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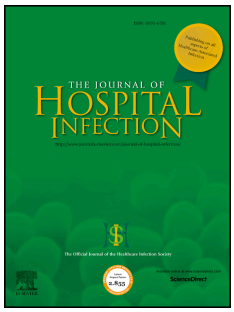

The method used to dry washed hands affects the number and type of transient and residential bacteria remaining on the skin

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The method used to dry washed hands affects the number and type of transient and residential bacteria remaining on the skin.

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Running title: Effect of hand drying method on hands' bacteria

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Summary

Background: Widespread antibiotic resistance has led to fears that we are entering a pre-antibiotic era and the relatively simple premise of hand washing to reduce transfer of bacteria and viruses has never been more important. Much of the emphasis has been on handwashing technique, type of soap and maintaining compliance but effective drying of the hands is just as important.

Aim: To compare the efficacy of drying washed hands with a jet air dryer or paper towels to remove transient bacterial contamination and to determine the effect on residential flora.

Methods: Eighty volunteers were recruited. The entire surfaces of volunteers' hands were artificially contaminated with *Escherichia coli* before being washed and dried; then bacteria remaining on the skin were recovered and enumerated. In the second part of the study the number and types of bacteria comprising the natural flora remaining on washed and dried hands were determined.

Findings: Significantly fewer transient and residential bacteria remained on the skin if hands were dried with a jet air dryer ($P < 0.001$). Drying hands with paper towels increased the number of resident bacteria, including potentially pathogenic species, released from the volunteers' skin, compared to a jet air dryer.

Conclusion: The number and types of bacteria remaining on washed hands were affected by the drying method. Hands dried with a jet air dryer harboured fewer viable bacteria reducing the risk of infection transmission via touch. This could be particularly important for healthcare workers who are constantly in contact with large numbers of vulnerable patients.

Keywords: hand hygiene, hand drying, jet air dryer, transient bacterial flora, resident bacterial flora

Introduction

The positive effects that good hand hygiene can have in reducing infection transmission have been known since Ignaz Semmelweis faced opposition for introducing handwashing regimes in the 1840s [1]. Overuse and misuse of our arsenal of antibiotics has led to pandemics of hospital acquired (HAI) and more recently widespread community- associated infections with multidrug resistant (MDR) organisms [2]. In Germany, although the incidence of HAI caused by meticillin-resistant *Staphylococcus aureus* (MRSA) has declined, the imported MRSA incidence by colonised patients is significantly associated with high numbers of nosocomial MRSA cases [3,4]. Horizontal gene transfer of antibiotic resistance genes amongst *Enterobacteriacae* has resulted in widespread contamination of our environment [5] and the role of environmental bacterial species in the spread of MDR bacteria cannot be underestimated [6].

Contamination of the hands of health care workers can have serious consequences for those in their care [7,8]. Bingham et al, 2016 [9] observed that for almost 30% patient encounters healthcare workers' (HCW) hands were contaminated with a pathogen, and the risk is greatly enhanced if the contaminants carry drug resistance. The World Health Organisation (WHO) has formulated guidelines to be implemented globally to 'ensure that no patient is unavoidably harmed through lack of compliance with hand hygiene' [10–13]. In 2018 the WHO aims to concentrate on reducing the incidence of healthcare associated sepsis in which affects more than 30 million people per year [14] .

An efficient handwashing regime depends on a multitude of factors including washing technique, types of soaps and antibacterial agents as well as other factors including wearing of jewellery and nail length. It is known that the risk of transmitting infection is greater if hands are wet therefore the method used to dry the hands is an important part of hand hygiene [10]. The commonest methods are paper towels, mechanical hot air or jet air dryers. A model handwashing technique can be ruined if hands are not sufficiently dry or have become recontaminated during the drying process. There is conflicting evidence regarding hot air and jet air dryers. Concerns about the dispersal of pathogens into the environment have been expressed [15–17] as well as high energy consumption, noise and longer hand drying times [18]. However, Snelling et al [19] observed improved performance with a jet air dryer compared to hot air dryer in volunteers who had contaminated their hands by handling raw meat.

In this study washed hands dried with paper towels or with a jet air dryer were compared concerning the removal of transient bacterial flora and the risk of further touch contamination was assessed. The hands of the volunteers had been artificially contaminated with *E. coli*. In the second part of the study the effect of the two drying methods on the residential flora of the volunteers' hands was investigated. In addition, the bacteria of the natural flora were identified as well as enumerated.

