of users and the level of contamination were unclear. For example, contamination does not always increase from 50 to 100 users, suggesting that the specific level of contamination of the dryer surfaces was a random event, most likely related to individual hand contact with the machine surface rather than the number of drying uses.

#### All coliforms

Over all trials on all days, the number of coliforms obtained for all swabbing positions and all settle plates did not result in statistical significance as most of the counts were below the detection limits for swabs and zero for settle plates. Only two exceptions were noted: a bin swab count after 50 people and an air blade front panel swab count after 50 people where swab results were 1.0 and 1.6 log cfu per 25 cm<sup>2</sup>, respectively.

#### Discussion

The aim of the study was to analyse the difference in microbial contamination of the washroom environment generated by two different hand-drying methods; any possible differences in hand-drying efficacy were not examined. Few, if any, published reports have considered the route of micro-organisms naturally present on people's hands, from their hands to the surrounding environment during the drying process. Campden BRI has previously conducted a series of experiments to assess the generation and spread of microbial aerosols by different hand-drying techniques (unpublished report). The results from ballistic droplets generation confirm the results obtained previously, where the water droplets generated by the air blade dryer extended to at least 2 m to the sides of the equipment. In the previous studies, there were no practical differences between any of the handdrying techniques investigated with regard to microbial aerosol generation, and all the counts were very low (maximum 14 cfu per plate). This may be due to a smaller number of volunteers (5) used in the previous studies comparing to the described studies (100). Several studies have focused on the comparison of the contamination of the surrounding environment caused by paper towels and hot air dryers (Huang et al. 2012); however, a limited number of studies have focused on air blade dryers. Redway and Fawdar (2008) investigated the spread of artificial contamination via different drying methods and concluded that micro-organisms were spread significantly further when using an air blade dryer rather than paper towels. The European Tissue Paper Industry Association (2012) funded research focused on investigating the contamination levels of washrooms with paper towels and air blade dryers installed. The total microbial count on the washrooms' floors where an air blade dryer was installed was  $4.44 \times 10^5$  cfu per 100 cm<sup>2</sup> higher that in the washrooms where paper towels were used. This amount is higher than in this work; however, the experimental conditions differ significantly, with our studies being conducted in the laboratory and the other in a real washroom environment.

It was found that both the air blade and paper towel methods produced ballistic droplets when used to dry hands, particularly close to the hand-drying event. These droplets have the potential to carry skin flora, which may contain pathogens. It was found that the ballistic droplets number and distance of travel were slightly higher for the air blade unit. There were differences between each volunteer; this may have been due to differences in skin, body temperature and technique of hand drying. However, results from 15 volunteers should be reflective of general water droplet distribution. On a more practical level, the droplet distribution patterns shown in Fig. 2 could help installers to position hand dryers so that droplets are not spread to, for example, subsequent hand contact points in washrooms, exposed food products in food-handling areas or patients in a clinical setting.

Settle plates left for the duration of the trials (1 h) showed that, for all four zones, the counts of microorganisms on the air blade settle plates were higher than for paper towels. Whilst the average difference in count per individual settle plate was only approx. 60 colonies, over the whole of the laboratory floor, it can be estimated, that there could be approx.  $1.7 \times 10^5$  cfu more micro-organisms deposited following air blade hand drying than when using paper towels. This is not significant if only nonpathogenic micro-organisms are spread; however, it may increase the risk of pathogen contamination of the environment when pathogens are occasionally present on people's hands. There was no statistical difference between micro-organism levels in zone 1 when comparing the two drying methods, and on average, the contamination in zone 1 was higher than in the other zones. This may not be surprising as most of the ballistic droplets generated for both drying methods were found to fall in this zone in the preliminary trials (Fig. 2). The microbial levels on settle plates follow a similar pattern to the ballistic droplets, suggesting that water droplets transfer micro-organisms from people's hands to the environment. The results for the shortterm exposure settle plates broadly reflect the results for the long-term exposure plates and show a gradual increase in micro-organism level on the floor, during the trial.

On each trial day, it was recognised that there was inherent variability in the volunteers; they were wearing different clothes and they had undertaken different tasks prior to the trial (e.g. engineers, lab technicians and office staff). Such variation within the volunteers could potentially affect their level of microbial contamination and therefore their ability to shed micro-organisms to the laboratory environment. However, to overcome this variable, the number of volunteers was very high (100), the results were reported separately for each trial day, and microbiological levels were monitored on the sink and soap dispenser to make sure they were similar for each trial. Microbiological levels increased on the sink and soap dispensers as they were used by people during the trial, indicating, as expected, a degree of microbial contamination on the volunteers' hands. There was no statistical

Assessing hand-drying contamination

difference between the levels of micro-organisms on the sink and soap dispenser during all four trial days, suggesting that the level of contamination on the volunteers' hands each day would be unlikely to significantly affect the outcome of the hand-drying assessment. Surface swabbing of the walls suggested that contamination of the wall area close to the hand-drying event was greater, particularly following air blade drying. From the trials undertaken, however, this contamination was not consistent following all hand-drying events. There was no indication that for either hand-drying method, there was any spread of contamination of practical significance to wall surfaces at distances away from the hand-drying event.

The bin for receiving used paper towels, placed directly below the hand towel dispenser, showed microbial contamination levels in excess of 1 log greater than control values and cross-contamination to personnel who could make inadvertent contact with the bin could be possible. There was little evidence of microbial contamination of the paper towel dispenser during use. Whilst the paper towel collection bin showed an increase in microbial levels, it was not clear if such contamination was derived from water splashes or hand contact with the bin during towel disposal and therefore whether positioning the bin further away from the hand-drying event would mitigate such microbial increase.

On all sampling occasions following 50 and 100 handdrying events, the level of micro-organisms on the front and back panels of the air blade dryer was in excess of one log order (and on most sampling occasions in excess of two log orders) greater than control values. Microbial contamination on the front and back panel could therefore potentially form a cross-contamination risk to dryer users. The specific level of contamination of the dryer surfaces was probably a random event, related to individual hand contact with the machine surface rather than the number of volunteers using the dryer. Microbial levels were considerably higher on the air blade than the towel dispenser and could suggest a cross-contamination risk to air blade users. However, the level of cross-contamination risk was impossible to compare directly between these two pieces of equipment because they are used in different ways by the washroom users.

Air impaction sampling showed no significant evidence of any difference between the methods of hand drying with respect to airborne microbial counts. The fact that the level of micro-organisms in the air for both drying methods was similar is not surprising as the air samplers were primarily detecting microbial aerosols that were not carried on ballistic droplets following hand drying – microbial sampling of the floor is more likely to establish ballistic microbiological counts. Nonballistic microbial aerosols could be generated by hand drying, but could also be generated by person movements and hand washing. As they are not ballistic, they are also dependent on air movements in the sampling room for their positional orientation and, as 100 people moved around the laboratory during the sampling period, such air movements in the room were likely to be considerable. Air impaction results were therefore likely to be reflective of the effects of the actions and movements of 100 people in a confined laboratory space rather than any effects of handdrying method. From the air impaction samples results, it can be also seen that the microbial level in the room's air rises rapidly after a few minutes of hand washing/ drying activities.

