Journal of Applied Microbiology 2001, **90**, 962–970

Transfer of bacteria from fabrics to hands and other fabrics: development and application of a quantitative method using *Staphylococcus aureus* as a model

S.A. Sattar[1], S. Springthorpe[1], S. Mani[1], M. Gallant[1], R.C. Nair[2], E. Scott[3] and J. Kain[4]

[1]Centre for Research on Environmental Microbiology, Faculty of Medicine, University of Ottawa, [2]Department of Epidemiology and Community Medicine, Faculty of Medicine, University of Ottawa, Canada, [3]98 Ridge Ave., Newton, MA, and [4]The Procter & Gamble Co., Ivorydale Technical Center, Cincinnati, OH, USA

544/9/00: received 27 September 2000, revised 16 February 2001 and accepted 16 February 2001

S.A. SATTAR, S. SPRINGTHORPE, S. MANI, M. GALLANT, R.C. NAIR, E. SCOTT AND J. KAIN. 2001.

Aims: To develop and apply a quantitative protocol for assessing the transfer of bacteria from bleached and undyed fabrics of 100% cotton and 50% cotton + 50% polyester (poly cotton) to fingerpads or other pieces of fabric.

Methods and Results: Test pieces of the fabrics were mounted on custom-made stainless steel carriers to give a surface area of 1 cm in diameter, and each piece seeded with about 10^5 cfu of *Staphylococcus aureus* from an overnight broth culture; the inoculum contained 5% fetal bovine serum as the soil load. Transfer from fabric to fabric was performed by direct contact using moist and dry fabrics. Transfers from fabrics to fingerpads of adult volunteers were tested using moist, dry and re-moistened pieces of the fabrics, with or without friction during the contact. Bacterial transfer from fabrics to moistened fingerpads was also studied. All the transfers were conducted under ambient conditions at an applied pressure of 0·2 kg cm^{-2}. After the transfer, the recipient fingerpads or fabric pieces were eluted, the eluates spread-plated, along with appropriate controls, on tryptic soy agar and the percentage transfer calculated after the incubation of the plates for 24 h at 37°C.

Conclusions: Bacterial transfer from moist donor fabrics using recipients with moisture was always higher than that to and from dry ones. Friction increased the level of transfer from fabrics to fingerpads by as much as fivefold. Bacterial transfer from poly cotton was consistently higher when compared with that from all-cotton material.

Significance and Impact of the Study: The data generated should help in the development of better models to assess the role fabrics may play as vehicles for infectious agents. Also, the basic design of the reported methodology lends itself to work with other types of human pathogens.

INTRODUCTION

Exposure to pathogens on contaminated garments, bed linen and other types of fabrics may occur either by direct contact (McNeil 1964) or indirectly through airborne particles (Whyte 1988). Thus far, fabrics have been mainly incriminated, albeit rarely, in outbreaks of nosocomial infections (Barrie *et al.* 1992; Standaert *et al.* 1994; Weernink *et al.* 1995). However, there is renewed concern regarding the potential of fabrics to spread infections (Neely and Maley 2000) with increases in home care (Wilkins and Park 1998), immunosuppression (Morris and Potter 1997), life expectancy, antibiotics resistance (Strausbaugh 1997), and changes in the nature of fabrics as well as laundering practices (Terpstra 1998).

Correspondence: Dr S.A. Sattar, Centre for Research on Environmental Microbiology, Faculty of Medicine, University of Ottawa, Ottawa, Ontario, Canada K1H 8M5.

While contamination of fabrics with human pathogens occurs on a regular basis, the potential of such contaminated items to spread infections is related directly to the ease with which they can release pathogens on contact. While earlier studies on such contact transfer were qualitative in nature (Marples and Towers 1979; Mackintosh and Hoffman 1984; Scott and Bloomfield 1990), the one reported here was not only quantitative but also designed to assess the transfer of bacteria, during handling, from fabrics to fingerpads as well as to other fabrics under standardized levels of pressure and friction during the contact.

The two types of fabric selected for this study are commonly used for making garments and bed linen. *Staphylococcus aureus* was chosen because (i) it is a common member of the resident as well as transient skin microflora, (ii) it is frequently associated with a variety of infections in humans, (iii) it can survive well on experimentally-contaminated hands (Sattar and Springthorpe 1996) and fabrics (Sattar *et al*. manuscript in preparation), (iv) it is able to withstand drying on fabrics as well as on human skin (Sattar and Springthorpe 1996) and (v) it is a prominent nosocomial pathogen.