Methods

Bacterial strain:

Escherichia coli, strain DSMZ 11250, an ancestral K12 strain, originally isolated from human faeces, was used as an indicator in experiments to determine efficacy of hand drying methods to remove transient bacterial contamination from washed hands.

Volunteers

Eighty healthy volunteers were recruited into the study. All the recruits worked at the University of Marburg, Germany, and included clinicians, medical students, health care workers, research scientists and technicians. The hands of all volunteers were examined and only those displaying healthy intact skin without any cuts, abrasions, dermatitis or any other skin conditions on their hands were allowed to take part in the study. Individuals with any past history of a skin disorder or those receiving treatment were excluded. In addition the nails of the volunteers were cut short and free of nail polish.

Hand washing and drying protocols:

All volunteers washed their hands for 1 minute with 5ml pure potash soap, pH 10.5 (Urkon, Germany), as described in the European Standard method EN 1499 [20].

Hands were dried either with paper towels or using a jet air dryer. For hand towels all volunteers dried their hands the same way using two sheets of paper towel (Torck).

The jet air dryer used for the study was a 'hands in' Dyson Airblade dB (Dyson, UK). Air is drawn into the bottom of the dryer which then passes through a HEPA filter at high velocity which removes > 99.95 % of particles ≥ 0.3 µm , which, as bacteria typically exhibit diameters of ≥ 1-2 µm is sufficient to remove them. Wet hands are placed in the machine and two jets of filtered air, at room temperature, pass through 0.8 mm apertures where the

resulting high pressure clean air 'scrapes' the water from the hands and avoids lengthy drying protocols and recirculated 'dirty' air previously observed with hot air dryers.

Volunteers drying their hands with a jet air dryer all followed the same protocol by slowly moving their hands down into the basin of the dryer to ensure all areas of the hands were exposed to the air. Total drying time was 1 minute.

The same washroom (4 x 7.5 x 3 m) was used throughout this study, which also housed an air conditioner. There was a time interval of one week between each parameter (artificially contaminated or natural contamination on hands dried using paper towels or jet air dryer) therefore the washroom was dedicated to a single drying method each time.

Method to determine the efficacy of drying methods on washed hands to remove transient bacterial contamination:

The hands of 70 volunteers were artificially contaminated with a bacterial strain to mimic natural faecal contamination. A suspension of 10^8 colony forming units (cfu) / mL *E. coli* DSMZ 11250 was prepared in sterile saline within a polypropylene bag, dimensions 30 x 20cm, (Sarstedt, Germany) which had previously been sterilised by autoclaving at 121^{o}C, 15 psi. Volunteers placed their hands inside the bag for 5 seconds. The hands were then withdrawn and held with fingers apart for 3 minutes during which time the inoculum dried. All volunteers then washed their hands as described. This was performed on three separate occasions where the contaminated hands were either a) dried with paper towels, b) dried under a jet air stream or c) not dried at all. Conventional methods to recover bacterial contamination of the hands have been to place the hand in direct contact with agar plates. However, this method introduces bias selecting for those areas touching the agar and may

be influenced by other factors, for example, pressure and duration of hand contact and results may be variable. The German Society for Hygiene and Microbiology (DGHM) recommends the whole hand to be sampled based on the method by Fuls et al., 2008 [21]. This method is described in detail elsewhere [13]. Briefly, each volunteer's hand was immersed in a sterile polypropylene bag containing 100 mL saline and rigorously washed for 20 seconds. An aliquot, 100 µ L, was removed immediately, serially diluted in saline containing neutralisers (3% Tween 80 3 g / L, lecithin 3 g / L and L-Cystein 1 g / L) and further aliquots plated onto selective media (MacConkey). When the inoculum was dry plates were inverted and incubated at 36^{o}C for 24 hours. Colonies were counted and the recovered *E. coli* enumerated.

Method to determine the efficacy of drying methods on washed hands to remove bacteria comprising the natural skin flora:

Eighty volunteers washed their hands as described. The bacterial load was also determined by the whole hand sampling method from hands that were a) dried with paper towels, b) dried under a jet air stream or c) not dried at all. This was done for each volunteer. Aliquots were diluted and this time plated onto non-selective Columbia blood agar (5% sheep blood,) and MacConkey agar selective for coliforms (Beckton Dickinson, Germany). Plates were incubated aerobically at 36^{o}C for up to 48 hours. Bacterial growth was enumerated and the species identified by matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF) mass spectrometry or the Siemens Walkaway System.