Overall, this work has shown evidence that the air blade produces more ballistic droplets which are spread further and may carry micro-organisms, than drying with paper towels. There was no evidence that there were any differences between the methods with respect to micro-organisms carried by nonballistic aerosols. Microbial levels on the equipment were higher for the air blade dryer; however, this may not indicate that the risk of cross contamination is also higher due to the different procedures used for each hand-drying method. The study suggests that when selecting a hand-drying method, the risk of cross contamination of micro-organisms to washroom users and the environment must be considered, and the methods to control this risk must be established.

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#### ORIGINAL ARTICLE

## Evaluation of the potential for virus dispersal during hand drying: a comparison of three methods

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#### Keywords

aerosolization, cross-contamination, dispersal, hand drying, hand hygiene, MS2 bacteriophage, virus.

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#### Abstract

Aims: To use a MS2 bacteriophage model to compare three hand-drying methods, paper towels (PT), a warm air dryer (WAD) and a jet air dryer (JAD), for their potential to disperse viruses and contaminate the immediate environment during use.

Methods and Results: Participants washed their gloved hands with a suspension of MS2 bacteriophage and hands were dried with one of the three hand-drying devices. The quantity of MS2 present in the areas around each device was determined using a plaque assay. Samples were collected from plates containing the indicator strain, placed at varying heights and distances and also from the air. Over a height range of 0.15-1.65 m, the JAD dispersed an average of >60 and >1300-fold more plaque-forming units (PFU) compared to the WAD and PT (P < 0.0001), respectively. The JAD dispersed an average of >20 and >190-fold more PFU in total compared to WAD and PT at all distances tested up to 3 m (P < 0.01) respectively. Air samples collected around each device 15 min after use indicated that the JAD dispersed an average of >50 and >100-fold more PFU compared to the WAD and PT (P < 0.001), respectively.

**Conclusions:** Use of the JAD lead to significantly greater and further dispersal of MS2 bacteriophage from artificially contaminated hands when compared to the WAD and PT.

**Significance and Impact of Study:** The choice of hand-drying device should be considered carefully in areas where infection prevention concerns are paramount, such as healthcare settings and the food industry.

#### Introduction

The importance of hand hygiene in minimizing the risk of transmission of pathogenic micro-organisms has been recognized since Semmelweis's work on puerperal fever transmission (Codell Carter 1983). Hand hygiene is considered to be an integral component of the practice of infection control both in the home and in community and healthcare settings (Curtis *et al.* 2003; Bloomfield *et al.* 2007). It has been estimated that cross-infection contributes to 40% of cases of healthcare-associated infections and hand hygiene compliance represents an essential step in minimizing such infections (Pittet 2000; Weist *et al.* 2002; Pittet *et al.* 2006). Hand hygiene

comprises two different possible procedures; decontamination using a hand sanitizer, such as alcohol, or washing with soap and water and, with the latter, drying of the hands by various methods.

In healthcare settings, the appropriate cleansing of the hands of staff or visitors prior to, or after, certain procedures is of particular importance and various guidelines on hand washing and cleansing have been issued by the CDC (Centers for Disease Control and Prevention 2002), the NHS (National Health Service) and the WHO (World Health Organization) (Boyce and Pittet 2002; WHO 2009; NHS Professionals 2013). The WHO guidelines state that water alone is unsuitable for cleaning visibly soiled hands and that soap or detergent must be used as well as water. There has been much research on the effectiveness of soap and other agents in reducing the microbial count of both resident and transient flora on the hands. A study and review of the literature concluded that the main factors affecting bacterial counts on the hands were the hand sanitizer or soap used and the drying method (Montville *et al.* 2002) and that hands which are inadequately dried are more likely to transmit micro-organisms when compared to those which have been completely dried (Patrick *et al.* 1997).

The importance of thorough cleansing of the hands with soap and water or a hand sanitizer to reduce healthcare-associated infections is well documented, having been publicized for years such as by National Health Service poster campaigns and by initiatives such as the Cleanyourhands campaign (Stone *et al.* 2012). However, in reality the general public and some healthcare professionals do not always follow the advice. Washing procedures can be poor and compliance rates low (Knights *et al.* Unpublished data; Anderson *et al.* 2008).

If it is accepted that the hands become contaminated with micro-organisms when using the toilet, these studies would indicate that, due to low compliance rates and inadequate hand cleansing procedures, the majority of persons drying their hands in washrooms are likely to have microbial contamination on their hands when they dry them. This has implications for the aerosolization and dispersal of that contamination by the hand-drying method that is used and the risk of transmission of potentially disease-causing micro-organisms into the washroom environment and to other persons using the washroom.

There are a number of different methods available for hand drying in public washrooms. These include paper towels, continuous roller towels, warm air dryers and jet air dryers. There have been relatively few studies evaluating the capacity for the different hand-drying devices to aerosolize and disperse microbial contamination on the hands into the immediate environment and to other persons using a washroom. Matthews and Newsom (1987) concluded that there was no significant difference between warm air dryers and paper towels in terms of aerosol liberation and that the former could be considered safe but Ngeow et al. (1989) demonstrated the dispersal of marker bacteria within a radius of 1 m from a warm air dryer. When comparing the use of paper towels with a jet air dryer to dry the hands of 100 volunteers, Margas et al. (2013) showed that the two hand-drying methods produced different patterns of ballistic droplets: the jet air dryer producing a greater number of droplets dispersed over a larger area and more microbial contamination of the immediate environment than paper towels. Best et al. (2014) used a paint and a Lactobacillus bacterial model to compare aerosolization and dispersal following hand drying with paper towels, a warm air or jet air dryer. They showed that paper towels produced less dispersal from the hands into the surrounding environment than jet air dryers. Using an acid-indicator model and artificial contamination of the hands with yeast, Best and Redway (2015) demonstrated that the use of a jet air dryer to dry the hands dispersed liquid, and, consequently, potential microbial contamination on the hands, to greater distances (up to 1.5 m) than paper towels, roller towels or warm air drvers (up to 0.75 m). In the same study, jet air dryers were also shown to disperse more liquid from the hands to a range of different heights compared to the other hand-drying methods. However, such studies have focused on micro-organisms other than viruses and to date there have been few studies to evaluate the aerosolization and dispersal of virus particles during hand drying.

Viral pathogens such as Norovirus are thought to have a low infectious dose and can be shed in large numbers in faeces (Gerhardts *et al.* 2012). In a review, Kampf and Kramer (2004) cited studies that show that viruses can survive on the hands for varying times; Influenza and CMV (10–15 min), HSV (up to 2 h), Adenovirus (for many hours), Rhinovirus (7 days) and Rotavirus and HAV (up to 60 days). Therefore, virus dispersal in the washroom has the potential to contaminate persons and surfaces, including those of hand-drying devices.

This study used bacteriophage MS2 as a surrogate for nonenveloped human viruses. MS2 has been used in this way in a number of prior studies due to its stability and similar characteristics to human enteric viruses such as Picornaviruses and Caliciviruses, including Norovirus (Sickbert-Bennett *et al.* 2005; Gerhardts *et al.* 2012). Additionally, MS2 has the added advantage in that virus numbers can be readily quantified using a plaque assay. In this work, the capacity for three hand-drying devices, namely paper towels, a warm air dryer and a jet air dryer, to aerosolize and disperse water on the hands, and contaminate the air and surfaces around the drying device with MS2 phage was investigated.

