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Major article

Fomite-fingerpad transfer efficiency (pick-up and deposit) of *Acinetobacter baumannii*—with and without a latex glove

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Background: *Acinetobacter baumannii* is a significant health care–associated pathogen because it is easily transmitted via fomites, extremely difficult to eradicate from the environment, and highly drug resistant. Understanding the environmentally mediated transmission dynamics of *A baumannii* is critical for more effective infection control. However, transfer efficiency of pathogen pick-up and deposit remains poorly understood. Our study estimates the transfer efficiency of *A baumannii* with and without latex glove use from the fingerpad to a fomite and from a fomite to the fingerpad.

Methods: Fomite-fingerpad transfer efficiencies were determined for 6 materials (glass, stainless steel, porcelain, polypropylene, polycarbonate, and rubber).

Results: For *A baumannii*, the fomite-to-fingerpad transfer efficiency was 24.1%, and the fingerpad-to-fomite transfer efficiency was 5.6%. When latex gloves were worn, the fomite-to-fingerpad transfer efficiency was reduced by 55.9% (to 10.6%) and the fingerpad-to-fomite transfer efficiency was reduced by 47.1% (to 3.0%). The average transfer efficiency between 2 skin surfaces was 32.5%.

Conclusions: The fomite-to-fingerpad transfer efficiency of *A baumannii* was statistically significantly higher than the fingerpad-to-fomite transfer efficiency, regardless of glove use. There was no significant difference in transfer efficiency by material type, except for rubber, which resulted in marginally higher transfer efficiencies. Our results underscore the importance of frequently changing gloves during patient care and frequent handwashing-hand hygiene during bare-handed care for the reduction of pathogen transmission.

Acinetobacter baumannii transmission within hospitals is a significant problem.[1,2] This gram-negative, frequently multidrug-resistant bacterium produces a variety of health care–associated infections, including pneumonia, bacteremia, wound infections, and urinary tract infections, primarily among those who are already very ill, making it particularly a problem within intensive care units.[3] Effective control is challenging because *A baumannii* can survive long periods of desiccation, persisting in the environment for 1-4 months,[4-6] and typical disinfection practices are often inadequate.[7,8] Therefore, understanding the environmentally mediated transmission dynamics of *A baumannii* is critical for identifying a more targeted approach to effective infection control. Previous studies have determined the pick-up transfer efficiencies (fomite-to-fingerpad or hand) for a variety of gram-positive and gram-negative bacteria,[9,10] but to our knowledge, transfer efficiencies in the direction of fingerpad and hand to fomite have not been previously reported. Because these studies have already shown that transfer efficiency is dependent on organism and material type, we have chosen 6 nonporous surface materials that are commonly found in the hospital environment to evaluate the variation in transfer efficiencies.

Most fate and transport mathematical models assume the same transfer efficiency value for calculating both the fomite-to-fingerpad rate of pathogens and the fingerpad-to-fomite rate of pathogens.[11-13] This assumption may be appropriate when the 2 contacting surfaces are composed of the same material of similar physical characteristics (ie, dry skin-skin contact). However, when

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the 2 contacting surfaces are not composed of the same material (ie, contact between the skin and an environmental surface), this assumption may not hold. Moreover, transfer efficiencies of *A baumannii* have never been quantified. Therefore, the first aim of this study is to compare the transfer efficiencies of *A baumannii* in 2 directions: fomite to fingerpad and fingerpad to fomite, with and without the use of latex gloves. For comparative purposes, we also determined the transfer efficiency of *A baumannii* between 2 skin surfaces: fingerpad to fingerpad. Specific pathogen transmission parameters, such as pathogen transfer efficiencies in both directions of transfer, are needed to fill current knowledge gaps of environmental infection transmission systems. These data will enable more robust use of quantitative microbial risk assessment models for exposure assessment and evaluation of pathogen fate and transmission in the hospital environment.

MATERIALS AND METHODS

Ten volunteer subjects participated. The study protocol was reviewed and approved by the University of Michigan Institutional Review Board (HUM00075484).