MATERIALS AND METHODS

Preparation of stock culture

A lyophilized seed of *Staph. aureus* (ATCC no. 6538) was obtained from the American Type Culture Collection (ATCC; Rockville, MD, USA). It was rehydrated in 1 ml sterile distilled water and the suspension immediately inoculated on a plate of tryptic soy agar (TSA; Quelab Labs). The plate was incubated overnight at 37°C, and several colonies from the culture plate were picked up with a sterile disposable loop and resuspended in the proprietary cryopreservative fluid contained in the Microbank^{TM} vials (Pro-Lab Diagnostics, Richmond Hill, Canada) for storage at −80°C.

Preparation of test inocula

When a fresh inoculum of the bacterium was required, a single bead from the Microbank vial was aseptically removed, placed into 10 ml sterile tryptic soy broth (TSB; Quelab Labs) and incubated for about 17 h at 37°C. The colonies were counted using a Quebec colony counter (New Brunswick Scientific, Edison, NJ, USA). The bacterial suspension was diluted in sterile saline to yield approximately 10^7 cfu ml^{-1}. Fetal bovine serum (Gibco-BRL), used as the soil load (to represent body fluids), was then added to the test suspension at a final concentration of 5%. Each fingerpad or fabric disk received 10 μl of this test inoculum containing about 10^5 cfu.

Fabrics

Two types of locally purchased, bleached and undyed fabrics were used. One was 100% cotton and the other a blend of 50% cotton and 50% polyester (poly cotton), both with a count of 72 threads cm^{-1}. They were washed with a laundry detergent without bleach to remove any chemical residues, rinsed several times in water and dried in a laundry dryer. A scoring tool (Graham *et al*. 1996) was used to mark out several discs of 2·3 cm diameter from each type of fabric, and the marked areas were cut out with a pair of scissors. Each fabric disc was used only once and discarded.

Fabric carriers

Each fabric disc was mounted on a custom-made tubular stainless steel holder (Rehabilitation Centre Workshop, Ottawa, Canada) by stretching the disc over the mouth of the holder and securing it in place with a rubber 'O' ring (Spaenaur, Kitchener, Canada). Additional details on the carriers have already been published (Graham *et al*. 1996). Custom-made Teflon inserts (Rehab Workshop) were used with the carriers to provide a non-absorptive solid support at the back of the fabric when pressure was applied during the transfer experiments. Before use, the assembled carriers (Fig. 1) were placed in a 150 mm diameter glass Petri dish and autoclave sterilized for 20 min at 121°C.

Volunteers

Permission of the Ethics Committee of the University of Ottawa was obtained for the use of adult volunteers. Any individual with cuts and abrasions on the hands was automatically excluded from the study. Each volunteer was then thoroughly briefed on the experimental protocol and any risks involved before being asked to sign a consent form.

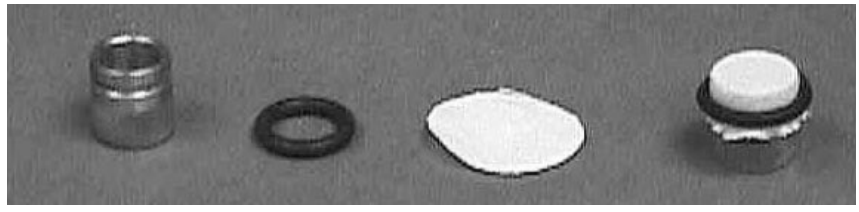

Fig. 1 Components of the fabric carrier

Eluent

A neutralizer blank solution (AOAC 1998) containing lecithin (Sigma), Tween 80 (BioShop Canada Inc.) and phosphate buffer (Sigma), at pH 7·2, was used as the eluent to recover the bacterial cells from fabric discs and fingerpads.

Recovery medium

Disposable plastic plates (100 mm in diameter) with TSA were used to grow the bacteria eluted from the fabric discs and fingerpads. Each plate received 0·1 ml of the sample to be titrated and the inoculum spread evenly on the agar surface with a disposable spreader (Pro-Lab Diagnostics). The inoculated plates were held at 37°C for 24 h before counting the colonies on them.

Transfer experiments

All transfer experiments were carried out under ambient conditions. However, hygrothermometer recordings showed the air temperature to range between 22 and 25°C and the relative humidity as 47–58%.

Table 1 lists the variations used in assessing the transfer of the bacterial contamination from donor to recipient surfaces. The contact time in all experiments was 10 s and the pressure 0·2 kg cm^{-2}. When friction was applied during transfer, it consisted of 10 half-circles of rotation of the fingerpad during the 10 s contact (Mbithi *et al.* 1992). To ensure a high degree of consistency in the experimental protocol, each volunteer was required to go through several practice runs of the transfer protocol several times.