#### Materials and methods

#### Preparation and use of MS2 bacteriophage

MS2 bacteriophage (ATCC 15597-B1) was propagated at 37°C overnight in log phase tryptone soya broth (Oxoid, Basingstoke, UK) cultures of *Escherichia coli* (ATCC 15597) to yield a mean count in the range of  $10^{10}$  plaque-forming units (PFU) per mL. Following infection, nonlysed bacteria were removed by centrifugation (3000 **g**, 10 min) and the supernatant phage suspension

generated was used in subsequent experiments. Each batch of phage suspension was titrated on the same day as experiments were performed to ensure that approximately equal numbers of phage particles were used each time. Participants were asked to rinse their gloved hands in 50 ml of the phage suspension for 10 s and simulate the process of washing during this period followed by shaking three times and then drying them using one of the hand-drying devices. All experimental work took place in a university teaching laboratory and the washing and drying areas were separated by a distance of approx. 5 m.

For quantitative detection of MS2 phage, plates of tryptone soya agar (TSA) (Oxoid) were overlaid with a thin layer of 0.5% sloppy TSA containing 1% (v/v) log phase *Escherichia coli* (ATCC 15597). Dispersal experiments were performed and, following incubation overnight at  $37^{\circ}$ C, the number of plaque-forming units determined by visualization and counting of plaques.

#### Hand-drying devices

Three hand-drying methods were compared in this study; the use of two paper towels (Wepa Clou Comfort, Arnsberg, Germany) for 10 s, warm air drying (World Dryer Corporation, Berkeley, IL), model LE48 for 20 s and jet air drying (Dyson, Malemsbury, UK), model AB01 for 10 s. Drying times for the paper towel and warm air dryer were based on the mean times recorded during the observation of 292 members of the public in male and female washrooms in various London locations (Knights et al. Unpublished data). The 10-s drying time for the jet air dryer was based on the manufacturer's recommendations displayed on the device. The devices were mounted onto a wooden board placed at a height that would be typical for use in a washroom. The dryers used were not new but had never been used in a washroom and were decontaminated between tests by thorough wiping with 70% (v/v) ethanol.

#### Virus dispersal at different heights and distances

90 mm diameter Petri dishes (Fisher Scientific, Loughborough, UK) containing TSA and an overlay of the *E. coli* host were affixed to a vertical board at intervals of 0.30 m at six different heights (0.15, 0.45, 0.75, 1.05, 1.35 and 1.65 m) from the floor. The agar plates were affixed to the mid-point of six zones (1-6) chosen to represent a typical human torso, including head, trunk and legs, of a person using a washroom (Fig. 1). During tests, the vertical board was held 0.4 m from the hand-drying device; this distance being based on measurement of the mean distance between multiple hand-drying



**Figure 1** Photograph of vertical board with human figures and diagram showing the 6 different height zones and height of mid-point from floor (m) used to assess vertical dispersal.

devices in large public washrooms at a mainline railway station.

#### Air sampling

An Air Trace<sup>®</sup> Environmental air sampler (Biotrace, Runcorn, UK) model ATEM 240 with a 1 m Tygon tube was used to sample air in the vicinity of each hand-drying device at a rate of  $28.3 \text{ l min}^{-1}$ , a total of 424.5 l of airwas sampled. The air was impacted at 70 m s<sup>-1</sup> via a  $44 \times 0.152 \text{ mm}$  slit onto a rotating 140 mm Petri dish (Fisher Scientific) containing 0.5% sloppy TSA with 1% (v/v) log phase *Escherichia coli* (ATCC 15597).

Petri dishes were orientated so that the start point could be determined and sampling was performed over a period of 15 min, after which the plate had made one complete rotation. The air sampler was subjected to a 1-h purge cycle before and after daily use and in between changes of hand-drying device. In addition, a 15-min control air sample was collected before each run or change of hand-drying device. As with the height and distance dispersal experiments, settle plates were placed around each device to confirm that no residual MS2 phage was present at the beginning and end of each test run.

In order to assess virus dispersal in air a method based on that used by Best *et al.* (2014) was employed. The Tygon tube inlet was placed at a height of 1.2 m which corresponded to the height of both the bottom of the paper towel dispenser and the bottom of the warm air dryer and was 0.25 m above the height of the jet air dryer. Air samples were collected at three different positions (Fig. 2):

- i At a distance of 0.1 m from the left and right-hand side of each device;
- ii At a distance of 1 m from the left and right-hand side of each device;
- iii At a 1 m distance behind and offset by 0.3 m from the right-hand side of the device.

Two participants were used and an equal number (10) of samples were taken from the left and right-hand side for each of the distances and positions used. The sequence by which different samples were collected and devices tested was randomised.

After incubation, plates were divided into six sectors, each sector representing a 2·5-min time interval and the number of PFU in each sector was counted. Where plaque formation was confluent, semi-confluent or uncountable, and for calculation purposes, the number of plaques per sector was recorded as follows: confluent plaque formation was scored as 500 per sector; confluent/semi-confluent plaque formation was scored as 400 per sector; semi-confluent plaque formation was scored as 300 per sector; uncountable numbers of plaque were scored as 200 per sector. Uncountable refers to the presence of discrete plaques that were present in high numbers which could not be counted with accuracy.

When necessary to enable visualization of plaques as clear areas against a red background, the plates were flooded with tryptone soya broth (Oxoid) containing 0.1% (w/v) 2,3,5, triphenyltetrazolium chloride (Fisher



Figure 2 Diagram showing the three different air sampling positions used in this study.

Scientific) followed by incubation at 37°C for 20 min (Pattee 1966).

#### Statistical analysis

Data from plaque assays were analysed by Students *t*-test using MICROSOFT EXCEL (Microsoft, Redmond, WA), with a confidence interval of 95%. A P value of <0.05 was used to denote statistical significance.

#### Results

#### Virus dispersal at different heights

The vertical board with attached Petri dishes was divided into six zones to compare virus dispersal at a range of heights covering a range of 0.15-1.65 m (Fig. 1). For each of the six zones, a total of at least ten replicates were used for each hand-drying device performed approximately equally on the left and right-hand side of the device.

The jet air dryer dispersed a significantly greater number of virus particles than the other hand-drying devices (Table 1). The greatest mean number of PFU was observed in zones 3 (0.75 m) and 4 (1.05 m), 710 and 834 PFU respectively. These two zones represented nearly 70% of the total detected virus dispersed by the jet air dryer. In contrast, the warm air dryer dispersed a mean of 5 PFU in zone 4, 167-fold lower than the jet air dryer and with the difference being significant (P < 0.0001). Paper towels dispersed a mean of 0.1 PFU in zone 4, 8340-fold lower than the jet air dryer (P < 0.0001). Control samples collected with the devices switched off and

 Table 1
 Counts of viral plaques on 90 mm agar plates of a bacterial lawn at different heights at a set distance (0.4 m) from hand-drying devices used to dry the hands of participants after contamination with a bacteriophage suspension. Data are presented as means with standard deviation in parentheses

	Hoight	Mean number of plaques (SD)						
Height zone	from floor (m)	Paper towel	Warm air dryer	Jet air dryer				
1	1.65	0.5 (1.0)	0.7 (1.7)	248.9 (309.6)				
2	1.35	0.7 (1.6)	8.7 (10.7)	335.9 (285.0)				
3	1.05	0.1 (0.3)	4.6 (4.9)	709.5 (331.9)				
4	0.75	0.1 (0.3)	5.4 (6.5)	833.6 (258.3)				
5	0.45	0.1 (0.3)	3.9 (4.5)	63.9 (89.7)				
6	0.15	0.1 (0.3)	11.1 (14.6)	26.9 (44.4)				
Ν		11	11	11				
Mean total number (all heights)		1.6	34.4	2218.7				

performed before and after each experiment yielded no plaques.