Preparation of initial inoculum

All transfer experiments were performed using *A baumannii* ATCC 17978 (American Type Culture Collection, Manassas, VA). The initial inoculum was prepared fresh for each experiment by transferring a frozen aliquot of the ATCC 17978 into 2.5 mL of BBL Mueller Hinton II Broth (BD Diagnostics, Sparks, MD) and incubating at 37°C for 18 ± 2 hours on a rotating shaker table (150-180 rpm). The culture was streaked onto BBL Mueller Hinton II Agar (BD Diagnostics, Sparks, MD) and grown at 37°C. An isolated colony was transferred to Mueller Hinton II Broth and incubated at 37°C with shaking at 150-180 rpm for 15-18 hours. From this, a starting culture with an OD600 of 0.200 ± 0.01, which approximates 10^8 colony forming units (CFU)/mL, was used (Synergy HT Multi-Mode Microplate Reader; BioTek Instruments, Winooski, VT).

Preparation of fomite material coupons

All material coupons were round disks that are 1 cm in diameter and approximately 3 mm thick. The following nonporous material coupons were used to determine *A baumannii* transfer efficiencies: medical grade stainless steel (RD128-304), white high grade BUNA-N Rubber (RD128-BUNA), porcelain (RD128-PL), polycarbonate plastic (RD128-PC), polypropylene plastic (RD128-PP), and borosilicate glass (RD128-GL) (all material coupons from BioSurface Technologies, MO). Before and after each use, all material coupons were washed with soap and water, followed by a 70% ethanol bath, and then autoclaved for sterilization.[10]

Method for determining the direct recovery rate of bacteria

The direct recovery rate was determined to estimate the total amount of bacteria that can theoretically be recovered from each surface after drying. The direct recovery rate was used to help validate study results by demonstrating that differences seen between the fomite-to-finger and fingerpad-to-fomite transfer efficiencies were not caused by possible biases in recovery methods from the various surface types. For this determination, a transfer of bacteria between the 2 surfaces was not performed. In triplicate, each material used in these experiments (6 material coupons, glove fingertips, and fingerpads of a hand) was prepared as described for each material type, inoculated with 20 μL (or 1.4×10^9 CFU) of *A baumannii*, and allowed to dry. Once dry (with no transfer event), the bacteria was recovered exactly as subsequently described for that surface type, and the percentage of CFU recovered was calculated by $(CFU_{Recovered}/CFU_{Applied}) \times 100$.

Preparation of volunteer hands

Before and after each transfer event, volunteer hands were prepared using the following control wash procedure regardless of glove use[10]: hands were squirted with 70% ethanol for 10 seconds, alcohol was rubbed thoroughly over hands (concentrating on the finger tips) for 15 seconds, and hands were then rinsed with tap water for 15 seconds. Hands were then scrubbed for 1 minute with 2 mL of Huntington Brand Medi-Scrub liquid soap containing the active ingredient 0.6% chloroxylenol (Ecolab, Hanover, MN) and warm water. Hands were rinsed in warm water for 15 seconds and air dried until thoroughly dry.

Recovering bacteria from the fingerpad

Immediately after each transfer event, bacteria on the finger were recovered using a sterile, individually wrapped CultureSwab (BD Diagnostics, Sparks, MD) swab, moistened in 3 mL of 1 × phosphate-buffered saline (PBS) solution. Excess buffer was first pressed out of the swab by pressing the tip of the swab against the inside of the tube. The fingerpad was swabbed in both a forward-back motion and a side-to-side motion while rotating the tip of the swab.[10] The swab was then returned to the 1× PBS buffer and homogenized in the buffer using Omni Tips disposable rotor stator generator probes (OMNI International, Kennesaw, GA) for 45 seconds to remove all cells from the swab. Samples were then serial diluted to 10^{-3}, spread plated onto Mueller Hinton II Agar, and incubated overnight at 37°C for colony enumeration. All samples were kept on ice during sampling. This swab method was used to avoid an additional step of bacterial transfer (eg, from fingerpad to the inside wall of the centrifuge tube containing the PBS buffer).

