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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, $P < 0.00001$). 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 β-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.

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 ~15 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^2, 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 ~10 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 hand-drying 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 vancomycin-resistant enterococci (VRE), enterobacteria including *Escherichia coli* and *Klebsiella* spp., extended spectrum β-lactamase (ESBL)-producing enterobacteria, and *Clostridium difficile*.

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

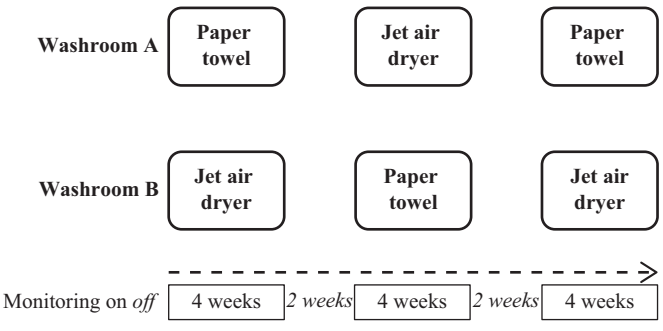

Figure 1. Overview of sampling periods at each hospital site according to hand-drying method.

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) × 12 (weeks) × 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 μL) for total aerobic counts (Trypticase Soy Agar 43011), *S. aureus* and MRSA (Chrom ID 419398; bioMérieux), 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, ~10 × 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.

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 μL 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 carry-over, 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 χ^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).

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

Washrooms	Mean footfall (people/h)	Mean temperature (°C)	Median total aerobic bacteria (cfu) recovered [a,b]					
			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 ($N = 60$)								
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

[a] 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^2 per agar plate.
[b] Significant differences highlighted in text.

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;

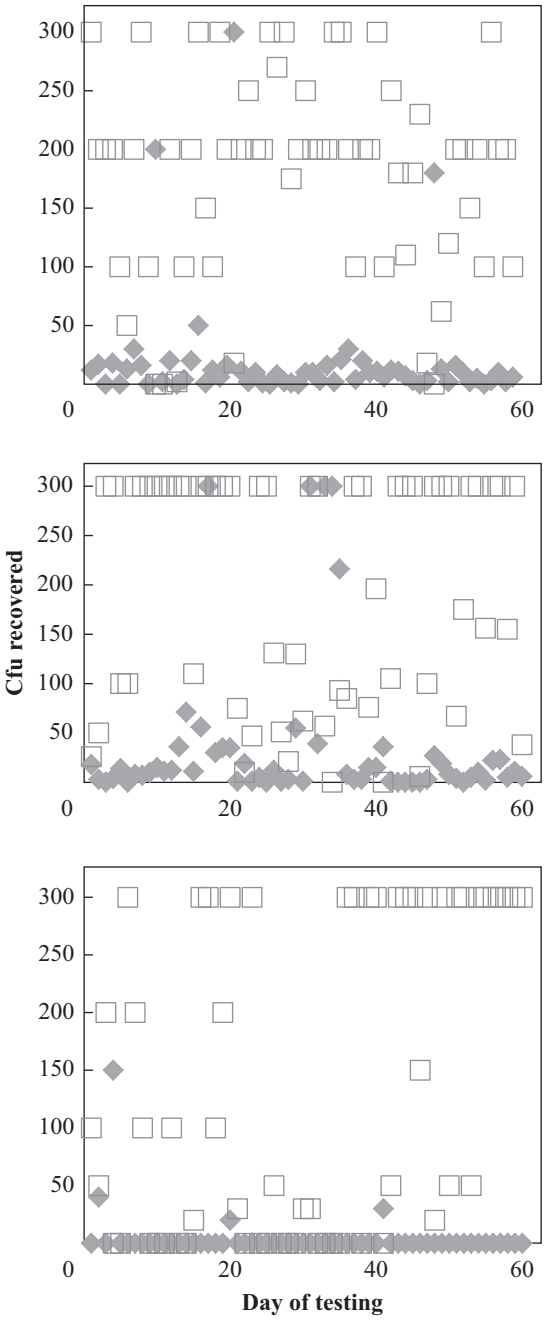

Figure 2. Total aerobic counts (all sites) in each washroom by testing day in UK (upper), France (middle), and Italy (lower) according to hand-drying method. Filled diamonds: paper towels; open squares: jet air dryer. cfu, colony-forming units.