Transfer from fabrics to fingerpads

Preparation of the hands of volunteers. Just prior to each experiment, the hands of the volunteer were thoroughly inspected to ensure their freedom from any apparent damage to the skin. The individual was then required to wash both hands with a non-germicidal liquid soap, rinse them thoroughly with tap water and dry them with a paper towel. About 5 ml 75% (v/v) ethanol were placed in cupped hands and the volunteers asked to rub the alcohol over both hands until they became visibly dry. A circular indentation was marked at the centre of each fingerpad by pressing against it the mouth (8 mm inside diameter) of an empty plastic cryovial (Sarstedt Inc., St Laurent, Canada).

Transfer and elution. A pre-sterilized fabric carrier with a Teflon insert (Fig. 2) was inoculated with 10 μl of the test suspension and placed on a digital read-out, top-loading balance (Mettler PC2000, Mettler Instruments, Zurich, Switzerland). The pre-marked area on the fingerpad was brought into contact with the fabric and the transfer carried out, with or without friction, as described above. The bacteria transferred to the fingerpads were recovered using the method described earlier (Ansari *et al.* 1989; Mbithi *et al.* 1992). Briefly, the fingerpad to be eluted was placed over the mouth of a cryovial (Sarstedt) containing 1 ml eluent. The vial was inverted with the fingerpad still in place to bring the eluent in contact with the skin. After a 5 s contact, the vial was subjected to 20 full inversions. The contact and inversion steps were repeated once, the fingerpad was lifted off gently and its surface scraped against the inside lip of the mouth of the vial in a downward motion to recover as much of the eluate as possible. The

Table 1 Variations used to study the transfer of *Staphylococcus aureus* to and from fabrics

Donor	Recipient
Transfer from fabric to fabric without friction	
Fabric still moist with the inoculum	Fabric moistened with water*
Fabric still moist with the inoculum	Fabric dry
Fabric allowed to dry after inoculation	Fabric dry
Fabric allowed to dry after inoculation	Fabric moistened with water*
Transfer from fabric to fingerpads with† and without friction	
Fabric still moist with the inoculum	Fingerpad dry
Fabric allowed to dry after inoculation	Fingerpad dry
Fabric inoculated, dried and remoistened*	Fingerpad dry
Fabric still moist with the inoculum	Fingerpad moistened with water
Fabric allowed to dry after inoculation	Fingerpad moistened with water
Fabric inoculated, dried and remoistened*	Fingerpad moistened with water

The bacterial transfer was tested under ambient conditions. The recorded values for air temperature and relative humidity were 22–25°C and 47–58%, respectively. In all experiments, the contact time was 10 s.

*10 μl sterile distilled water were used to re-moisten donors or to moisten recipients.

†Pressure applied was 0·2 kg cm^{-2}.

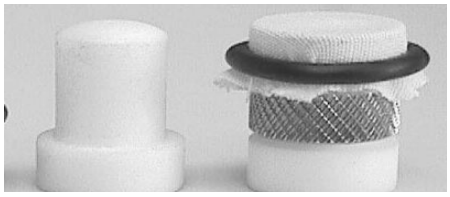

Fig. 2 Carrier and Teflon insert for pathogen transfer

eluate was subjected to serial 10-fold dilution in sterile saline, and two 100 mm diameter Petri plates were separately inoculated with 0·1 ml from each appropriate dilution. The inoculum was spread on the agar surface and the plates incubated for 24 h at 37°C. The eluates from the fingerpads were titrated for cfu to determine the percentage transferred.

The transfer of the bacterium from both types of contaminated fabrics to clean fingerpads was tested, with and without friction, under the following three scenarios.

(i) Transfer from moist pieces of fabric: The inoculated fabric pieces were still moist when they were brought into contact with fingerpads;
(ii) Transfer from dry pieces of fabric: The inoculum on the fabric pieces was air-dried at room temperature for 1 h before bringing them in contact with fingerpads; and
(iii) Transfer from re-moistened pieces of fabric: The air-dried inoculum on the fabric pieces was re-moistened with 10 μl sterile distilled water before bringing them in contact with fingerpads.

Transfer from fabric to moist fingerpads

These experiments were similar to the previous ones except that the volunteers' fingerpads were moistened with 10 μl sterile distilled water just before the transfer.

Transfer from fabric to fabric

Sterile 'donor' carriers with Teflon inserts were inoculated with the bacterial suspension. When the transfer was made to a moist 'recipient' fabric, it was pre-treated with 10 μl sterile distilled water and contacted immediately with the donor. First allowing the inoculum on the donor fabric to dry for 1 h, and then bringing the recipient into contact with it, represented the 'dry' transfer. To determine the effect of re-moistening the dried inoculum on bacterial transfer, the donor received 10 μl sterile distilled water before contact with the recipient. All transfers were made between fabrics of the same type.

The recipient carrier was placed on the pan of the balance and the donor carrier was then inverted and brought into contact with the recipient while applying a pressure of 0·2 kg cm^{-2} for a period of 10 s. No friction was used in these experiments.

