American Journal of Infection Control 41 (2013) 19-23

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major article

The effect of glove material upon the transfer of methicillin-resistant *Staphylococcus aureus* to and from a gloved hand

Ginny Moore PhD [a,*], Charles W. Dunnill PhD [b], A. Peter R. Wilson MD, FRCP, FRCPath [a]

[a] *Clinical Microbiology and Virology, University College London Hospitals NHS Foundation Trust, London, UK*
[b] *Department of Chemistry, Centre for Materials Research, University College London, UK*

Key Words:
Disposable gloves
Cross contamination
MRSA

Background: Although disposable gloves can protect the hands of a health care worker from acquiring bacteria, during patient care the glove surface itself can become heavily contaminated making cross transmission via contaminated gloved hands likely. The aim of this study was to determine whether the type of glove worn by health care workers could influence the spread of methicillin-resistant *Staphylococcus aureus* (MRSA).

Methods: Laboratory studies were conducted to assess the ease with which MRSA was transferred between different types of glove and surfaces likely to be found within the ward environment.

Results: In the absence of simulated body fluid, mean bacterial transfer to and from the different gloves ranged from 0.1% to 16% and from 0.01% to 19.5%, respectively. Glove material and glove hydrophobicity were identified as the 2 most important factors influencing bacterial transfer. Nitrile gloves were associated with the lowest transfer rates. The highest numbers of bacteria were transferred to and from the most hydrophilic and most hydrophobic glove, respectively. The adsorption of simulated body fluids altered the physiochemical properties of the gloves. Bacterial transfer significantly increased and was similar to and from all glove types.

Conclusion: Disposable glove type can affect cross-contamination rates among patient, health care worker, and environment. Nonetheless, choice of glove should be considered less important than the correct use of gloves and proper hand hygiene.

In the United Kingdom, hospital-acquired infection costs the National Health Service £1 billion a year, affects 1 in 10 patients, and is responsible for 5,000 deaths annually. Nosocomial pathogens can reach patients by a variety of routes, and, although the relative contribution of each vector is disputed, transmission by health care workers hands is considered the most likely. Consequently, hand hygiene, either by handwashing or hand disinfection, is considered the most important means of preventing nosocomial infections and should form the basis of infection prevention and control in all clinical areas.[1,2] However, hand hygiene is often poorly performed by health care workers, and compliance with recommended hand-hygiene practices can be low.

Poor adherence to hand hygiene has long been a concern, and, in the early 1980s, guidelines were issued recommending gloves as a practical means of preventing transient hand contamination and cross transmission of pathogens.[3] Gloves continue to be an important element of personal protective equipment and, in accordance with recent evidence-based practice in infection control (epic)[4] and Healthcare Infection Control Practices Advisory Committee[5] guidelines, "must be worn for invasive procedures; contact with sterile sites and nonintact skin or mucous membranes; and all activities that have been assessed as carrying a risk of exposure to blood, body fluids, secretions or excretions, or sharp or contaminated instruments".[4] Health care workers caring for patients colonized or infected with pathogens transmitted by the contact route, for example, methicillin-resistant *Staphylococcus aureus* (MRSA), should also wear gloves "for all interactions that may involve contact with the patient or potentially contaminated areas in the patient's environment".[5]

Disposable gloves should be worn as single-use items; they should not be washed, decontaminated, or reprocessed.[4,6] Whereas

* Address correspondence to Ginny Moore, PhD, UCLH Environmental Research Group, Department of Microbiology, Royal Free Hampstead NHS Foundation Trust, London NW3 2Q, UK.

E-mail address: ginny.moore@uclh.nhs.uk (G. Moore).

Supported, in part, by the UCLH/UCL CBRC/NIHR Biomedical Research Centres funding scheme (to A.P.R.W.), and The Healthcare Infection Society, which provided funding for consumables.

Conflicts of interest: None to report.