#### Virus dispersal at different distances

Comparisons of virus dispersal at varying distances from the hand-drying device were performed using Petri dishes placed on a vertical surface at 0.25–0.5 m intervals and ten replicates were assayed for each distance point, performed equally on the left and right-hand side of the device. Distances from 0 to 3 m were compared and at

**Table 2** Counts of viral plaques on 90 mm agar plates of a bacterial lawn at a set height (0.71 m) and at different distances from handdrying devices used to dry the hands of participants after contamination with a bacteriophage suspension. Data are presented as means with standard deviation in parentheses

Distanco	Mean number of plaques (SD)						
from device (m)	Paper towel	Warm air dryer	Jet air dryer				
0.00	13.2 (8.4)	50.2 (26.1)	565.5 (427.1)				
0.25	0.0 (0.0)	49.0 (31.3)	924.0 (194.6)				
0.50	0.0 (0.0)	3.8 (2.3)	546.8 (428.5)				
0.75	0.0 (0.0)	1.1 (1.4)	322.1 (319.4)				
1.00	2.0 (2.8)	0.2 (0.4)	212.3 (224.5)				
1.50	0.2 (0.4)	0.2 (0.4)	214.3 (190.8)				
2.00	0.0 (0.0)	0.0 (0.0)	184.5 (215.0)				
2.50	0.0 (0.0)	0.0 (0.0)	179.9 (205.1)				
3.00	0.0 (0.0)	0.3 (0.6)	177.4 (243.5)				
Ν	10	10	20				
Mean total number (all distances)	15.4	103.7	3004.5				



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all distances tested the jet air dryer dispersed significantly greater (P < 0.01) numbers of virus particles than either the warm air dryer or paper towel devices (Table 2). For the jet air dryer, the maximum mean number of PFU was seen 0.25 m from the device and there was a decline in PFU with increasing distance from the device. However, the mean number of PFU observed 3 m from the device was more than 500-fold greater than that for the warm air dryer and paper towel devices (Fig. 3). Control samples collected with the device switched off and performed before and after each experiment yielded no plaques.

#### Air sampling

For all three devices, PFU counts were generally greater when air samples were collected closer to the device, in this case 0.1 m compared to 1 m (Table 3) and the number of detectable PFU decreased over time (Fig. 4). However, airborne virus counts for the jet air dryer were significantly greater (P < 0.001) than those for the warm air dryer and paper towel devices for each position and for each time interval.

For the jet air dryer, during the immediate 2.5 min after use and at 0.1 m from the device, 30-fold and 13fold more PFU were detected in air compared to the warm air dryer and paper towel devices respectively (between which there was no significant difference). For the last time period (12.5–15 min) after hand drying, more than 50-fold numbers of PFU were detected when the jet air dryer was tested at any of the three sample positions used compared to paper towels and the warm air dryer. The number of PFU detected in the air from the jet air

**Table 3** Counts of viral plaques produced by air sampling at three different positions onto 140 mm agar plates of a bacterial lawn at different times over a 15-min period after use of hand-drying devices to dry the hands of participants subsequent to contamination with a bacteriophage suspension

			Mean number of plaques (SD)					
Time (min)	Distance (m)	Position	Paper towel	Warm air dryer	Jet air dryer			
0.0–2.5	0.1	L & R	36.7 (24.5)	15.9 (12.6)	470.0 (45.8)			
	1.0	L & R	17.8 (21.5)	9.2 (10.0)	350.0 (102.5)			
	1.0/0.3 B		6.9 (8.8)	9.1 (8.2)	343.0 (79.0)			
	Mean total (L, R & B)		20.5 (23.1)	11.4 (10.9)	387.7 (97.8)			
	Max/Min		79.0/0.0	35.0/0.0	500.0/200.0			
2.5-5.0	0.1		5.2 (3.8)	4.4 (3.5)	235.7 (50.0)			
	1.0		6.8 (6.5)	5.2 (7.5)	200.0 (0.0)			
	1.0/0.3		3.7 (3.8)	7.3 (8.6)	230.0 (45.8)			
	Mean total (L, R & B)		5.2 (5.1)	5.6 (7.0)	226.7 (42.8)			
	Max/Min		19.0/0.0	27.0/0.0	300.0/200.0			
5.0-7.5	0.1		4.2 (4.5)	2.2 (2.6)	179.8 (61.0)			
	1.0		2.3 (4.0)	1.9 (2.5)	134.5 (61.5)			
	1.0/0.3		2.7 (2.9)	5.5 (5.2)	122.0 (60.4)			
	Mean total (L, R & B)		3.1 (3.9)	3.2 (4.0)	145.4 (66.1)			
	Max/Min		13.0/0.0	16.0/0.0	300.0/18.0			
7.5–10.0	0.1		1.8 (1.9)	2.7 (2.2)	101.2 (47.1)			
	1.0		1.9 (2.8)	1.0 (0.9)	85.8 (66.1)			
	1.0/0.3		2.4 (3.0)	1.2 (1.5)	70.3 (63.4)			
	Mean total (L, R & B)		2.0 (2.6)	1.6 (1.8)	85.8 (61.7)			
	Max/Min		9.0/0.0	5.0/0.0	200.0/4.0			
10.0-12.5	0.1		1.1 (2.7)	1.8 (2.5)	57.2 (54.2)			
	1.0		0.9 (1.6)	0.8 (1.5)	46.5 (36.0)			
	1.0/0.3		0.4 (0.9)	1.9 (2.3)	43.9 (45.8)			
	Mean total (L, R & B)		0.8 (23.1)	1.5 (2.2)	49.2 (47.1)			
	Max/Min		9.0/0.0	8.0/0.0	200.0/2.0			
12.5–15.0	0.1		0.0 (0.0)	1.4 (2.1)	61.0 (48.2)			
	1.0		1.0 (2.0)	0.5 (1.2)	38.5 (31.8)			
	1.0/0.3		0.1 (0.3)	0.6 (1.2)	31.8 (38.0)			
	Mean total (L, R & B)		0.4 (1.3)	0.8 (1.6)	43.8 (42.5)			
	Max/Min		6.0/0.0	6.0/0.0	186.0/0.0			

Data are presented as means with standard deviation in parentheses. L, left-hand side of device; R, right-hand side of device; B, 1 m behind device with 0.3 m offset; Max, maximum plaque count; Min, minimum plaque count; N, 30 (5 for each position and time period).

Confluent plaque formation was scored as 500 per sector.

Confluent/semi-confluent plaque formation was scored as 400 per sector.

Semi-confluent plaques formation was scored as 300 per sector.