At the end of the contact period, the fabric from the recipient carrier was removed aseptically, placed in 2 ml of the eluent and vortexed (Vortex Genie 2, Fisher Scientific, Ottawa, Canada) for 1 min. The eluates were titrated for cfu as described above.

Input controls were set up by inoculating each fabric type with 10 μl of the test inoculum, immediately eluting the inoculum, and spread-plating appropriate dilutions of the eluate on the recovery medium.

Controls

Controls were regularly run to ensure that the fingerpads were free from any detectable bacteria after the alcohol treatment. Sterility controls were also run on the tubes of broth, plates of recovery medium and all diluents and eluents.

Statistical analyses

Each experiment was repeated at least three times and no less than two replicates were used in each experiment.

The transfer of the organism was analysed using a two- or three-way analysis of variance, with control values as a co-variate adjustment, as well as a non-parametric analysis of variance (Kruskall–Wallis).

The counts were obviously skewed and did not follow Normal distribution. The variances of the counts were also different, making the analysis of variance on the counts not valid. Log_e transformations of the counts made the data appear more normal and the variances more homogeneous. The test for variance homogeneity was statistically significant; however, the differences in variances were minimal and not considered serious enough to affect the validity of the analysis of variance (ANOVA).

RESULTS

Liquid absorptive capacity of the two types of fabrics

Sterilized carriers with both types of fabric received either 5 or 10 μl of a 0·1% (w/v) aqueous solution of crystal violet to provide an immediate visual indication of the surface area covered by the absorption of the inoculum. As shown in Fig. 3, almost the entire exposed area of both types of fabric was covered with 10 μl, hence the choice of this volume for all the subsequent experiments.

Figure 3 also shows a distinct difference between the patterns of absorption of the dye in the two types of fabric selected. While the cotton-based material gave a roughly

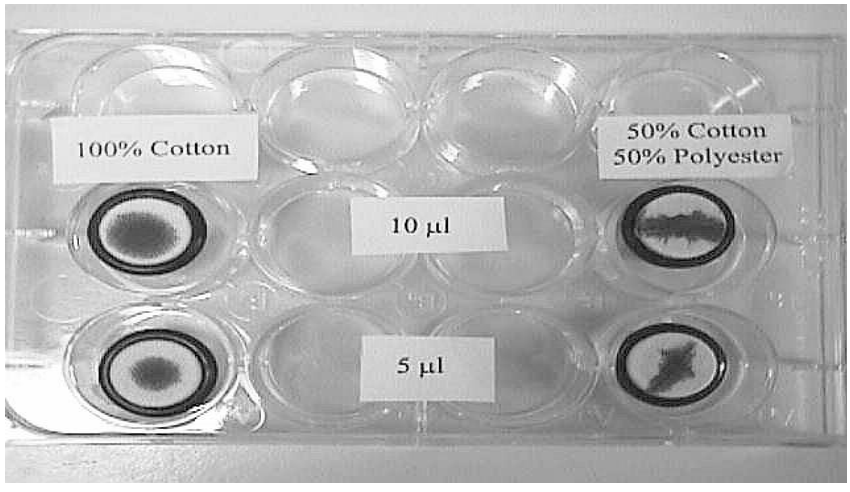

Fig. 3 Fabric pieces inoculated with 5 or 10 μl of a dye solution

circular area of absorption, the corresponding pattern on poly cotton was distinctly long, narrow and somewhat elliptical, perhaps reflecting the predominance of the type of fibre used as warp and weft.

Bacterial transfer

Tables 2 and 3 show the data from all the experiments performed in this study and their statistical analyses. The details of the findings for the three main transfer scenarios tested are given below.

Transfer from fabric to fingerpad. As can be seen from Fig. 4, bacterial transfer from moist or re-moistened fabrics to fingerpads was higher from poly cotton than that from the all-cotton fabric. The same trend was seen during the dry transfer. Incorporation of friction increased the level of transfer by two- to fivefold from both types of fabric, but the increases were again substantially higher with the poly cotton material.