0196-6553/$36.00 -
doi:10.1016/j.ajic.2012.03.017

health care workers often remove gloves after a single contact,[7] they are less likely to change gloves between procedures, particularly those conducted on the same patient.[7,8] Pittet et al observed health care workers to change gloves after interacting with a patient on just 16% of occasions.[9] Of those interactions considered by Thompson et al to be associated with "potential microbial transmission," 75% occurred because of a failure to change or remove gloves.[10] Katherason et al reported that more than 70% of staff failed to change gloves between patients and/or procedures,[11] and Girou et al concluded that failure to remove gloves after patient contact resulted in 64% of all contacts being performed without adequate hand hygiene.[3]

Gloves manufactured for health care purposes are available in a variety of materials (eg, natural rubber latex, vinyl, and nitrile). Although the sensitivity of both patient and caregiver to latex proteins must be taken into account, the selection of glove type is usually based on its ability to protect against bloodborne viruses (ie, its strength and permeability) and the ability of the wearer to maintain dexterity.[4] However, the failure to change or remove gloves facilitates the spread of microorganisms,[6] and, given the observed level of improper glove use, we propose that the ease with which nosocomial pathogens can be transferred to and from the glove material should also be considered.

Microorganism, moisture level, inoculum size, and donor and recipient surface properties can all influence the transfer of bacteria from surface to surface.[1] Very little information exists regarding the effect of glove type upon cross-contamination rates. The aim of this study was to assess, under controlled laboratory conditions, the ease with which MRSA is transferred to and from different glove materials and a range of environmental surfaces.

METHODS

Selection and characterization of gloves

Seven different gloves were selected on the basis of material (latex, nitrile, vinyl) and/or protein content (as stated by the manufacturer). The gloves were further characterized by their hydrophobicity (Table 1). Drops of 8.6 μL were formed and dispensed under gravity from a gauge 27 needle. Once equilibrium had been achieved, the drops were photographed on the surface of each glove using a side-mounted camera. The contact angle ($^{\theta}$) of each drop was measured using an optical contact angle measuring system (FTA 1000; First Ten Angstroms Inc, Portsmouth, VA); the greater the contact angle, the more hydrophobic the glove material.

Preparation of test surfaces

Three high-contact surfaces of the type and in the condition of those likely to be found in the ward environment were used throughout the study. These included a plastic storage trolley drawer (used and slightly scored), a mild steel bed rail (painted with nylon polyester), and a silicone-coated computer keyboard (Contech, Cambridgeshire, UK).[12] The drawer and bed rail were marked with 1.5-cm × 1.5-cm test areas. The keyboard was delineated using the individual computer keys.

Prior to inoculation, each surface was cleaned using antibacterial wipes (active ingredients: peroxides, benzalkonium chloride; VWR International, Lutterworth, UK), rinsed thoroughly with boiling water, and left to air-dry at room temperature. Preliminary experiments confirmed that this cleaning protocol effectively removed all chemical residues (ie, that there was no residual antibacterial effect) and consistently reduced microbial numbers to below detectable levels.

Table 1
Glove material and associated contact angle

Glove	Material	Visual appearance of fingertip	Mean (SD) contact angle
A	Latex	Smooth	77 (2)
B	Latex; low protein content (<50 μg/g)	Smooth	114 (1)
C	Latex; very low protein content (<10 μg/g)	Smooth	41 (2)
D	Nitrile plus accelerator	Textured	79 (7)
E	Nitrile without chemical accelerators	Lightly textured	94 (3)
F	Nitrile	Textured	98 (7)
G	Vinyl	Smooth	64 (5)

NOTE. Values represent the means (and standard deviation) of 3 replicate measurements.
The greater the contact angle, the more hydrophobic the glove material.

Test organism and preparation of bacterial suspensions

A single colony of methicillin-resistant *Staphylococcus aureus* (a clinical isolate previously typed as being EMRSA-15) was aseptically transferred into 10 mL sterile nutrient broth (Oxoid, Basingstoke, UK). A stationary-phase culture ($\sim 10^8$ colony-forming units [cfu]/mL) was obtained by incubating the bacteria at 37°C for 18 hours. After incubation, the culture was transferred to a sterile universal container and centrifuged at 3,000 rpm for 10 minutes. The supernatant was discarded and the remaining pellet resuspended in 10 mL, sterile, one-quarter-strength Ringer's solution; oxalated horse blood (Oxoid); or, to represent proteinaceous organic debris, tryptone soya broth (TSB; Oxoid) supplemented with 5% horse serum (HS; Oxoid). Each bacterial suspension was diluted 100-fold using the corresponding test soil.