Recovering bacteria from fomite coupons and latex gloves

Bacteria on the coupons and gloves were recovered by vortexing the sample in a sterile, 50-mL conical centrifuge tube (Falcon; Corning Life Sciences, Corning, NY) containing 6 mL of 1× PBS buffer for 1 minute. Samples were then serial diluted to 10^{-3}, spread plated onto Mueller Hinton II Agar, and incubated overnight at 37°C for colony enumeration. All samples were kept on ice during processing.

Simulation of fingerpad-to-fomite transfer event by the fingerpad (n = 10)

A cleaned, randomly chosen fingerpad was inoculated with 20 μL of *A baumannii* ATCC 17978 and allowed to air dry for 10-15 minutes in a laminar hood. Once dry, the inoculated fingerpad was placed onto a coupon, applying an average constant pressure of 25 kPa (range, 16-38 kPa) for 30 seconds.[14] This was performed using a top-loading balance (XP-150; Denver Instrument, Bohemia, NY) to monitor the amount of pressure applied in grams per centimeter squared. After the transfer event was complete, the coupon was placed in a centrifuge tube containing 1× PBS buffer, and the finger was swabbed (Fig 1A). All samples were stored on ice.

Simulation of fingerpad-to-fomite transfer event by the latex glove (n = 10)

Powder-free, single-use, latex examination gloves (19-058-801C; Thermo Fisher Scientific, Pittsburgh, PA) were placed on a clean hand (cleaned as previously described). The fingerpads of the