A three-way ANOVA with type of fabric, friction and method of transfer as the independent variables did not show statistically significant differences ($P > 0{\cdot}3$) between

Table 2 Transfer of *Staphylococcus aureus* from fabric to fingerpad

Friction?	Type of fabric	Method of transfer	Mean l n (cfu)	S.E.M.* l n (cfu)	Statistical significance†
No	Poly cotton	Control	13·599	0·219	
		Dry	5·924	0·251	(Reference)
		Moist	9·188	0·326	$P < 0{\cdot}01$
		Re-moist	7·070	0·115	$P < 0{\cdot}01$
	Cotton	Control	12·583	0·230	
		Dry	4·833	0·179	(Reference)
		Moist	5·913	0·145	$P < 0{\cdot}01$
		Re-moist	5·281	0·178	$P < 0{\cdot}05$
Yes	Poly cotton	Control	13·525	0·099	
		Dry	5·973	0·139	(Reference)
		Moist	9·676	0·122	$P < 0{\cdot}01$
		Re-moist	7·036	0·176	$P < 0{\cdot}01$
	Cotton	Control	12·446	0·196	
		Dry	5·209	0·376	(Reference)
		Moist	6·591	0·121	$P < 0{\cdot}01$
		Re-moist	5·626	0·197	$P < 0{\cdot}05$

*Standard error of the mean.
†Statistical significance of comparisons.
Duncan's multiple range test of transfer of cfu for moist and re-moist transfer, compared with dry transfer. Transfer of cfu for cotton fabric significantly ($P < 0{\cdot}001$) lower than poly cotton fabric. Transfer of cfu significantly ($P < 0{\cdot}001$) increased with friction.

Table 3 Transfer of *Staphylococcus aureus* from fabric to fabric

Friction?	Type of fabric	Method of transfer	Mean l n (cfu)	S.E.M.* l n (cfu)	Statistical significance†
No	Poly cotton	Control	12·706	0·142	
		Dry	2·418	0·116	(Reference)
		Moist	6·304	0·208	$P < 0·01$
		Re-moist	5·231	0·154	$P < 0·01$
	Cotton	Control	11·870	0·180	
		Dry	2·901	0·331	(Reference)
		Moist	5·377	0·163	$P < 0·01$
		Re-moist	4·425	0·138	$P < 0·01$
Yes	Poly cotton	Control	12·706	0·142	
		Dry	2·534	0·169	(Reference)
		Moist	8·097	0·141	$P < 0·01$
		Re-moist	5·856	0·169	$P < 0·01$
	Cotton	Control	11·870	0·180	
		Dry	2·669	0·366	(Reference)
		Moist	6·326	0·208	$P < 0·01$
		Re-moist	4·755	0·162	$P < 0·01$

*Standard error of the mean.

†Statistical significance of comparisons.

Duncan's multiple range test of transfer of cfu for moist and remoist transfer, compared with dry transfer. Transfer of cfu for cotton fabric significantly ($P < 0·001$) lower than poly cotton fabric. Transfer of cfu significantly ($P < 0·001$) increased with friction.

the types of fabrics. Friction had a significant impact ($P < 0·001$) on the transfer rate. The method of transfer was a significant factor ($P < 0·001$), with the dry transfer showing the least amount of transfer of the organism. Notably, there was statistical interaction between the type of transfer and friction ($P < 0·001$), and between the type of transfer and the type of fabric ($P < 0·001$). Because of the significant interaction, comparison of marginal means for the single factors is not advisable. Comparison of combinations of factors was done using a *post hoc* test (Duncan's multiple range test); this test is most appropriate because of the unequal number of replications for the experiments (Popham and Sirotnik 1992). The test showed dry transfer from cotton fabric without use of friction with the least amount of transfer. Transfer from poly cotton with friction under dry condition was increased, but with moisture, the increase in transfer was much more pronounced.

Because of the variance heterogeneity, a non-parametric analysis of variance (Kruskall–Wallis) was also performed on the counts of the organism with the two variables above. The results were similar to the parametric analysis and therefore, the parametric analysis (ANOVA on Ln Counts) is reported as it is easier to interpret the results.

The results of the experiments for bacterial transfer from contaminated fabrics to uncontaminated but moistened fingerpads are presented in Fig. 5. In this scenario also, the transfer (without friction) was always higher from poly

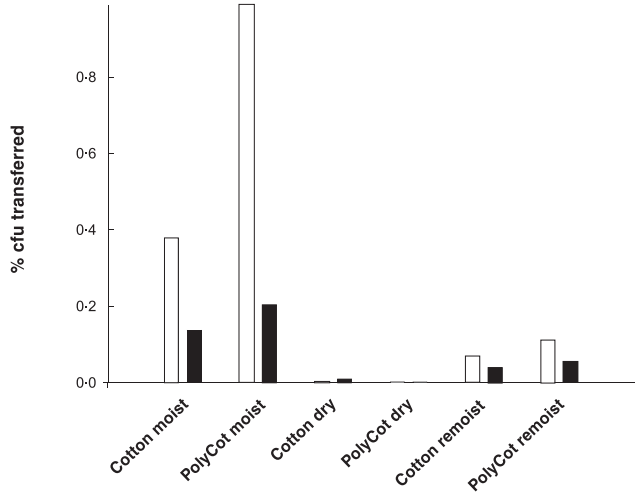

Fig. 4 Transfer of *Staphylococcus aureus* from fabric to fingerpads. (□), With friction; (■), without friction

cotton ($P < 0·01$). Application of friction further increased the level of transfer except in the case of dry poly cotton; this difference, however, did not prove to be statistically significant ($P > 0·05$). In these experiments, the highest level of transfer was obtained when a moistened fingerpad was brought into contact with a re-moistened poly cotton donor fabric with or without friction.