Cross-contamination assay

Transfer of MRSA from a contaminated glove to a clean, dry environmental surface

A test glove was donned over the investigator's washed and disinfected hand. Ten microliters of test suspension (containing approximately 10^4 cfu of MRSA) was inoculated onto the pad of the forefinger and spread over a 1.0-cm × 1.0-cm area. Immediately after inoculation, the gloved finger was pressed onto a single test area for 5 seconds. The glove was discarded and the recipient test surface sampled using a premoistened cotton-tipped swab. The swab bud was snapped off into 1 mL one-quarter-strength Ringer's solution and vortexed for 20 seconds to release the bacteria. One hundred microliters of the resulting suspension was plated onto blood agar.

Transfer of MRSA from a contaminated surface to a disposable glove

Ten microliters of bacterial suspension ($\sim 10^4$ cfu) was inoculated onto a test surface and spread over a single 2.25-cm^2 test area. A test glove was donned by the investigator and the forefinger pressed onto the test area for 5 seconds. The glove was aseptically removed and the fingertip snipped into 1 mL one-quarter-strength Ringer's solution before being vortexed for 20 seconds to release the bacteria. One hundred microliters of the resulting suspension was plated onto blood agar. All agar plates were incubated at 37°C for 24 hours.

Statistical analysis

Transfer rate (TR) gives a straightforward indication of the probability of cross contamination[13] and is expressed as the percentage ratio of the number of bacteria on the 2 surfaces in question:

$$\text{TR } (\%) = (\text{cfu recovered from recipient surface}/\text{cfu inoculated onto donor surface}) \times 100$$

Each experiment comprised 10 replicate samples and was repeated using each glove in combination with each surface and contaminating soil. Data analysis was performed using Microsoft Excel 2007 (Microsoft Corp, Redmond, WA). Transfer rates were log-transformed to normalize the data[14] and compared using a 1-way analysis of variance combined with Tukey multiple comparison test. Multiple regression analysis was performed to investigate which factors (glove material, glove hydrophobicity, environmental surface, soil type) were most important in relation to transfer rate.

RESULTS

Transfer of MRSA from a contaminated glove to a clean, dry environmental surface

In the absence of contaminating soils (ie, when the bacteria were suspended in one-quarter-strength Ringer's solution), mean bacterial transfer from disposable glove to test surface ranged from 0.01% to 19.5% (Table 2). Transfer of MRSA from nitrile glove D to any of the recipient surfaces did not exceed 0.7% and was significantly lower than that from any of the other gloves tested ($P < .05$). Bacterial transfer from nitrile glove E ranged from 4% to 8%, which, in turn was significantly lower than that from nitrile glove F (11% to 14%). Regardless of test surface, the highest transfer rates were from latex gloves A and B (Table 2). These gloves consistently transferred significantly more bacteria than gloves D, E, and latex glove C ($P < .05$).

Multiple regression analysis confirmed the regression coefficients for latex and nitrile gloves had a positive ($t = 2.14$, $P = .03$) and negative ($t = -6.28$, $P < .0001$) effect on transfer rate, respectively, and demonstrated that, in the absence of organic soiling, glove material and glove hydrophobicity ($t = 9.04$; $P < .0001$) were the 2 most important factors influencing the number of bacteria transferred from a contaminated glove (adjusted $R^2 = 0.50$; $P < .0001$). The effect of recipient surface was weaker but was also significant. In general, more bacteria were transferred to the bed rail ($t = 2.18$, $P = .03$) and fewer to the trolley drawer ($t = -1.98$, $P = .05$).

In the presence of contaminating soils (ie, when the bacteria were suspended in blood or TSB + HS), bacterial transfer from disposable glove to test surface ranged from 8% to 50.5% (Table 2). Regression analysis confirmed that blood and TSB + HS had a positive effect on transfer rate. However, it was the presence of a contaminating soil ($t = 13.61$, $P < .0001$) rather than the type of contaminating soil ($t = 0.95$, $P = .34$) that was the most important influencing factor.