$P < 0.0001$). 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;

$P < 0.0001$), 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; $P < 0.00001$). 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 ESBL-producing 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,

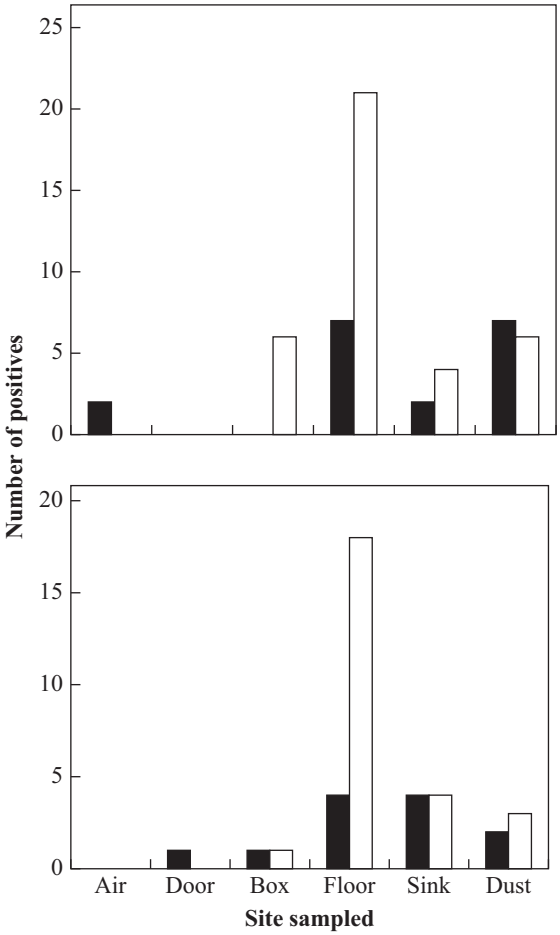

Figure 3. Environmental recovery of MRSA (upper) and ESBL-producing bacteria (lower) from UK washrooms (60 samples per site). Filled bars: paper towels; open bars: jet air dryer.

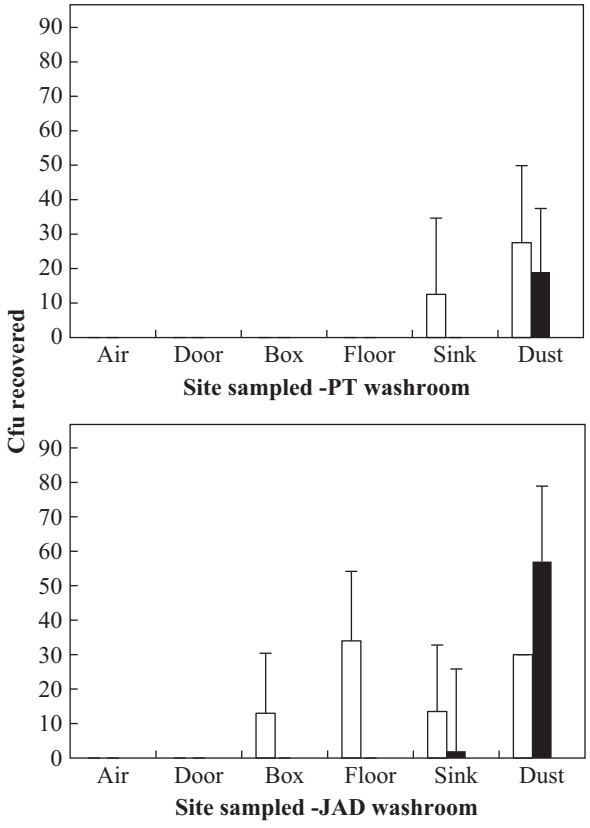

Figure 4. Comparison of enterobacteria counts from washrooms in the UK (open bars) and France (filled bars). Error bars represent 95% confidence intervals. cfu, colony-forming units.

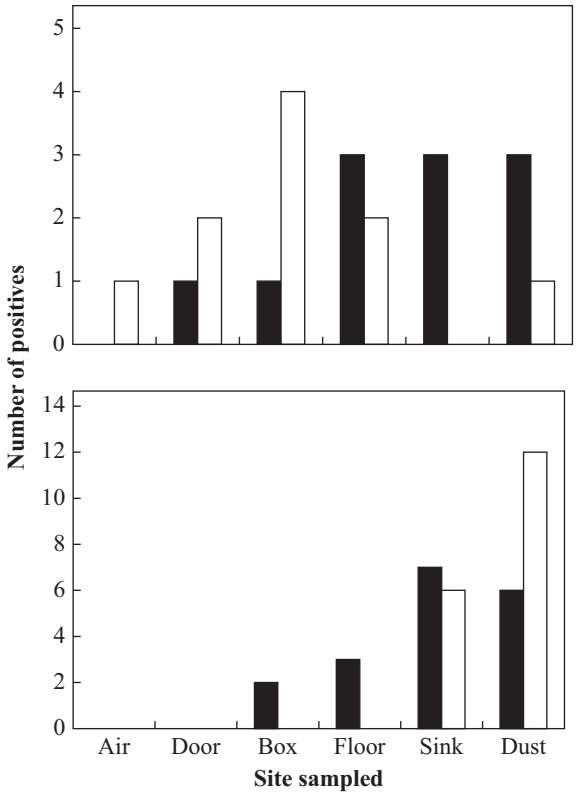

Figure 5. Frequency of environmental recovery of meticillin-susceptible *Staphylococcus aureus* (upper) and extended-spectrum β-lactamase-producing bacteria (lower) from washrooms in France (60 samples per site). Filled bars: paper towels; open bars: jet air dryer.

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 non-significant 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, high-quality 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 ~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

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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