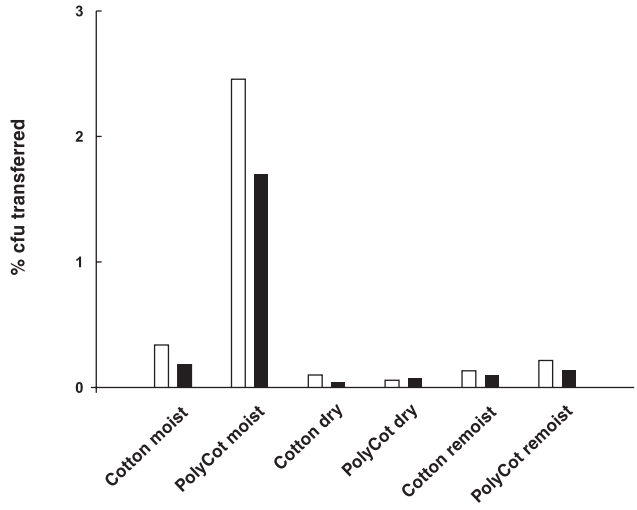

Fig. 5 Transfer of *Staphylococcus aureus* from fabric to moist fingerpads. (□), With friction; (■), without friction

Transfer from fabric to fabric. The results of these experiments are summarized in Fig. 6. The level of transfer from a moist donor fabric to a moist recipient fabric was highest between the poly cotton pieces, followed by that between cotton to cotton ($P < 0{\cdot}05$). The numbers of cfu transferred in the other variations tested in this set of experiments were too low and barely detectable.

A two-way ANOVA with type of fabric and method of transfer as the independent variables showed statistically significant ($P < 0{\cdot}001$) differences between the types of fabrics (lower transfer from cotton fabric) and between the methods of transfer. Although some interaction between the independent variables was present, it was not statistically significant ($P > 0{\cdot}1$), perhaps because of the small sample size. A *post hoc* comparison of the four transfer methods

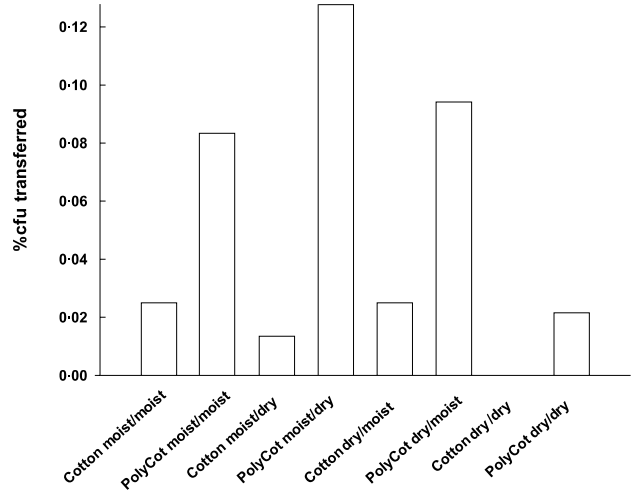

Fig. 6 Transfer of *Staphylococcus aureus* from fabric to fabric

using the Duncan's multiple-range test (this test is most appropriate because of the unequal number of replications for the experiments) showed the dry-to-dry mode with the least transfer, and the moist-to-moist mode with the highest transfer. Contact between moist-to-dry or dry-to-moist surfaces showed similar (statistically non-significant) levels of transfer.

Because of the variance heterogeneity, a non-parametric analysis of variance (Kruskall–Wallis) was also performed on the counts with the two variables above. The results were similar in that the type of fabric and the method of transfer were statistically significantly different ($P < 0{\cdot}001$), supporting the conclusions from the earlier analysis using the two-way ANOVA on log counts.

DISCUSSION

The higher levels of transfer of contamination between moist donor and/or recipient surfaces, as shown in this study, were not unexpected, nor was the demonstrated increase in transfer when friction was applied during contact. However, the data presented here provide the first clear and quantitative demonstration of the impact of these common factors in the release of pathogens from contaminated fabrics. The basis for the consistently higher levels of bacterial transfer from poly cotton require further study. The ease with which bacteria were released from such material may be due to the higher hydrophobic nature of its polyester component, thereby reducing the ability of the bacterial cells to penetrate deeper into individual fibres.

The variations included in the experiments covered the scenarios commonly encountered in the handling of fabrics. The method developed in this study using *Staph. aureus* as a model can be readily adapted to other human pathogenic bacteria, as well as to fungi and viruses.