When suspended in blood or TSB + HS, the transfer of MRSA from latex glove C ranged from 8.5% to 33% (Table 2), significantly lower than that from latex glove B or any of the nitrile gloves (D, E, F; $P < .05$). Latex glove B and nitrile glove E consistently transferred the highest number of bacteria, significantly more than latex gloves A and C and vinyl glove G ($P < .05$). Although differences existed among the different glove types, in the presence of organic soiling, the regression coefficients for glove material had no effect on transfer rate ($P > .1$). Glove hydrophobicity and recipient surface were important factors (adjusted $R^2 = 0.23$; $P < .0001$), and, whereas bacterial transfer increased with glove hydrophobicity ($t = 6.12$; $P < .0001$), fewer bacteria were transferred to the trolley drawer ($t = -4.90$; $P < .001$) and computer keyboard ($t = -9.41$; $P < .0001$) than to the bed rail.

Transfer of MRSA from a contaminated surface to a disposable glove

In the absence of contaminating soils, mean bacterial transfer from test surface to disposable glove ranged from 0.1% to 16% (Table 3). Regardless of donor surface, the transfer of MRSA to glove D was significantly lower than to any of the other gloves tested ($P < .05$). In general, significantly fewer bacteria were transferred to nitrile gloves than to latex or vinyl gloves ($P < .05$). The highest numbers of bacteria were consistently transferred to gloves C and G (Table 3).

Glove material and glove hydrophobicity were the most important factors influencing bacterial transfer from a contaminated surface to a gloved hand (adjusted $R^2 = 0.57$; $P < .0001$). The regression coefficient for vinyl gloves ($t = 2.17$; $P = .03$) had a positive effect on transfer rate, whereas those for nitrile gloves ($t = -11.1$; $P < .0001$) and glove hydrophobicity ($t = -4.88$; $P < .0001$) had a negative effect. Donor surface also influenced the transfer of MRSA, with more bacteria being transferred from the computer keyboard than from the trolley drawer ($t = 3.49$; $P = .0005$).

The presence of organic soil significantly increased the number of MRSA transferred to all glove types ($P < .0001$). Mean bacterial transfer ranged from 7% to 71% (Table 3), and significantly more bacteria were transferred to gloves B, C, and F than to any of the other gloves tested ($P < .05$). The type of contaminating soil had a significant effect on bacterial transfer ($t = 2.66$; $P = .008$), with more bacteria being transferred from a surface contaminated with TSB + HS than from one contaminated with blood. Regression analysis implied that glove hydrophobicity ($t = -6.01$; $P < .0001$), glove material, and donor surface were more important influencing factors. More bacteria were transferred to latex ($t = 4.92$; $P < .0001$) than to vinyl gloves, and more bacteria were transferred from the trolley drawer ($t = 5.20$; $P < .0001$) than from the bed rail or the computer keyboard. Nonetheless, the multiple correlation coefficient (R^2) was small (0.19), suggesting that, in this case, the variation in the number of bacteria transferred to a gloved hand was more likely because of random error and/or variables not included in the study.

DISCUSSION

There is evidence to suggest that glove use can interrupt nosocomial transmission.[15,16] However, during patient care, the glove surface itself can become heavily contaminated,[3,9,17] and the ease with which pathogens can be transferred from the gloves of health care workers to patients and/or environmental surfaces has been demonstrated.[18] An outbreak of *Acinetobacter calcoaceticus* var *anitratus* has been directly attributed to contaminated latex gloves.[19] In this case and others, health care workers perceived glove use as a self-protective practice rather than one of infection prevention and control.[19,20]