Statistical analysis

Graphical representations were prepared using Sigma Plot Version 14, Systat Software Inc., and statistical analysis using the Mann Whitney test where statistical significance was expressed as $P < 0.05$.

Results

Recovery of transient bacterial contamination from washed hands

In the volunteers who had dried their hands using paper towels or a jet air dryer there was a significant reduction in the number of contaminating transient bacteria remaining on the skin compared to leaving their hands wet ($P < 0.001$) (Figure 1). However, hands dried with the Dyson Airblade hand dryer harboured significantly less transient bacterial contaminants ($P < 0.001$) than hands dried with paper towels.

Although all the volunteers using paper towels complied with the study protocol in drying their hands there was much greater variation (Standard Deviation (SD) 3.679) in bacteria present on the skin compared to those volunteers using the jet air dryer (SD 0.93) presumably related to natural human variation compared to uniformity of machines (Table IA).

Recovery of bacteria comprising the natural flora on volunteers washed hands

Similar results were observed in the second part of the study to determine numbers of residential bacteria remaining on the skin after washing and drying (Figure 2). The reduction in bacteria recovered was significantly lower on hands dried with a jet air dryer compared to not drying hands at all ($P= 0.005$). However, more bacteria remained on the skin of hands

dried with paper towels than if hands were left wet although the results were not significant (P = 0.183).

As in the first part of the study there was a greater variation in bacterial numbers recovered from volunteers using hand towels (SD 21.76) compared to other parameters (Table IB).

The majority of volunteers harboured normal skin commensals on their washed hands including *S. epidermidis*, *Micrococcus luteus* and *Corynebacterium* spp. Species that were deemed to be opportunistic or facultative pathogens were also recorded for each volunteer (Table II). Facultative pathogenic bacteria were recovered from more than 15% of volunteers that had used either paper towels or not dried their hands. In contrast, only 5% volunteers using the Dyson Airblade hand dryer harboured potentially pathogenic bacteria on their hands. *S. aureus* accounted for approximately 50% of the 17 individuals using paper towels from which pathogenic species were isolated. Also the number of facultative pathogenic species was greater if hands had been dried using paper towels (Table II). Four volunteers that had used paper towels or did not dry their hands harboured more than 1 species of potentially problematic bacteria on their skin.

Discussion

In the first part of the study, drying washed hands with a jet air dryer was more efficient than paper towels in removing transient faecal contaminants. The large number of coliforms remaining on the hands of volunteers who had not dried their hands highlights the infection risk as viable microorganisms could be transferred to others, to surfaces or clothing if they are touched before the hands are dry. Studies have shown that office personnel were found

196 to touch their faces on average 15 times every hour [22] and it has also been shown that
197 contaminated fingertips can transfer infectious virus to up to 7 clean surfaces [23]. The role
198 of surface contamination as well as person-to-person contact is an important and often
199 overlooked aspect of transmission of infective microorganisms [24] . If the person washing
200 their hands had been nursing a patient with an infectious disease the risk of infecting
201 themselves, others or their environment with hands, although washed but remaining wet, is
202 greatly increased.

203 Although drying hands with paper towels was found to be better than leaving hands wet at
204 reducing numbers of bacterial contaminants remaining on the skin there was a large
205 variation in the volunteer cohort. However, drying the hands with a jet air dryer was the
206 most efficacious way to remove transient bacterial contaminants and dried hands in a
207 reproducible and consistent manner which would be an asset in a busy, high pressure
208 environment which exists in health care facilities.

209 In the second part of the study the jet air dryer was also found to be the most superior
210 method to dry hands and reduce the risk of transfer of viable bacteria by touch. Drying
211 hands with paper towels or leaving hands wet after washing significantly increased the
212 numbers of potentially problematic bacteria on the skin surface which could present a risk
213 of infection to others, either by direct contact or indirect via fomites. The increased
214 numbers of bacteria found on the skin of volunteers who had used paper towels, which was
215 greater than if they had not dried their hands at all, may be due to the rubbing, exfoliating
216 action required to dry the hands by this method removing skin squamae and releasing
217 bacteria from deeper layers of the skin.