Uncountable plaque formation was scored as 200 per sector.

dryer showed exponential decline with an acceptable coefficient of determination  $(R^2)$  of 0.9781.

When drying hands using paper towels, virus counts in the air to the sides of the device were slightly higher than those obtained using a warm air dryer for most of the time periods but this difference was not statistically significant. Additionally, sampling at 1 m offset by 0.3 m behind the device produced no statistical difference between paper towels and warm air drying. Control samples run before and after each experiment yielded no plaques and no differences could be detected between sampling on the left or right-hand side of any of the hand-drying devices.

#### Discussion

When the three hand-drying devices were compared in this study, there were clear differences in the extent of virus dispersal from the hands. This was evident from the results of the experiments in which MS2 was dispersed from the hands and transferred onto agar plates affixed at varying heights and distances from the hand-drying devices and also into the air as sampled at three different positions in the vicinity of the device. In each case, the jet air dryer produced significantly greater virus dispersal compared to the warm air dryer and paper towel devices. Combined results for all six heights tested showed that



the jet air dryer produced over 60 times more viral plaques than the warm air dryer, and over 1300 times more than paper towels (P < 0.0001). The maximum numbers of plaques detected were at a height range of 0.75-1.25 m which would equate to the height of the face of a small child standing near the device when operated by their parent. Virus dispersal was detected up to 3 m from the jet air dryer. Combined results for all nine distances tested showed that the jet air dryer produced over 20 times more viral plaques than the warm air dryer, and over 190 times more than paper towels (P < 0.01). Combined results for the air counts after 15 min at the three sampling positions showed that the jet air dryer produced over 50 times more viral plaques than the warm air dryer, and over 100 times more than paper towels (P < 0.001). The number of PFU detected in the air showed exponential decline which would suggest that virus would still be present in the air beyond the 15-min period used in this study.

These differences in results between the three handdrying devices can be largely explained by their mode of drying the hands: paper towels remove water by absorption; warm air dryers of the type tested remove water mainly by evaporation (Huang *et al.* 2012); jet air dryers remove water by shearing forces and dispersal into the air (Snelling *et al.* 2010). Furthermore, the use of paper towels produces relatively little air movement and, while warm air dryers produce more, the air movement is mainly downwards. In contrast, jet air dryers generate air speeds which are claimed to be over 600 kph and the movement of air out of the chamber of the device is sideways.

This study used a standardized method of hand drying and so did not take into account the variations in individual behaviour, or the behaviour of participants outside

**Figure 4** Graph of mean number of viral plaques per 140 mm bacterial overlay agar plate detected by air sampling over 15 min at 2.5-min time intervals after use of three hand-drying devices: jet air dryer ( $\bullet$ ); warm air dryer ( $\blacksquare$ ); paper towel ( $\blacktriangle$ ). Standard error bars and exponential trendline (—) are shown.

of the laboratory. Both participants were of a similar height and the effect of a user's physical dimensions on virus dispersal, particularly the distribution of plaques onto different height zones (Fig. 1) was not addressed. Gloved hands were artificially contaminated with a relatively high concentration of MS2 but the inoculum was standardized for all three hand-drying methods. When counting plaques, for plate sectors that were confluent, confluent/semiconfluent or semi-confluent or over 200 (the limit of the counting method) it is likely that the numbers of PFU assigned to such plate sectors (500, 400, 300 and 200 respectively) underestimated the true numbers of plaques present. Finally, it is acknowledged that only one example of each type of hand-drying device was tested.

A high bacteriophage concentration of  $\sim 10^{10}$  PFU ml<sup>-1</sup> was used in this study but work on the shedding of Rotavirus and Norovirus indicate that similar levels, or greater, can be present in faeces during gastro-intestinal infections (Ward et al. 1984; Atmar et al. 2008) and, therefore, also on contaminated hands which have not been washed, or washed inadequately. Although a bacteriophage model was used to demonstrate aerosolization and dispersal by three hand-drying methods, the implications for the transmission of actual viral pathogens in washrooms are clear. The jet air dryer produced significantly greater dispersal at different heights and different distances than the warm air dryer or paper towels. The jet air dryer also produced significantly greater aerosolization of virus on the hands than the other two hand-drying methods, with virus being detected 15 min after use. The results of this study suggest that in locations where hygiene and cross-infection considerations are paramount, such as healthcare settings and the food industry, the choice of hand-drying method should be considered carefully.

#### **Conflict of Interest**

This study was independently funded in full from a University of Westminster research reserve account. Keith Redway has received honoraria from the European Tissue Symposium for microbiological advice and travel expenses to attend meetings and conferences.

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# Environmental contamination by bacteria in hospital washrooms according to hand-drying method: a multi-centre study

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#### SUMMARY

**Background:** Hand hygiene is a fundamental component of infection prevention, but few studies have examined whether hand-drying method affects the risk of dissemination of potential pathogens.

*Aim:* To perform a multi-centre, internal-crossover study comparing bacterial contamination levels in washrooms with hand-drying by either paper towels (PT) or jet air dryer (JAD; Dyson).

*Methods:* A total of 120 sampling sessions occurred over 12 weeks in each of three hospitals (UK, France, Italy). Bacteria were cultured from air, multiple surfaces, and dust. Washroom footfall (patients/visitors/staff) was monitored externally.

**Findings:** Footfall was nine times higher in UK washrooms. Bacterial contamination was lower in PT versus JAD washrooms; contamination was similar in France and the UK, but markedly lower in Italian washrooms. Total bacterial recovery was significantly greater from JAD versus PT dispenser surfaces at all sites (median: 100–300 vs 0–10 cfu; all P < 0.0001). In the UK and France, significantly more bacteria were recovered from JAD washroom floors (median: 24 vs 191 cfu, P < 0.0001). UK meticillin-susceptible *Staphylococcus aureus* recovery was three times more frequent and six-fold higher for JAD vs PT surfaces (both P < 0.0001). UK meticillin-resistant *S. aureus* recovery was three times more frequent (21 vs 7 cfu) from JAD versus PT surfaces or floors. Significantly more enterococci and extended-spectrum  $\beta$ -lactamase (ESBL)-producing bacteria were recovered from UK JAD versus PT washroom floors (P < 0.0001). In France, ESBL-producing bacteria were recovered from dust twice as often during JAD versus PT use.

**Conclusion:** Multiple examples of significant differences in surface bacterial contamination, including by faecal and antibiotic-resistant bacteria, were observed, with higher

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levels in JAD versus PT washrooms. Hand-drying method affects the risk of (airborne) dissemination of bacteria in real-world settings.

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#### Introduction

Hand hygiene is a crucial component for controlling the spread of infection. It is an important public health measure to raise awareness of the necessity for optimal hand hygiene [1,2]. Whereas there are advised methods, guidelines and products in place for handwashing or decontamination according to setting, less attention is paid to the importance of optimal hand-drying. The effectiveness of hand-drying can play a key role in the prevention of the transfer of micro-organisms between people and in the environment [3]. However, the relative risk of dissemination of micro-organisms — those that are not removed from hands during washing — by wet hands during hand-drying remains uncertain.