Bacterial transfer is largely determined by the adhesion forces between cell and surface(s). For transfer to occur, the bacteria must detach from one surface and adhere to another.[21] During the current study, in the absence of contaminating soils, glove hydrophobicity and glove material were the 2 most important factors influencing bacterial transfer to and from a gloved hand. It is well documented that bacteria can rapidly attach to a variety of different surfaces with hydrophilic strains preferentially adhering to hydrophilic materials.[14,21] *Staphylococcus aureus* has been shown to readily transfer to hydrophilic surfaces (eg, stainless steel), yet, because of strong adhesion forces, its potential to transfer from such a surface to other materials is markedly reduced.[22] The transfer of MRSA was greatest to latex glove C, the most hydrophilic

Table 2
Transfer of MRSA from different disposable glove types to a range of environmental surfaces

		Mean (SD) transfer rate (%)						
		Glove type						
		Latex			Nitrile			Vinyl
Surface	Suspending medium	A	B	C	D	E	F	G
Bed rail	Ringer's	16.5 (5.6)	18 (5.2)	10 (4.7)	0.7 (1.1)	7 (3.7)	14 (4.7)	11 (3.4)
	TSB + HS	18 (6.4)	23 (5.6)	9 (4.6)	8 (1.5)	15 (2.9)	19 (4.8)	15 (5.0)
	Blood	29 (5.8)	49 (19.4)	33 (3.7)	34 (6.1)	36 (8.0)	50.5 (6.8)	43 (8.0)
Keyboard	Ringer's	16 (1.6)	19.5 (3.8)	7 (1.9)	0.4 (0.5)	4 (3.0)	11 (3.8)	7.5 (1.9)
	TSB + HS	12 (2.3)	18 (3.3)	12 (2.7)	15 (2.4)	44 (11.5)	14 (3.7)	15 (2.9)
	Blood	14.5 (8.3)	17 (4.1)	8.5 (2.5)	18 (4.2)	19 (3.6)	13 (2.7)	9 (1.9)
Drawer	Ringer's	11 (3.2)	11 (1.3)	6 (1.4)	0.01 (0)	8 (3.9)	11 (3.4)	8 (3.4)
	TSB + HS	34 (9.4)	37 (11.1)	27 (10.3)	31 (10.5)	45 (11.0)	29.5 (7.3)	23 (6.7)
	Blood	11 (2.4)	16 (3.4)	10 (1.4)	23 (3.6)	25 (11.6)	18 (2.8)	17 (6.0)

HS, 5% Horse serum; *TSB*, tryptone soya broth.
NOTE. MRSA suspended in one-quarter-strength Ringer's solution, tryptone soya broth supplemented with 5% horse serum (TSB + HS), or oxalated horse blood. The higher the transfer rate, the more bacteria were transferred from glove to surface. Values represent the means (and standard deviation) of 10 replicate samples.

Table 3
Transfer of MRSA from a range of environmental surfaces to different types of disposable gloves

		Mean (SD) transfer rate (%)						
		Glove type						
		Latex			Nitrile			Vinyl
Surface	Suspending medium	A	B	C	D	E	F	G
Bed rail	Ringer's	5 (1.6)	8 (2.3)	15 (3.0)	0.1 (0.1)	2 (1.7)	2 (0.8)	9 (1.4)
	TSB + HS	27 (5.5)	29 (12.5)	40 (18.4)	25 (7.4)	28 (5.0)	24.5 (6.2)	35 (8.7)
	Blood	12 (1.9)	14 (3.3)	47 (34.1)	13 (2.4)	5.5 (1.1)	48 (14.5)	3 (0.4)
Keyboard	Ringer's	5 (2.6)	9 (2.4)	12 (2.8)	0.3 (0.74)	3 (3.2)	4 (2.0)	16 (6.1)
	TSB + HS	28 (4.7)	28 (6.5)	35 (5.5)	21 (7.0)	25 (5.5)	20.5 (4.8)	30 (9.7)
	Blood	28 (7.5)	23 (3.3)	43 (10.9)	19 (4.1)	11.5 (3.1)	42 (6.4)	7 (1.8)
Drawer	Ringer's	8 (4.6)	6 (2.1)	10 (3.5)	0.5 (0.9)	0.4 (0.3)	2 (0.8)	8 (3.4)
	TSB + HS	41 (5.5)	34.5 (16.0)	37 (17.0)	25.5 (16.4)	33 (7.7)	25 (15.8)	54 (21.2)
	Blood	56 (16.1)	8 (2.1)	71 (23.0)	10 (6.1)	23 (6.5)	56 (24.4)	15 (4.7)

HS, 5% Horse serum; *TSB*, tryptone soya broth.
NOTE. MRSA suspended in one-quarter-strength Ringer's solution, tryptone soya broth supplemented with 5% horse serum (TSB + HS), or oxalated horse blood. The higher the transfer rate, the more bacteria were transferred from surface to glove. Values represent the means (and standard deviation) of 10 replicate samples.