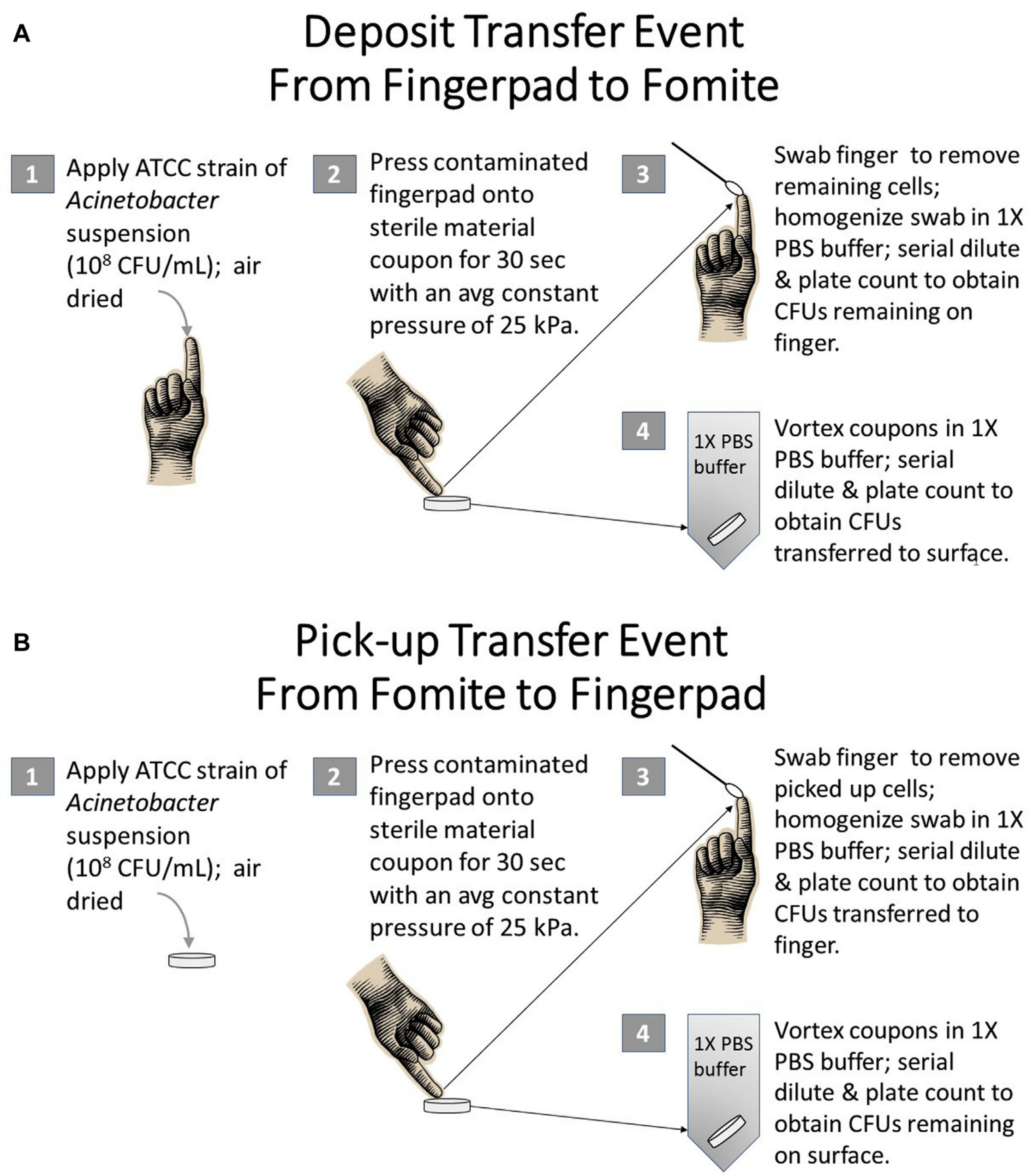

Fig 1. Schematic show of procedures for simulating deposit (A) and pick-up (B) transfer events. *CFU*, colony forming units; *PBS*, phosphate-buffered saline.

glove were cleaned with 70% ethanol, inoculated with 20 μL of *A baumannii* ATCC 17978, and allowed to air dry in a laminar hood. Once dry, the inoculated area of the latex fingerpad was placed onto a coupon, and the transfer event was performed in the same manner as for determining the fingerpad-to-fomite transfer efficiency previously described (Fig 1A). After the transfer event was complete, the top 3 cm of the glove fingertip was aseptically snipped from the finger and immediately placed into a centrifuge tube containing 1× PBS buffer. The coupon was placed in a separate centrifuge tube containing 1× PBS buffer.

Simulation of fomite-to-fingerpad transfer event by the fingerpad (n = 10)

Sterile coupons were inoculated with 20 μL of *A baumannii* ATCC 17978 and allowed to air dry for 15-20 minutes in a laminar hood. Once dry, a cleaned fingerpad was placed onto the contaminated coupon, applying an average constant pressure of 25 kPa (range, 16-38 kPa) for 30 seconds, using the same top-loading balance as previously described. After the transfer event was complete, the coupon was placed in a centrifuge tube containing 1× PBS buffer, and the finger was swabbed (Fig 1B).

Simulation of fomite-to-fingerpad transfer event by the latex glove (n = 10)

This was performed in the same manner as the pick-up transfer efficiency by the fingerpad except that the cleaned hand was wearing a latex glove (Fig 1B). After the transfer event was complete, the top 1.5 in of the glove finger was aseptically snipped from the finger and immediately placed into a centrifuge tube containing 1× PBS buffer.

Simulation of fingerpad-fingerpad (skin-skin) transfer event (n = 6)

A cleaned fingerpad was inoculated with 20 μL of *A baumannii* ATCC 17978 and allowed to air dry for 10-15 minutes in a laminar hood. Once dry, the inoculated fingerpad (the donor finger) was pressed up against a clean recipient finger with pressure similar to that of a handshake for 1 minute. This was performed with 3 fingers at a time (fore, middle, and ring fingers) to achieve consistency in applied pressure between transfer events. Both the donor and recipient fingers were swabbed, and samples were stored on ice.

Statistical analysis

Mean colony counts recovered from the material coupons, fingerpads, and gloves were determined and used to calculate percentage transfer efficiency. Colony forming units recovered (CFU_R) were determined for both surfaces involved in each transfer event. CFU_R were used to calculate the percentage transfer efficiency for each direction in the transfer event where CFU_R = (average CFU counted/volume of sample plated) × (sample volume) × (dilution factor).

$$\text{Percentage transfer efficiency}^{14} = \left[\frac{CFU_{RR}}{(CFU_{RR} + CFU_{RD})}\right] \times 100$$

where CFU_{RR} = CFU recovered from the recipient surface, and CFU_{RD}=CFU recovered count from the donor surface.