There are several methods in use for hand-drying. Paper towels (PTs) or electric warm or jet air dryers (JADs) are the most widely used. PTs absorb excess moisture, whereas JADs rely on a very-high-speed air flow and sheering forces to remove water droplets and so dry hands rapidly (within 15 s) if used correctly [4]. The selection of hand-drying methods may be influenced by cost, service/cleaning issues, footfall, space availability, and access to a power source. In clinical settings, UK National Health Service (NHS) infection control building guidance states that 'Hot-air hand dryers reduce paper waste and may be considered for use in public areas of healthcare facilities, but should not be installed in clinical areas as they are noisy and could disturb patients' [5].

A small number of published studies have investigated the transmission of micro-organisms during different hand-drying methods [6-14]. Several studies have demonstrated that some hand-drying methods are associated with a greater risk of dissemination of residual microbes from hands after (particularly suboptimal) handwashing [9-13]. A recent pilot in-situ study demonstrated the feasibility of testing strategies to examine prospectively the environmental contamination in hospital washrooms that is associated with hand-drying methods, finding that bacterial burdens may be higher with JADs versus PTs, consistent with in-situ testing data [9-13]. Our aim was to perform a multi-centre study across three countries to measure the prevalence of environmental contamination, including by antibiotic-resistant bacteria, in washrooms according to hand-drying method (PTs vs JADs).

#### Methods

#### Locations for testing

Two different washrooms were selected for testing at each of three hospital locations (UK, France, and Italy). In the UK, two adjacent washrooms (each  $\sim 15 \text{ m}^2$ ) in Leeds General Infirmary were accessed from a large entrance foyer in a main hospital entrance and thoroughfare. Within each foyer there were other facilities, including a food/drink supplier. The male and female washrooms were used by hospital staff, patients,

and visitors. Washroom A contained seven separate toilet cubicles, six washbasins, two wall-mounted JADs, and one PT dispenser. Washroom B contained three separate toilet cubicles, six washbasins, four urinals, two wall-mounted JADs, and one PT dispenser. Both washrooms had PTs and JADs that were equidistant between the door and sinks.

In France, two washrooms were used at the Hospital Saint-Antoine. Washrooms A and B were ~4 and ~9 m<sup>2</sup>, respectively. Washroom A had one sink and one toilet; washroom B contained two sinks and two toilets. Both washrooms had one wall-mounted JAD and a PT dispenser. Both washrooms were accessed from a reception area and patient waiting area, and were used by patients, healthcare workers, and visitors, but were in different buildings.

In Italy, two washrooms were used at the Hospital of Udine. Both washrooms were  $\sim 10 \text{ m}^2$ , with two sinks and two toilets, one wall-mounted JAD and a PT dispenser. The washrooms were adjacent, were accessed from a gallery near to patient waiting areas and used by healthcare workers, patients, and visitors. No washrooms had windows or air-conditioning.

#### Study organization and set-up

A crossover design was used to compare contamination levels within each washroom, i.e. switching between handdrying methods. This approach allowed each washroom to act as its own control, with a 'washout' period occurring between each hand-drying 'intervention' (Figure 1). Only one drying method was available for use in each washroom (ensured by either the hand dryer being switched off at the master switch, or the PTs being removed from the dispenser with no refilling permitted). There were six intervention periods per (N = 3) hospital, i.e. 18 intervention periods in total. Target bacteria included meticillin-susceptible (MSSA) and -resistant *Staphylococcus aureus* (MRSA), enterococci including vancomycinresistant enterococci (VRE), enterobacteria including *Escherichia coli* and *Klebsiella* spp., extended spectrum  $\beta$ -lactamase (ESBL)-producing enterobacteria, and *Clostridium difficile*.

During standardized sampling, washrooms were closed-off for  $\sim 10$  min, at the same time of day throughout the study,



**Figure 1.** Overview of sampling periods at each hospital site according to hand-drying method.

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immediately before cleaning. Thus, sampling occurred at times likely to represent maximum surface (but not air) environmental contamination. One sampling session was carried out per day per washroom for five separate days in each monitoring week; hence 5 (days)  $\times$  12 (weeks)  $\times$  2 (washrooms) = 120 sampling sessions per hospital. Footfall was measured on three occasions per washroom before environmental sampling began (to confirm similar numbers of users) and then on two occasions per washroom during each week of sampling by unobtrusive/external monitoring (i.e. on a total of 27 occasions).

#### Air sampling

A 5 min sample of washroom air was collected while vacant (Coriolis air sample; Bertin Instruments, Montigny-le-Bretonneux, France). The sampler collected 300 L of air per minute into a vial of spinning collection fluid (7.5 mL), which was transported to the laboratory and used to inoculate agar plates. Thus, the effective volume of air sampled, after accounting for sample dilution and volume adjustment, was 20 L per agar plate. Agar plates (all bioMérieux, Basingstoke, UK) were inoculated (100  $\mu$ L) for total aerobic counts (Trypticase Soy Agar 43011), S. aureus and MRSA (Chrom ID 419398; bio-Mérieux), ESBLs (Chrom ID-43484), enterococci (D-coccosel Agar 43151), VREs (Chrom ID 43004), C. difficile (Chrom ID 43871), and enterobacteria (Eosin Methylene Blue 43081). All plates were incubated aerobically for 24 h at 37°C, except for C. difficile plates (anaerobically at 37°C for 48 h). In France, ESBL-producing Acinetobacter spp. and Stenotrophomonas spp. were not measured.

#### Surface sampling

Sterile sampling sponges (Polywipes; MWE Medical Wire, Corsham, UK) were used to sample frequently touched areas within the washroom, including the sink, doorplate, floor under the JAD or PT unit, and the outside casing of the JADs or the outside of a PT dispenser. Other sites sampled included floors under dryers and the sink area (including the bowl and the taps). For each site,  $\sim 10 \times 10$  cm (where possible) was sampled. Sampling sponges were transported to the laboratory, soaked in neutralizer recovery diluent (50 mL) (E&O Laboratories, Bonnybridge, UK) and then plated on to selective/ non-selective agars.

#### Table I

Comparison of data for the paper towel and jet air dryer washrooms in each country

#### Sampling the dust from surfaces

A high-efficiency vacuum cleaner (Dyson, Malmesbury, UK) was used to sample washroom environmental surfaces, collecting dust/debris via the hose attachment. This involved 'vacuuming' in a standardized way most of the washroom surfaces, including high-reach areas (including tops of cubicles and trunking), middle-height areas (e.g. ledges by sinks and toilets), and low areas including a substantial amount of the floor, under the drying unit, inside toilet cubicles, and around washbasins. The collected dust was transported back to the laboratory in the cylinder, diluted in neutralizer recovery diluent (50 mL as before), sieved to remove large particles (if necessary) and a 100  $\mu$ L aliquot inoculated on to agars.

#### Control samples and quality control

For each testing session, a blank sampling sponge was processed alongside other samples. To ensure non-contamination of the vacuum cleaner before testing and to prevent carryover, neutralizer solution was added to the cylinder, swirled around and then processed as for dust samples.

#### Data analysis

Data were presented as median colony-forming units (cfu) and analysed with the Mann–Whitney *U*-test to assess significance. Counts of samples that yielded >300 colonies on a plate were recorded as 300, as higher numbers could not be counted accurately.  $P \leq 0.05$  was considered statistically significant. Frequency data were used to show the proportion of samples positive for target bacteria, and the  $\chi^2$ -test was used to determine significance.  $P \leq 0.05$  was considered statistically significant.