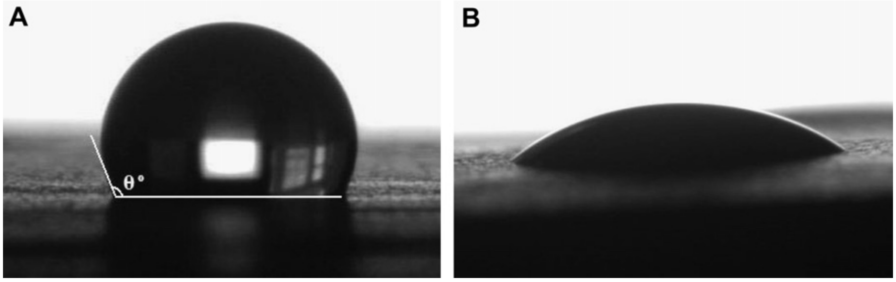

Fig 1. Water contact angle (θ°) associated with (A) latex glove B (θ = 114°) and (B) latex glove C (θ = 41°).

of the gloves tested (θ = 41°), yet transfer from this glove type was generally lower than that from any other glove. In contrast, the highly hydrophobic glove B (θ = 114°) consistently transferred the highest numbers of bacteria (Table 2).

Figure 1 illustrates how latex gloves B and C differ in terms of their hydrophobicity and how the higher surface free energy associated with glove C increases the wettability of the surface. This wetting allows for closer association between bacteria and surface and, despite a relatively short attachment time, likely encouraged bonds between bacteria and glove C to form. Bacteria inoculated onto glove B were more likely to remain suspended in the droplet and, therefore, more readily detached and transferred. However, in comparison with latex gloves, fewer bacteria were generally transferred to and from nitrile gloves, despite them also being hydrophobic (D [θ = 79°]; E [θ = 94°]; F [θ = 98°]) (Table 2).

An evaluation of materials used in clean rooms aimed to identify a glove that was "clean" (ie, would not transfer molecular or particulate species from its surface) and electrostatic discharge protective (ie, maintain static dissipation).[23] A dissipative material does not accumulate charge, and, thus, such a glove would also attract less particulate contamination to its surface. Nitrile gloves showed the best combination of cleanliness and static dissipation compared with latex or vinyl,[23] and these superior electrical properties may have contributed to the reduced bacterial transfer observed in the current study. Additionally, the fingertips of the latex and vinyl gloves were smooth, whereas those of all 3 nitrile gloves were textured (Table 1). Macroscopic topographical features reduce the contact area between donating and receiving surface. Bacteria colonizing irregularities associated with the donor surface will not come into contact with the recipient surface, and, as such, bacterial transfer is reduced. A lower contact area also results in fewer bacteria being transferred to a rougher surface.[21] These results imply that a textured, moderately hydrophobic, nitrile glove (similar to type D) would be most suited for use within the ward environment. However, when MRSA was suspended in a protein- or blood-based soil, its transfer to and from all glove types, particularly the nitrile gloves, significantly increased.

Surfaces that come into contact with body fluids are rapidly coated with proteins. Once adsorbed, the resulting conditioning film is likely to change the physiochemical properties of the substratum by altering surface resistance and reducing surface rugosity[24] and, as a result, the interaction between bacterium and surface. During the current study, any differences in glove material and/or texture were likely masked by the adsorption of the protein- or blood-based soils. Consequently, any advantage associated with donning a nitrile glove was lost, which, with a few exceptions, resulted in similar bacterial transfer to/from all glove types.