The two types of fabric selected are commonly used for making garments, bed sheets and pillowcases in domestic and institutional settings. The carriers were designed in such a way that they provided a standard surface area for bacterial transfer to and from the fabrics. Although the surface area was relatively small, it allowed the use of standardized inoculum volumes to contaminate the fabric pieces, and was convenient enough for contact with fingerpads and other carrier-mounted fabrics. The fabric pieces could easily be mounted or removed from the carriers. As the carriers were made of stainless steel, they could easily be re-used repeatedly. The 'O' rings required replacing after four or five uses.

This quantitative approach was in contrast to earlier studies (Marples and Towers 1979; Mackintosh and Hoffman 1984), in which larger pieces of fabric wrapped around bottles were inoculated with 1 ml of the test bacterial suspension for experimental contamination, and volunteers

asked to hold the bottles for 10 s for contact transfer of the bacteria to their hands. Such an approach is inherently more difficult to standardize because of the possible uneven distribution of the inoculum on the test fabric, and several uncontrollable variables in the contact process itself. In addition, the palmar surface of the hand, as used in previous studies, is less frequently used than fingerpads in self-inoculation, and in contacting other animate and inanimate surfaces.

Certain basic differences between the experimental designs of this study and those of earlier investigations make direct comparisons of the levels of bacterial transfer difficult (Mackintosh and Hoffman 1984; Scott and Bloomfield 1990). For example, Marples and Towers (1979) reported that when nearly 60 cm^2 of surface area of the hand were brought into contact during transfer, as much as 10% of the bacterial cells on a moist donor fabric could be acquired by the hands, and that the transfer from moist hands to fabric could be as high as 85%. In the study by Scott and Bloomfield (1990), the contact time between the donor and recipient surfaces was three times longer (30 s); the acquired bacteria were detected by pressing the fingers directly on the surface of a semi-solid culture medium, and the transfer reported was as high as 30%.

In the present study, even with a shorter contact time and a much smaller surface area for contact, the numbers of cfu transferred were as high as 700, and, on a proportional basis, these numbers compare well with those reported by Scott and Bloomfield (1990).

In the experimental system designed and described here, the standard volume of the microbial suspension used was just enough to contaminate the exposed surface of the test fabric. The number of cfu (about 10^5) placed on each donor surface was in line with the levels of bacterial contamination acquired by used articles of clothing and hands (Saltzman *et al.* 1967).

Each fabric piece was eluted by vortexing it for 1 min in 2 ml eluent because this volume was needed to completely immerse the fabric piece. Vortexing was selected because it required fewer handling steps, thus reducing the chances of sample contamination and the risk of exposure of the laboratory personnel to the test bacterium. In previous studies (Wilkoff *et al.* 1969), fabrics were eluted by cutting them into smaller pieces before macerating them in saline.

Fingerpads were eluted by the method of Ansari *et al.* (1989). This has already been shown to be an efficient and reproducible way of recovering bacteria from skin. It was also fully quantitative, in contrast to the approaches described earlier (Scott and Bloomfield 1990; Noskin *et al.* 1995).

The decontamination of the hands of the volunteers with 75% ethanol was not only safe but also highly effective in ridding the skin of both transient and resident skin microflora. Also, such treatment did not leave any residue on the skin which could interfere with the viability or recovery of the bacteria inoculated or transferred.

The hands of the volunteers were inspected thoroughly just prior to each experiment to rule out the presence of any cuts, abrasions or other damage to the skin. The contamination of only the fingerpads was also much safer for the volunteers because it avoided the possibility of any skin infections due to invisible breaks and cuts in other parts of their hands.

The level of pressure used in these experiments reflects that regularly applied when contacting various objects and porous or non-porous environmental surfaces (Mbithi *et al.* 1992). Since friction is often applied when contacting fabrics, its effect was also investigated using a standardized format.

A simple agar medium was used for bacterial recovery from the eluates because selective/differential media are much less hospitable for injured or stressed cells (LeChevallier and McFeters 1985). While no germicides were used in this study, stress on the bacteria due to drying and contact with the animate and inanimate surfaces could not be discounted.

While the basic objective of this investigation was to develop a quantitative method and apply it to study the transfer of a common bacterial pathogen, the data generated in this and future studies should be of value in the design of better models for assessing health risks that may be associated with pathogens in fabrics. Similar experiments using other types of fabrics, such as wool and 100% synthetics, and contact transfer of pathogens between fabrics of different types, should be considered. It would also be valuable to use the basic experimental design described here to study the transfer of pathogens from fingerpads to clean pieces of fabric.

The methodology described here has the potential for generating data for modelling disease transmission through fabrics and risk reduction from their laundering or decontamination.