All statistical analysis was performed using GraphPad Prism 6 for Windows (Version 6.01; GraphPad Software, La Jolla, CA). Statistical significance was assessed using paired and unpaired *t* tests (as appropriate), the Holm-Šídák test, and 1-way analysis of variance (ANOVA) with a significance level of $\alpha \leq 0.05$. To account for the possible errors in initial inoculum and differences in our ability to measure bacteria from each surface, a multivariate logistic regression analysis was conducted, which included the theoretical recovery and variation in initial concentration. Regression analysis was performed using R: A Language and Environment for Statistical Computing (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Table 1 shows the bidirectional transfer efficiency results generated by the fingerpad and latex glove and transfer efficiencies by material type for both directions of transfer. Four samples were removed from the analysis because of documented sampling or processing errors in the laboratory. We found that the fomite-to-fingerpad transfer efficiency was statistically significantly higher than the fingerpad-to-fomite deposit transfer efficiency for all material types, regardless of glove use, with the exception of rubber when gloves were worn (unpaired *t* test, *P* value = .37) (Table 1). The fomite-to-fingerpad transfer efficiencies did not depend on material type, regardless of glove use (fingerpad and latex glove 1-way ANOVA, *P* = .08 and *P* = .26, respectively) (Table 1). The fingerpad-to-fomite transfer efficiencies by the bare fingerpad also did not depend on material type, but when gloves were worn, we found a statistically significant difference in the fingerpad-to-fomite transfers by material type (1-way ANOVA, *P* = .30 and *P* = .01, respectively) (Table 1). A pairwise comparison of the latex glove fingerpad-to-fomite transfer efficiencies singles out the transfer efficiency to rubber as statistically significantly higher than glass, stainless steel, porcelain, polypropylene, and polycarbonate (*P* = .002, *P* = .002, *P* = .003, *P* = .005, and *P* = .02, respectively).

The overall mean transfer efficiencies generated with and without latex glove use, skin-skin transfer efficiencies, and associated statistical significances are shown in Table 2. Regardless of

Table 1
Average percentage TE by material type for transfers occurring by the fingerpad only and for transfers with the use of latex gloves

	Average percentage TE by material type										
	Fingerpad					Latex gloves					Fingerpad versus latex gloves	
Fomite material type	Fomite to fingerpad (% TE) ± SD	Min-Max	Fingerpad to fomite (% TE) ± SD	Min-Max	*t* test *P* value*	Fomite to fingerpad (% TE) ± SD	Min-Max	Fingerpad to fomite (% TE) ± SD	Min-Max	*t* test *P* value†	Fomite to fingerpad‡	Fingerpad to fomite§
Glass	22.00 (13.51)	4.50-44.00	5.40 (2.49)	2.53-10.46	.0013	11.73 (14.48)	0.0-45.09	0.82¶ (1.58)	0.0-4.87	.039	<0.0001	<0.0001
Stainless steel	21.11 (11.44)	6.98-37.66	5.59 (4.55)	0.67-16.70	.0009	5.39 (4.67)	0.0-11.76	0.71 (0.61)	0.0-1.84	.006	0.001	<0.0001
Porcelain	27.43 (15.46)	10.4-53.72	4.80 (5.27)	0.40-4.80	.0004	6.07 (4.34)	0.25-12.28	1.18 (2.04)	0.0-6.54	.005	<0.0001	0.009
Polypropylene	21.37 (13.30)	3.70-43.75	4.21 (3.99)	0.34-12.63	.0010	11.02 (12.80)	0.0-36.67	1.62¶ (2.61)	0.0-7.63	.045	0.063	0.030
Polycarbonate	17.26 (10.30)	4.82-39.91	3.80 (3.64)	0.23-12.28	.0011	13.56 (13.73)	0.0-39.15	3.45 (6.11)	0.0-16.84	.047	0.347	0.139
Rubber	35.53 (19.24)	5.88-69.47	10.26¶ (13.28)	0.0-34.47	.0043	16.02 (13.06)	0.21-38.44	10.40¶ (14.17)	0.02-36.81	.371	0.023	0.592
1-way ANOVA *P* value	.0816		.3021			.2556		.0143‖				