Although the hydrophilic glove C consistently transferred the lowest numbers of MRSA, bacterial transfer to this glove type was considerable: in some cases as high as 70% (Table 3). When the surface contamination was blood based, the number of bacteria picked up by vinyl gloves was comparatively low, yet this glove type is prone to leaks and more likely to be associated with hand contamination.[25-27] Thus, although glove choice becomes less important if contact with body fluids is likely, neither latex glove C nor the vinyl glove would be the most appropriate glove to use during patient care.

Wearing gloves is a major component of contact precautions, yet recent research has suggested that contact precautions may increase the rate of MRSA transmission.[28] The current study demonstrates the ease with which MRSA can be transferred to and from disposable gloves. Bacterial transfer varied depending on the type of glove, the recipient surface, and the presence of simulated body fluids. However, it would be impractical to extrapolate the results from this laboratory-based study and to recommend that, in a 'real life' ward environment, different types of glove should be worn for specific procedures and tasks. Furthermore, whereas more than 97% of hospital surfaces are dry,[29] this study only assessed the transfer of MRSA from a wet, newly contaminated, environmental surface; bacterial transfer is reduced under relatively dry conditions.[30] Within the health care environment, the correct use of gloves and proper hand hygiene may be considered more important than the choice of glove material.[28] Nonetheless, this study reinforces the message that gloves should be single-use items. Failing to remove gloves after patient contact and/or to change them between patients can increase the risk of cross transmission via contaminated gloved hands.