REFERENCES

Ansari, S.A., Sattar, S.A., Springthorpe, V.S., Wells, G.A. and Tostowaryk, W. (1989) In vivo protocol for testing efficacy of hand-washing agents against viruses and bacteria: experiments with rotavirus and *Escherichia coli*. *Applied and Environmental Microbiology* **55**, 3113–3118.

AOAC (1998) Official Method 960.09. In *Official Methods of Analysis of AOAC International* 17th edn. AOAC International, Washington DC, USA.

Barrie, D., Wilson, J.A., Hoffman, P.N. and Kramer, J.M. (1992) *Bacillus cereus* meningitis in two neurosurgical patients: an investigation into the source of the organism. *Journal of Infection* **25**, 291–297.

Graham, M.L., Sattar, S.A. and Springthorpe, V.S. (1996) Ex vivo protocol for testing virus survival on human skin: experiments with Herpesvirus 2. *Applied and Environmental Microbiology* **62**, 4252–4255.

LeChevallier, M.W. and McFeters, G.A. (1985) Enumerating injured coliforms in drinking water. *Journal of the American Water Works Association* **77**, 81–87.

Mackintosh, C.A. and Hoffman, P.N. (1984) An extended model for transfer of microorganisms via the hands: differences between organisms and the effect of alcohol disinfection. *Journal of Hygiene* **92**, 345–355.

Marples, R.R. and Towers, A.G. (1979) A laboratory model for the investigation of contact transfer of micro-organisms. *Journal of Hygiene* **82**, 237–248.

Mbithi, J.N., Springthorpe, V.S., Boulet, J.R. and Sattar, S.A. (1992) Survival of hepatitis A virus on human hands and its transfer on contact with animate and inanimate surfaces. *Journal of Clinical Microbiology* **30**, 757–763.

McNeil, E. (1964) Dissemination of microorganisms by fabrics and leather. *Developmental and Industrial Microbiology* **5**, 30–35.

Morris, G. Jr and Potter, M. (1997) Emergence of new pathogens as a function of changes in host susceptibility. *Emerging Infectious Diseases* **3**, 435–441.

Neely, A.C. and Maley, M.P. (2000) Survival of enterococci and staphylococci on hospital fabrics and plastic. *Journal of Clinical Microbiology* **38**, 724–726.

Noskin, G.A., Stosor, V., Cooper, I. and Peterson, L.R. (1995) Recovery of vancomycin-resistant enterococci on fingertips and environmental surfaces. *Infection Control and Hospital Epidemiology* **16**, 577–581.

Popham, W.J. and Sirotnik, K.A. (1992) *Understanding Statistics in Education*. Itasca, IL, USA: F.E. Peacock Publishers.

Saltzman, T.C., Clark, J.J. and Klemm, L.M. (1967) Hand contamination of personnel as a mechanism of cross-infection in nosocomial infections with antibiotic-resistant *Escherichia coli* and *Klebsiella aerobacter*. *Antimicrobial Agents and Chemotherapy* **7**, 97–100.

Sattar, S.A. and Springthorpe, V.S. (1996) Transmission of viral infections through animate and inanimate surfaces and infection control through disinfection. In *Modeling Disease Transmission and its Prevention by Disinfection* ed. Hurst, C.J. pp. 224–257. Cambridge: Cambridge University Press.

Scott, E. and Bloomfield, S.F. (1990) The survival and transfer of microbial contamination via cloths, hands and utensils. *Journal of Applied Bacteriology* **68**, 271–278.

Standaert, S.M., Hutcheson, R.H. and Schaeffner, W. (1994) Nosocomial transmission of salmonella gastroenteritis to laundry workers in a nursing home. *Infection Control and Hospital Epidemiology* **15**, 22–26.

Strausbaugh, L. (1997) Antimicrobial resistance: problems, laments and hopes. *American Journal of Infection Control* **25**, 294–296.

Terpstra, P.M.J. (1998) Domestic and institutional hygiene in relation to sustainability. Historical, social and environmental implications. *International Biodeterioration and Biodegradation* **41**, 169–175.

Weernink, A., Severin, W.P.J., Tjernberg, I. and Dijkshoorn, L. (1995) Pillows, an unexpected source of *Acinetobacter*. *Journal of Hospital Infection* **29**, 189–199.

Whyte, W. (1988) The role of clothing and drapes in the operating room. *Journal of Hospital Infection* **11** (Suppl. C), 2–17.

Wilkins, K. and Park, E. (1998) Home care in Canada. *Health Reports* **10**, 29–37.

Wilkoff, L.J., Westbrook, L. and Dixon, G.J. (1969) Factors affecting the persistence of *Staphylococcus aureus* on fabrics. *Applied Microbiology* **17**, 268–274.