

ORIGINAL ARTICLE

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

P.T. Kimmitt and K.F. Redway

Department of Biomedical Sciences, Faculty of Science and Technology, University of Westminster, London, UK

Keywords

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

Correspondence

Patrick T. Kimmitt, Department of Biomedical Sciences, Faculty of Science and Technology, University of Westminster, 115 New Cavendish Street, London W1W 6UW, UK.
E-mail: p.kimmitt@westminster.ac.uk

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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 led 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* bacte-

rial 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 dryers (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 10¹⁰ 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°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

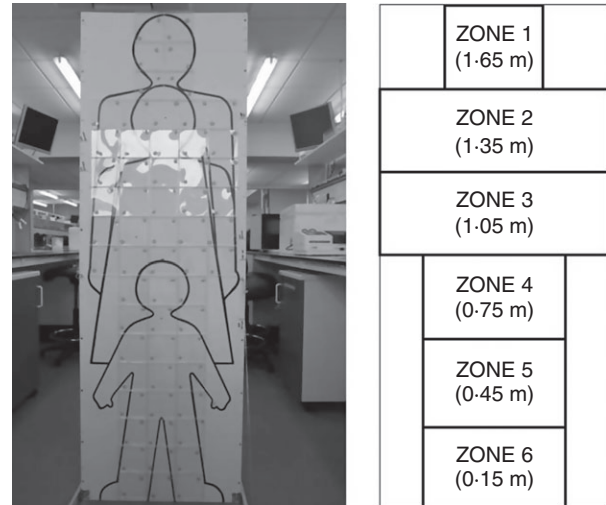


Figure 1 Photograph of vertical board with human figures and diagram showing the 6 different height zones and height of mid-point from floor (m) used to assess vertical dispersal.

devices in large public washrooms at a mainline railway station.

Air sampling

An Air Trace[®] 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 l min⁻¹, a total of 424.5 l of air was sampled. The air was impacted at 70 m s⁻¹ via a 44 × 0.152 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

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

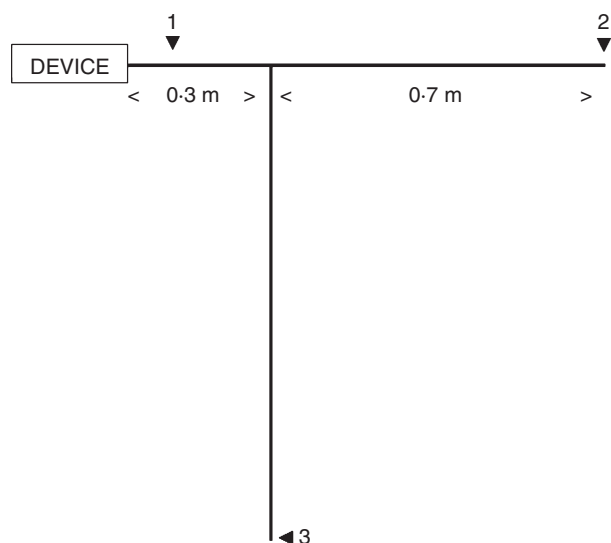


Figure 2 Diagram showing the three different air sampling positions used in this study.

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

Height zone	Height from floor (m)	Mean number of plaques (SD)		
		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)
N		11	11	11
Mean		1.6	34.4	2218.7
total number (all heights)				

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

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.

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 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

Distance from device (m)	Mean number of plaques (SD)		
	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)
N	10	10	20
Mean total number (all distances)	15.4	103.7	3004.5

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 13-fold 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

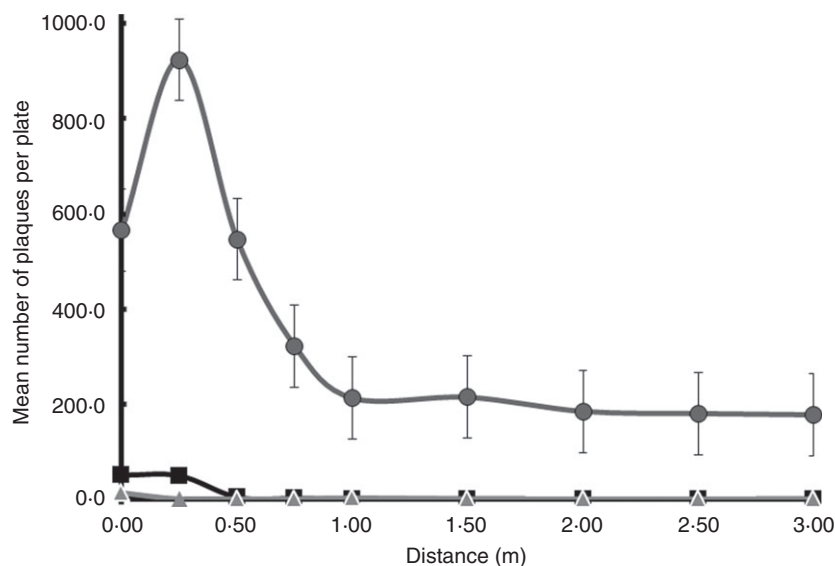


Figure 3 Mean number of viral plaques per 90 mm bacterial overlay agar plate detected at different distances after use of three hand-drying devices: jet air dryer (●); warm air dryer (■); paper towel (▲). Standard error bars are shown.

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

Time (min)	Distance (m)	Position	Mean number of plaques (SD)		
			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

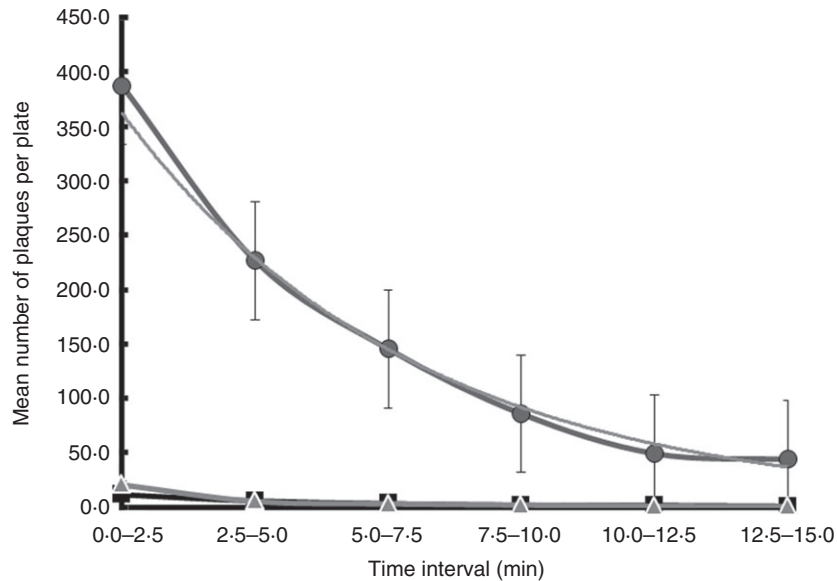


Figure 4 Graph of mean number of viral plaques per 140 mm bacterial overlay agar plate detected by air sampling over 15 min at 2.5-min time intervals after use of three hand-drying devices: jet air dryer (●); warm air dryer (■); paper towel (▲). Standard error bars and exponential trendline (—) are shown.

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 hand-drying 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

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/semi-confluent 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⁻¹ 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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