References

1. Pittet D, Allegranzi B, Sax H, Dharan S, Pessoa-Silva CL, Donaldson L, et al. Evidence-based model for hand transmission during patient care and the role of improved practices. Lancet Infect Dis 2006;6:641-52.
2. Humphreys H, Grundmann H, Skov R, Lucet J-C, Cauda R. Prevention and control of methicillin-resistant *Staphylococcus aureus*. Clin Microbiol Infect 2009;15:120-4.
3. Girou E, Chai SHT, Oppein F, Legrand P, Ducellier D, Cizeau F, et al. Misuse of gloves: the foundation for poor compliance with hand hygiene and potential for microbial transmission? J Hosp Infect 2004;57:162-9.
4. Pratt RJ, Pellowe CM, Wilson JA, Loveday HP, Harper PJ, Jones SRLJ, et al. Epic2: national evidence-based guidelines for preventing healthcare-associated infections in NHS hospitals in England. J Hosp Infect 2007;65S:S1-64.
5. Siegel JD, Rhinehart E, Jackson M, Chiarello L, the Healthcare Infection Control Practices Advisory Committee. 2007 guideline for isolation precautions: preventing transmission of infectious agents in healthcare settings. Am J Infect Control 2007;35:S65-164.
6. World Health Organisation (WHO). Guidelines on hand hygiene in healthcare. Geneva [Switzerland]: WHO; 2009.
7. Eveillard M, Guilloteau V, Kempf M, Lefrancq B, Pradelle M-T, Raymond F, et al. Impact of improving glove usage on the hand hygiene compliance. Am J Infect Control 2011;39:608-10.
8. Chau JP-C, Thompson DR, Twinn S, Lee DTF, Pang SWM. An evaluation of hospital hand hygiene practice and glove use in Hong Kong. J Clin Nurs 2011; 20:1319-28.
9. Pittet D, Dharan S, Touveneau S, Sauvan V, Perneger TV. Bacterial contamination of the hands of hospital staff during routine patient care. Arch Int Med 1999;159:821-6.
10. Thompson BL, Dwyer DM, Ussery XT, Denman S, Vacek P, Schwartz B. Handwashing and glove use in a long-term-care facility. Infect Control Hosp Epidemiol 1997;18:97-103.
11. Katherason SG, Naing L, Jaalam K, Mohamad NAN, Bhojwani K, Harussani N, et al. Hand decontamination practices and the appropriate use of gloves in two adult intensive care units in Malaysia. J Infect Dev Ctries 2010;4:118-23.
12. Wilson APR, Ostro P, Magnussen M, Cooper B. Laboratory and in-use assessment of methicillin-resistant *Staphylococcus aureus* contamination of ergonomic computer keyboards for ward use. Am J Infect Control 2008; 36:e19-25.
13. Schaffner DW. Challenges in cross contamination modelling in home and food service settings. Food Aust 2003;55:583-6.
14. Pérez-Rodríguez F, Valero A, Carrasco E, García RM, Zurera G. Understanding and modelling bacterial transfer to foods: a review. Trends Food Sci Technol 2008;19:131-44.
15. Johnson S, Gerding DN, Olson MM, Weiler MD, Hughes RA, Clabots CR, et al. Prospective controlled study of vinyl glove use to interrupt *Clostridium difficile* nosocomial transmission. Am J Med 1990;88:137-40.
16. Safdar NS, Marx J, Meyer NA, Maki DG. Effectiveness of preemptive barrier precautions in controlling nosocomial colonization and infection by methicillin-resistant *Staphylococcus aureus* in a burn unit. Am J Infect Control 2006;34:476-83.
17. Zachary KC, Bayne PS, Morrison VJ, Ford DS, Silver LC, Hooper DC. Contamination of gowns, gloves and stethoscopes with vancomycin-resistant enterococci. Infect Control Hosp Epidemiol 2001;22:560-4.
18. Duckro AN, Blom DW, Lyle EA, Weinstein RA, Hayden MK. Transfer of vancomycin-resistant enterococci via healthcare worker hands. Arch Intern Med 2005;165:302-7.
19. Patterson JE, Vecchio J, Pantelick EL, Farrel P, Mazon D, Zervos MJ, et al. Association of contaminated gloves with transmission of *Acinetobacter calcoaceticus* var. *anitratus* in an intensive care unit. Am J Med 1991;91:479-83.
20. Pan A, Mondello P, Posfay-Barbe K, Catenazzi P, Grandi A, Lorenzotti S, et al. Hand hygiene and glove use behaviour in an Italian hospital. Infect Control Hosp Epidemiol 2007;28:1099-102.
21. Vermeltfoort PBJ, van der Mei HC, Busscher HJ, Hooymans JMM, Bruinsma GM. Physiochemical factors influencing bacterial transfer from contact lenses to surfaces with different roughness and wettability. J Biomed Mater Res Part B: Appl Biomater 2004;71B:336-42.
22. Knobben BAS, van der Mei HC, van Horn JR, Busscher HJ. Transfer of bacteria between biomaterials surfaces in the operating room: an experimental study. J Biomed Mater Res Part A 2007;80A:790-9.
23. Lesniewski T, Yates K. Evaluation of materials used in cleanrooms with ESD sensitive hardware. 22nd Electrical Overstress/Electrostatic Discharge Symposium. ESD Association, Rome, New York: Anaheim, CA; September 26–28, 2000.
24. Gorman SP, Jones DS, Mawhinney WM, McGovern JG, Adair CG. Conditioning fluid influences on the surface properties of silicone and polyurethane peritoneal catheters: implications for infection. J Mater Sci Mater Med 1997;8: 631-5.
25. Olsen RJ, Lynch P, Coyle MB, Cummings J, Bokete T, Stamm WE. Examination gloves as barriers to hand contamination in clinical practice. JAMA 1993;270: 350-3.
26. Rego A, Roley L. In-use barrier integrity of gloves: latex and nitrile superior to vinyl. Am J Infect Control 1999;27:405-10.
27. Korniewicz DM, El-Masri M, Broyles JM, Martin CD, O'Connell KP. Performance of latex and nonlatex medical examination gloves during simulated use. Am J Infect Control 2002;30:133-8.
28. Fuller C, Savage J, Besser S, Hayward A, Cookson B, Cooper B, et al. "The dirty hand in the latex glove": a study of hand hygiene compliance when gloves are worn. Infect Control Hosp Epidemiol 2011;32:1194-9.
29. Griffith CJ, Cooper RA, Gilmore J, Davies C, Lewis M. An evaluation of hospital cleaning regimes and standards. J Hosp Infect 2000;45:19-28.
30. Marples RR, Towers AG. A laboratory model for the investigation of contact transfer of micro-organisms. J Hyg Camb 1979;82:237-48.