#### Results

#### Washroom usage and temperatures

Footfall counts showed that UK washrooms were much busier, but the use of PT versus JAD washrooms at each site was very similar (Table I). Average temperatures of the two washroom types were very similar (Table I).

Washrooms	Mean footfall	Mean temperature (°C)	Median total aerobic bacteria (cfu) recovered <sup>a,b</sup>					
	(people/h)		Air	Door	Floor	Box	Sink	Dust
Paper towel	(N = 60)							
UK	93	21.9	5	1	40	9	85	115
France	9	23.4	5	12	24	9	37	300
Italy	10	27	5	<1	<1	<1	<1	75
Jet air dryer	( <i>N</i> = 60)							
UK	86	22.1	6	15	200	200	63	145
France	7	23.2	1	5	190	300	132	300
Italy	10	27	0	0	<1	100	<1	20

<sup>a</sup> Volume of air sampled was 1500 L, equivalent to 20 L per agar plate. Approximate surface area sampled was 10  $\times$  10 cm per site, equivalent to 0.2 cm<sup>2</sup> per agar plate.

<sup>b</sup> Significant differences highlighted in text.

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### Comparison of bacteria recovery from washrooms in the three countries

In the UK and France, total bacteria counts recovered from air, doors, and dryers were similar over the three separate testing sessions, with slightly more variation from floors, sinks, and dust (data not shown). The greatest discrepancies between sampling sessions were in Italy for counts obtained from dryer surfaces (e.g. session 1 vs 3; median: 100 vs 300 cfu) and the dust (e.g. session 1 vs 2/3; median: 25 vs 110/155 cfu). For PT washrooms, overall fewer bacteria were recovered from air, doors, and dispensers (median: <13 cfu), with greater recovery from floors, sinks, and dust (maximum median: 300 cfu) (Table I). For JAD washrooms, comparable recovery was seen from air and doors (median: <16 cfu), with greater recovery from the dryer surfaces, floors, sinks, and dust (maximum median: 300 cfu).

Overall, bacterial contamination levels were greater in UK washrooms, followed by France and then Italy (Table I, Figure 2). Fewer bacteria were consistently recovered from environmental samples from PT vs JAD washrooms in all three countries. In PT washrooms, bacteria recovery from air at all sites was similarly low (<5 cfu). Significantly more bacteria were recovered from floors in the UK versus France (median: 40 vs 24 cfu; P = 0.021) and Italy (Table I). Fewer bacteria recovered from dust samples in Italian washrooms versus UK (median: 75 vs 115 cfu; P = 0.19) and significantly fewer versus French washrooms (median: 75 vs 300 cfu; P = 0.0002). In JAD washrooms, dryer surfaces at all sites yielded median counts >100 cfu (Table I). Fewer bacteria were recovered from Italy (median: 100 cfu) when compared with the UK (median: 200 cfu; P = 0.077) and France (median: 300 cfu; P = 0.003). Significantly fewer bacteria were recovered from sinks in the UK than in France (63 vs 132 cfu; P = 0.016). In addition, fewer bacteria were recovered from dust in Italian washrooms (median: 20 cfu) compared with UK (median: 145 cfu; P = 0.07) and French washrooms (median: 300 cfu; P < 0.0005).

Considering potential pathogens recovered from washrooms, the frequency of MSSA detection was consistently highest in the UK versus both France and Italy. MSSA recovery was significantly greater from the UK versus France PT (42 vs 3 occasions; P = 0.00001) and JAD washrooms (43 vs 3 occasions; P = 0.00001). Similarly, there was a significant difference in the frequency of recovery of enterococci from floors in the UK versus France (23 vs 8 occasions, P = 0.0017). There was also more frequent enterococcal recovery from dust in the UK versus French washrooms (19 vs 12 occasions; P = 0.14). In JAD washrooms, there was similar higher frequency of recovery in UK versus French washrooms. Most notably, the greater differences were seen in the most contaminated sites, which included JAD surfaces (26 vs 6 occasions; P = 0.00003), floors (52 vs 9 occasions; P = 0.00001), and dust (30 vs 13 occasions; P = 0.00121).

#### Bacteria recovery from UK washrooms

All results were combined for the three intervention periods to provide data for 60 sampling sessions (PT vs JAD washrooms). There were significant differences between bacterial counts for PT dispensers versus JAD surfaces (median: 9 vs 200 cfu, respectively; P < 0.0001) and for floors (median: 40 vs 200 cfu;



**Figure 2.** Total aerobic counts (all sites) in each washroom by testing day in UK (upper), France (middle), and Italy (lower) according to hand-drying method. Filled diamonds: paper towels; open squares: jet air dryer. cfu, colony-forming units.

P < 0.0001). Total counts were similar for bacteria recovery from sinks, air, and doors (Table I).

Enterobacteria recovery from both washrooms followed a similar pattern to the total aerobic recovery. Significantly fewer enterobacteria were recovered from PT dispensers vs JAD surfaces (median: 0 vs 13; P < 0.00001). From floors, significantly more enterobacteria were recovered in JAD vs PT washrooms (median: 34 vs 0; P < 0.00001). Significantly more MSSA were recovered from JAD surfaces versus PT dispensers (median: 4 vs 0; P < 0.00001). A similar significant difference was seen for MSSA recovery from floors (median: 2 vs 13;

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P < 0.0001), with a less marked difference for dust (median: 1 vs 2; P = 0.095). Very few enterococci were recovered from PT washrooms, with significantly greater recovery from floors in JAD versus PT washrooms (median: 0 vs 37; P < 0.00001). Similarly, significantly more enterococci were recovered from dust in the JAD versus PT washrooms (median: 1 vs 0; P = 0.044).

Recovery of antibiotic-resistant organisms was generally low. Total counts of MRSA were very low from both washroom types (all <16 cfu), but recovery was significantly more frequent from the floors of JAD versus PT washrooms (21 vs 7; P = 0.002) (Figure 3). There were non-significant trends towards greater recovery of MRSA from the dryer surfaces (P = 0.35) and floors (P = 0.13) in JAD versus PT washrooms. Counts (P = 0.032) (Figure 3) and frequency of recovery (18 versus 4 occasions; P = 0.000001) of ESBL-producing bacteria were both significantly higher on floors of JAD versus PT washrooms. *C. difficile* was not recovered from any samples in any country.

#### Bacterial recovery from washrooms in France

Significantly fewer bacteria were recovered from PT dispensers versus JAD surfaces (median: 9 vs 300 cfu;



**Figure 3.** Environmental recovery of MRSA (upper) and ESBLproducing bacteria (lower) from UK washrooms (60 samples per site). Filled bars: paper towels; open bars: jet air dryer.

P < 0.00001). Significantly fewer bacteria were recovered from floors of PT versus JAD washrooms (median: 24 vs 190 cfu; P < 0.00001). Total aerobic bacteria recovery was similar from air and doors (median: <5 cfu) and from dust (both washrooms median: 300 cfu). Very low numbers of enterobacteria were recovered in both washrooms; in dust, significantly fewer enterobacteria were recovered from PT versus JAD washrooms (median: 19 vs 57 cfu; P = 0.02) (Figure 4). Enterococci counts and frequency of positives were very low in general. No vancomycin-resistant enterococci (VRE) were recovered.