NOTE. For each transfer event, the average percentage TE SDs and the minimum/maximum TE per fomite material type tested are presented along with the *t* test P value results for comparisons of the fomite-to-fingerpad versus the fingerpad-to-fomite transfer efficiencies for 6 material types. For each material type (in both directions of transfer), n = 10 except where otherwise noted.

ANOVA, analysis of variance; *Max*, maximum; *Min*, minimum; *TE*, transfer efficiency.

**t* test *P* value from comparing the pick-up versus deposit percentage TEs generated by the fingerpad for each material type.

†*t* test *P* value from comparing the pick-up versus deposit percentage TEs generated by the latex glove for each material type.

‡*t* test *P* value from comparing fingerpad pick-up versus glove pick-up percentage TEs for each material type.

§*t* test *P* value from comparing fingerpad deposit versus glove deposit percentage TEs for each material type.

‖Latex glove deposit TE for rubber is statistically higher than glass, stainless steel, and porcelain (Tukey multiple comparisons test, *P* = .03, *P* = .02, and *P* = .03, respectively).

¶n = 9.

Table 2
Overall mean percentage TEs, SDs, minimum/maximum TE, and *P* value results for overall mean TE comparisons (assumes no difference across fomite material types)

Direction of transfer	n	Overall mean % TE ± SD	Min-Max	Comparing % TE by direction (*P*)*	Comparisons with skin-skin (*P*)†
Fingerpad					
Fomite to fingerpad	60	24.12‡ (14.81)	3.70-69.47	<.0001	.0651
Fingerpad to fomite	59	5.60§ (6.46)	0.0-34.47		<.0001
Latex glove					
Fomite to fingerpad	60	10.63‡ (11.52)	0.0-45.09	<.0001	<.0001
Fingerpad to fomite	57	2.96§ (6.94)	0.0-36.81		<.0001
Skin-skin					
Fingerpad to fingerpad	6	32.53 (12.07)	17.32-43.26		

Max, maximum; *Min*, minimum; *TE*, transfer efficiency.
*Unpaired *t* test *P* values from comparing the fomite-to-fingerpad vs fingerpad-to-fomite overall mean percentage TEs for the fingerpad and for latex gloves.
†Holm-Šídák test *P* values from comparing the mean skin-skin percentage TE with each of the overall mean fomite-to-fingerpad and fingerpad-to-fomite percent TEs generated with and without glove use.
‡Unpaired *t* test of fingerpad vs glove overall mean fomite-to-fingerpad TEs: $P < .0001$.
§Unpaired *t* test of fingerpad vs glove overall mean fingerpad-to-fomite TEs: *P* value = .036.

Table 3
Estimates of direct recovery rates from each of the material types used, including latex gloves and the fingerpad

Material type	n	Mean CFU recovered	Min-Max	% recovery
Glass	3	2.43×10^5	1.72×10^5-3.02×10^5	0.017
Stainless steel	3	1.50×10^5	4.98×10^4-2.03×10^5	0.011
Porcelain	3	1.47×10^5	1.35×10^5-1.72×10^5	0.010
Polypropylene	3	1.24×10^5	1.08×10^5-1.38×10^5	0.009
Polycarbonate	2	1.17×10^5	8.46×10^4-1.50×10^5	0.008
Rubber	3	1.72×10^5	1.31×10^5-2.29×10^5	0.012
Fingerpad	3	1.33×10^5	1.15×10^5-1.60×10^5	0.009
Latex glove	3	6.46×10^5	3.60×10^5-9.18×10^5	0.046

NOTE. CFU of bacteria applied to each material type = 1.42×10^9 CFU.
CFU, colony forming units; *Max*, maximum; *Min*, minimum.