However, increasing the proportion of recycled fibres in paper manufacture is associated with an increase in microbial load [25]. Unused paper towels made from recycled paper may harbour more microorganisms, especially *Bacillus* and *Clostridium* species, compared to towels made with virgin wood pulp, which were found to transfer to gloved hands after drying hands washed with sterile water [26]. These bacterial species produce spores which may be resistant to skin cleansers and alcohol rubs. Sasahara et al observed frequent contamination of healthcare workers' hands with *Bacillus* and *Clostridium* spores attributed to inadequate hand hygiene [27]. The significance of this requires further investigation.

The prevention of infection from touch contamination cannot rely solely on any handwashing and drying method and has to be part of overall regimes of stringent cleaning, pre hospital admission screening, biocidal products and measures to maintain compliance [13]. This study has focussed on the bacteria remaining on the skin of washed and dried hands and the possible infection risk associated with this. The study limitations include the standardised method used by the volunteers to wash and dry their hands which may not reflect the real world scenario. In the study the volunteers' hands were dried for one minute in the jet air dryer which may be longer than usual in busy healthcare facilities. Likewise, two paper towels were used by volunteers which may not always be the norm. The potential contamination of the environment from the jet air dryer, unused or soiled paper towels and the possible risk of infection transmission associated with this were beyond the scope of this study. However, the air of the washroom was sampled at the beginning and end of the experiments with an RCS sampler and bacterial burden was less than 100 cfu / m^3 regardless if a jet air dryer or paper towels had been in use (results not shown).

Concerns have been expressed about the aerosolization of waterborne pathogens using mechanical dryers [28,29]. A recent study by Best et al [17] observed increased contamination of hospital washroom environments when jet air dryers were employed. As in any real world study there were a very large number of variables and not all values were statistically significant but it raises serious concerns requiring further investigation. It was interesting that the authors observed reduced environmental contamination overall in the Italian washroom compared to those in the UK and France, with a reduction in aerobic bacteria isolated from the air, door plates and dust when jet air dryer was used. There could be other factors contributing here such as higher ambient temperature, more effective cleaning regimes, model of jet air dryer and the users themselves. Harrison et al [30] reported cross contamination of paper towel dispensers in dirty and clean hands of volunteers highlighting the need for continuous and effective room disinfection measures.

Further research is needed to determine the optimal locations for positioning jet air dryers which is beyond the scope of this study. However, within hospitals in Germany and other countries, patients' hand washing facilities are usually located in separate rooms often containing a toilet and shower. This is primarily to reduce the infection risk from waterborne pathogens from the hand washing basins. Therefore, good locations for air dryers could be in the patients' bathrooms and all public restrooms. The increase in community associated MDR infections mean that efficient drying of hands is just as important in other communal areas of our society such as public transport, schools, food handling areas as well as healthcare facilities.

The results from this study suggest the latest generation of jet air dryers are effective at rapidly drying hands to remove the risk of bacterial pathogen transfer by touch. Jet air

dryers may also be beneficial where hands are continually washed and dried as in the case of health care workers to prevent skin excoriation. Gram-negative bacteria are more susceptible to environmental stress and further research could determine the effect rapid jet air drying has on the bacterial cell and efficacy against virus contamination of the hands, particularly those with low infectious dose such as norovirus, and also respiratory viruses and pathogenic fungi.

Conclusion

The results from this study suggest a jet air dryer alongside a rigorous handwashing technique was a superior way to dry hands compared to paper towels. Leaving hands wet posed a serious risk of further infection transmission by touch. Drying hands in filtered air removed more transient contaminants and residential bacteria including potentially problematic bacterial species than using paper towels. To be fully effective, as for any hand hygiene measures, there must be accompanying stringent, effective and regular environmental cleaning regimes and equipment maintenance.

A recent study [17] suggested jet air dryers should not be used in healthcare facilities. However, before significant investments and healthcare policy changes are made further studies are needed on the efficacy of the latest designs of jet air dryers, which have very rapid drying times (less than 20 seconds), features to reduce splashing and reduced noise output, to dry hands as well as the potential microbial hazards present in recycled paper towels. Then a balance can be made to achieve the most efficient and effective method to dry hands to reduce cross contamination combined with the need to reduce the cost to the environment.