MSSA were recovered from PT washrooms in very small numbers from all sites. Frequency of MSSA recovery was also generally low, but it was seen occasionally from most sites sampled. The highest frequency of recovery was from JAD surfaces (four occasions; P = 0.17) compared with PT dispensers (Figure 5). Recovery of resistant bacteria was generally low in both washroom types, with no MRSA and very few ESBLproducing bacteria isolated. There was a non-significant difference between the frequency of ESBL-producing bacteria isolation from dust samples in PT (n = 6) versus JAD (n = 12) washrooms (P = 0.12) (Figure 5).

#### Bacterial recovery from washrooms in Italy

Total aerobic bacteria recovery in washrooms was similarly low (<1 cfu) from air, doors, and sinks. There were significantly fewer aerobic bacteria recovered from PT dispensers versus JAD surfaces (median: 0 vs 100 cfu; P = 0.00001) and a similar,



**Figure 4.** Comparison of enterobacteria counts from washrooms in the UK (open bars) and France (filled bars). Error bars represent 95% confidence intervals. cfu, colony-forming units.

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**Figure 5.** Frequency of environmental recovery of meticillinsusceptible *Staphylococcus aureus* (upper) and extendedspectrum  $\beta$ -lactamase-producing bacteria (lower) from washrooms in France (60 samples per site). Filled bars: paper towels; open bars: jet air dryer.

non-significant trend for floors (P = 0.16). Frequency of total aerobic recovery from air, doors, sinks, and dust in both washrooms was similar. There was greater recovery from the dust from the PT versus JAD washrooms, but this was not a significant difference (median: 75 cfu vs 20 cfu; P = 0.79). Most notably, there was a significant difference in frequency of positive samples between PT dispensers versus JAD surfaces (4 vs 40, respectively; P < 0.00001). There were also nonsignificant trends for more frequent recovery of bacteria from floors of JAD versus PT washrooms (12 vs 19; P = 0.14) and sinks (5 vs 7; P = 0.37). A very limited range of bacteria was recovered in Italy: only very occasional enterobacteria, enterococci, or ESBL-producing bacteria, and no MSSA or MRSA were isolated.

#### Discussion

This is the largest study of its type to examine whether hand-drying method, in healthcare settings, affects the extent of environmental contamination by potential bacterial pathogens. We found multiple significant differences in levels of bacterial contamination, with generally lower contamination in PT versus JAD washrooms. These data are generally consistent with our pilot study data with in-situ studies and limited other available data [6–14]. Consequently, we believe that electric hand dryers are not suited to clinical settings, and, as such, existing (e.g. NHS) infection control building guidance needs to be amended and strengthened [5]. Furthermore, it is difficult to justify a hand-drying method that is associated with considerably greater propensity for microbe dispersal when potential pathogens are prevalent, including at certain times of the year or in specific settings. For example, during periods of high influenza and norovirus activity, airborne dispersal of pathogens, potentially during hand-drying following suboptimal handwashing, is an infection control and/or public health concern [15–18].

The fundamental explanation for the trends and significant differences seen is that JADs dry hands via high-velocity shearing forces that remove both water and bacteria from hands, propelling these into the air and on to washroom surfaces. By contrast, PTs absorb water and bacteria with consequently less potential for bacterial contamination of the environment. Clearly, the risks associated with microbial dissemination during hand-drying will vary according to the microbes and numbers remaining after handwashing. So, highquality handwashing should of course be the counsel of perfection. However, our real-world study design shows that there is still considerable potential for microbe dispersal during hand-drying, most notably with JADs.

Bacterial recovery was significantly greater from the external surfaces of JADs at all sites. In the UK and France, a similar effect was seen with higher numbers of the bacteria (enterobacteria and enterococci) recovered from the JAD surfaces when compared with the PT dispenser. Whereas we were unable to recover as many antibiotic-resistant bacteria, it is interesting that these were most frequently found on floors, dryer surfaces, and dust in JAD washrooms. Notably, whereas low numbers were recovered, significantly higher recovery of ESBL-producing bacteria occurred from floors of JAD washrooms in the UK.

Throughout the study, air samples yielded low numbers of bacteria. The timing of air sample collection was  $\sim 5$  min after the last possible visitor to the washroom. Bacterial counts in air due to contamination occurring during JAD use decrease over time, as the microbe-containing water droplets fall on to horizontal surfaces [12]. For example, in-situ experiments showed that 80% of airborne bacteria were recovered in the first 10 of 15 min following use of a JAD [9]. So, in the present washroom study, we likely missed the (multiple) peak periods of air contamination associated with JAD use. Nevertheless, the significantly increased levels of bacterial contamination that we found in all three sites, on the floors beneath JADs versus PT dispensers, is a proxy measure of the marked differences in air contamination associated with these hand-drying methods.

By comparing total aerobic counts between countries, it is possible to assess the contamination level according to washroom type. As the drying method was alternated in washrooms between sessions, the similarity of total bacteria counts in samples across these washrooms suggests that recorded differences were driven by hand-drying method rather than other factors, including washroom footfall. It is interesting that total aerobic counts from the most contaminated sites (i.e. the box, sink and dust) were similar in each country, despite differences in footfall, which was nine times higher in the UK compared with France and Italy. The range of bacteria recovered in France and the UK was broadly similar, but was more restricted in Italy. It is possible that differences in cleaning practices and methods used may be a contributing factor. The washrooms in the UK and Italy were cleaned three times per day and the

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washrooms in France were cleaned twice per day, with combinations of chlorine-releasing agents, limescale/grease removers, alcohol wipes, and a quaternary ammonium compound. Such differences were a limitation of our real-world study.

Further limitations of this study are acknowledged. As far as possible this was a controlled study, but we could not account for the behaviours and habits of people concerning the washing and drying of hands. It is possible that different behaviours before hand-drying could affect the extent of environmental contamination. For example, people about to use a JAD may shake their hands (dispersing water droplets) to remove excess water. We found higher bacterial contamination from JAD surfaces and floors, which is consistent with such behaviour, but this contamination could then be increased due to the way the dryers function. We note that samples yielding counts >300 cfu on an agar plate could not be counted accurately, and so we had to record these as 300 cfu, which could have underestimated the true bacterial burdens at some sites.

In summary, this multi-centre, real-world, healthcare setting study shows that options for hand-drying in washrooms are associated with clear differing potential for environmental bacterial contamination. There were multiple examples of significant differences in the extent of surface bacterial contamination, including by faecal-associated (enterococci and enterobacteria) and antibiotic-resistant bacteria (MRSA and ESBL-producing bacteria). Higher levels of contamination were measured in washrooms using a JAD compared with those using PTs. Hand-drying method can affect the risk of (airborne) dissemination of bacteria in real-world settings. JADs may not be suitable for settings where microbial cross-contamination risks are high, including hospitals.

#### Conflict of interest statement

M.H.W. has received honoraria from the European Tissue Symposium (ETS) for microbiological advice and lectures, and travel expenses to attend meetings. F.B. has received honoraria from ETS for microbiological advice and travel expenses to attend meetings.

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