glove use, we found a statistically significant difference between the overall mean bidirectional percentage transfer efficiencies both with and without latex glove use ($P < .0001$). The percentage transfer efficiency between the skin of 2 fingerpads was 32.5%. Using the Holm-Šídák's multiple comparisons test, the transfer efficiency between 2 skin surfaces was statistically higher than the overall fomite-to-fingerpad transfer efficiency by the latex glove ($P < .0001$), but it was not statistically different than the overall fomite-to-fingerpad transfer efficiency by fingerpad ($P = .06$). Skin-skin transfer efficiency was statistically higher than the fingerpad-to-fomite transfer efficiency regardless of glove use ($P < .0001$ for both latex glove and fingerpad transfers) (Table 2).

To evaluate the influence of measurement error from different surface types, we measured the direct recovery rate of bacteria from each of the surface types used in our primary experiments when no transfer event occurred (Table 3). We used a 1-way ANOVA to assess the differences between the means. We found an overall difference between the means of the CFU recovered (1-way ANOVA, $P < .001$) and found that the latex glove was significantly higher than the other material types ($P < .01$ for all comparisons).

The results of the regression analysis showed (1) for both glove-fomite and fingerpad-fomite transfers, there remained a significant difference between fomite-to-fingerpad and fingerpad-to-fomite transfer efficiencies ($P < .0001$ in both cases), even when accounting for theoretical recovery and variation in initial concentration; (2) for fingerpad-fomite transfers, material type did not affect transfer efficiency; (3) for glove-fomite transfers, rubber had a significant effect on transfer efficiency in both the fomite-to-fingerpad direction ($P = .03$) and fingerpad-to-fomite direction ($P = .02$); and (4) no interaction between the initial concentration and material type.

DISCUSSION

In this transfer efficiency study, conducted using 10 volunteer subjects, we had 3 key findings. First, the fomite-to-fingerpad transfer efficiency of *A baumannii* was significantly higher than the fingerpad-to-fomite transfer efficiency, regardless of glove use. Second, compared with no glove use, the *A baumannii* fomite-to-fingerpad transfer efficiency was reduced by 56%, and the fingerpad-to-fomite transfer efficiency was reduced by 47% when latex gloves were worn. Finally, the fomite-to-fingerpad and fingerpad-to-fomite transfer efficiency varied by fomite material type, but these variations were largely not statistically significant. Only rubber showed potential for having a significant influence on transfer efficiency.

We found no studies directly estimating transfer efficiencies of *A baumannii*. In addition, we found no studies that directly compared fomite-to-fingerpad to fingerpad-to-fomite transfer efficiencies. Lopez et al compared only the average fomite-to-fingerpad transfer efficiencies of *Escherichia coli*, *Staphylococcus aureus*, and *Bacillus thuringiensis* between porous and nonporous surfaces under conditions of high and low relative humidity.[10] By contrast, our experiments were performed at approximately 22°C (72°F) with a relative humidity level of approximately 40% throughout the study, and we compared fomite material types that were all nonporous. Given the differences in study design, methods, and microorganisms tested, our data and the Lopez et al data can only be compared qualitatively.

We compared the fomite-to-fingerpad transfer efficiency with the fingerpad-to-fomite transfer efficiency using bacteria. Under the assumption that recovery from different surfaces is equally effective, our study demonstrates that the fomite-to-fingerpad transfer efficiency is not equal to the fingerpad-to-fomite transfer efficiency when the 2 contact surfaces involved are not identical (ie, fomite-skin transfers or fomite-glove transfers). We found the overall fomite-to-fingerpad transfer efficiency (24.1%) by the fingerpad was 4.0 times greater than the overall fingerpad-to-fomite transfer efficiency (5.6%) by the fingerpad ($P < .0001$). Further, when we stratified by material type, the fomite-to-fingerpad transfer efficiency by the fingerpad was significantly higher than the fingerpad-to-fomite transfer efficiency by the fingerpad for each material type. These are novel findings that are significant for understanding the transmission dynamics of infectious diseases because most fate and transport mathematical models assume that the transfer efficiency value for calculating both the fomite-to-fingerpad rate and fingerpad-to-fomite rate of pathogens is the same value.[11-13] Our study demonstrates that for *A baumannii*, when the 2 contacting surfaces are of unlike material, this assumption of symmetrical transfer does not hold.