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Potential conflict of interest: None

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391 **Table I Recovery of bacterial contamination from the volunteers' washed hands**

	Study parameters	Method of hand drying	Mean number of *E. coli* recovered (cfu x 10^3/mL)	Standard deviation
A	Hands artificially contaminated with *E. coli* (transient)	Paper towel	1.89	3.679
		Dyson Airblade	0.845	0.93
		Hands not dried	3.642	4.491
B	Natural flora of the hands (residential)	Paper towel	9.69	21.176
		Dyson Airblade	3.44	3.369
		Hands not dried	5.44	4.856

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395 **Table II Facultative pathogenic bacteria recovered from washed hands which had been**
396 **dried with paper towels, jet air dryer or not dried**

Hand drying method	Species (Number of volunteers)	No. of positive samples in cohort of 80 volunteers (%)
Paper towel	*Staphylococcus aureus* (7) MRSA (1) *Klebsiella oxytoca* (2) *Corynebacterium amycolatum* (1) *Pseudomonas alcaliphila* (1) *Pseudomonas* spp.(1) *Enterobacter cloacae* (2) *Enterococcus* spp. (1) (2 volunteers harboured >1 species)	14 (17.5)
Dyson Airblade	*Staphylococcus haemolyticus* (1) *Klebsiella spp* . (1) *Klebsiella oxytoca* (1) *Enterococcus spp*. (1)	4 (5)
Hands not dried	*Staphylococcus aureus* (6) *Staphylococcus haemolyticus* (3) MRSA (2) *Pseudomonas* spp. (3) *Pseudomonas alcaliphila* (1) *Enterococcus* spp. (5) (2 volunteers harboured >1 species)	18 (22.8)* *n=79

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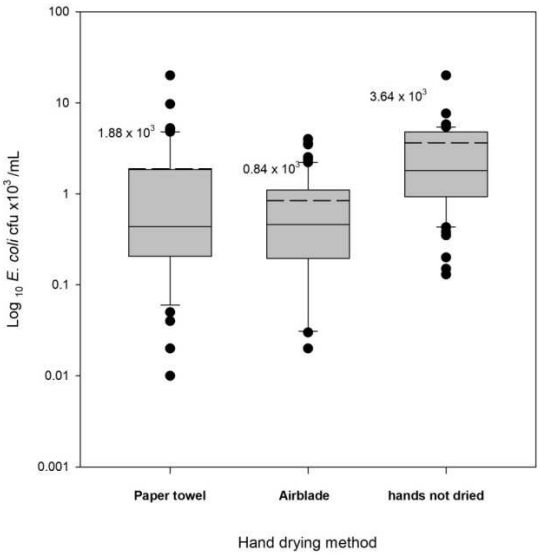
399 **Figure 1 Recovery of faecal coliforms from artificially contaminated hands of the**

400 **volunteers after washing**



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403 **Figure 2 Recovery of naturally occurring bacterial flora from the washed hands of**

404 **volunteers**

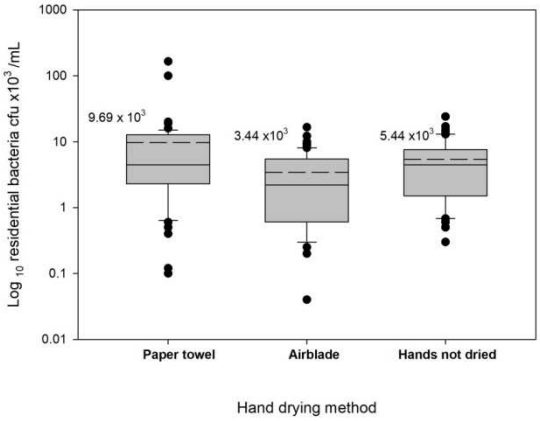

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Figure legends

Figure 1 Recovery of faecal coliforms from artificially contaminated hands of the volunteers after washing

The box plot demonstrates the faecal coliforms recovered from the hands of the volunteers (n=70) after washing and either drying with paper towels, a jet air dryer or not dried at all. Results are expressed as $\log_{10}$ cfu / mL (total volume 100 mL). The dotted line and numerical value represents the mean of each group.

Figure 2 Recovery of naturally occurring bacterial flora from the washed hands of volunteers

Each point represents the total bacterial count recovered from the hands of the volunteers after washing and either drying with paper towels, a jet air dryer or not dried at all. Results are expressed as $\log_{10}$ cfu / mL (total volume 100 mL). The dotted line and numerical value represents the mean of each group.

Word counts:

Summary:	250
Main body of text	3057
Figure legends	142
2 Figures equivalent to:	400
2 tables	400
TOTAL	**3999** (not including Summary and References as specified)