This study is again novel in that we evaluated the impact of using latex gloves on fomite-to-fingerpad and fingerpad-to-fomite transfer efficiencies. Similar to the transfer efficiencies by the fingerpad, the overall fomite-to-fingerpad transfer efficiency (10.6%) by the latex glove was also greater (3.6 times greater) than the overall fingerpad-to-fomite transfer efficiency (3.0%) ($P < .0001$). Further, we show a significant reduction in bacterial transfer efficiency with the use of latex gloves, reducing the fomite-to-fingerpad transfer efficiency by 55.9% and the fingerpad-to-fomite transfer efficiency by 47.1% with latex glove use. Standard precautions established by the Centers for Disease Control and Prevention[15] use gloves for the purpose of reducing pathogen transmission. Our study provides quantifiable evidence demonstrating that frequent glove changes during patient care are critical to ensure the greatest reduction in pathogen transmission. Further, we show that—although significantly reduced—there is still a transfer of pathogens between surfaces and the latex glove, underscoring the importance of frequent hand hygiene or glove changes by health care workers and hospital staff alike for the reduction of pathogen transmission. Stratifying by material type, the fomite-to-fingerpad transfer efficiency by the latex glove was statistically significantly higher than the fingerpad-to-fomite transfer efficiency by the latex glove for each material type except for rubber. Interestingly, when gloves were worn, the fomite-to-fingerpad and fingerpad-to-fomite transfer efficiencies for rubber were not statistically different ($P = .38$). Because latex gloves are composed of natural rubber lattices, it would make sense that the fomite-to-fingerpad transfer efficiency equals the fingerpad-to-fomite transfer efficiency between these 2 similar material types, adding support to our hypothesis that the fomite-to-fingerpad and fingerpad-to-fomite transfer efficiencies are not equivalent when the 2 surfaces involved are not identical. This study demonstrates that the use of latex gloves significantly reduces both the fomite-to-fingerpad and fingerpad-to-fomite transfer efficiencies compared with no glove use, but certainly does not eliminate it. Recognizing that nitrile gloves are a preferred alternative for those with allergies to latex, this study could be repeated to compare the reduction of transfer efficiencies by nitrile gloves with that of latex gloves. Nevertheless, these findings are significant in quantifying the importance of glove use by all persons who encounter patient areas and urge frequent glove changes, particularly during patient care.

We evaluated the transfer efficiencies across 6 nonporous surface types both with and without latex glove use. The results of this study suggest that, although there was variation in transfer efficiency by material types, there was no statistical difference by fomite material type with the possible exception of rubber. As for glass, porcelain, stainless steel, polypropylene, and polycarbonate, we found no statistical difference in the fomite-to-fingerpad transfer efficiency between these material types or in the fingerpad-to-fomite transfer efficiency values between these material types, regardless of glove use. This may be because of a loss of statistical power by stratification as we move from approximately $n = 60$ overall to approximately $n = 10$ per material type. The tendency for rubber to have higher transfer efficiencies regardless of glove use is a trend that warrants further investigation.

We also quantified the skin-skin transfer efficiency of *A baumannii* between the skin of 2 fingerpads. We determined that the percentage transfer efficiency from skin to skin was 33%. This is consistent with the results published by Rusin et al, who reported a 34% hand to lip transfer efficiency for *Serratia rubidaea* and 41% for *Micrococcus luteus*.[9] We compared the skin-skin transfer efficiency with that by the fingerpad and found that the transfer efficiency from the skin to the skin is 1.35 times greater than from the fomite to the skin and 5.8 times greater than from the skin to the fomite. Clearly, the highest transfer rates occur from skin to skin, further stressing the importance for hand cleaning and glove use during direct patient care.

There may be sources of error that could confound our measurements. Of particular interest is the possibility of differing errors and biases in both our initial inoculation of the fomite-glove-skin and our measurement of the bacteria on each surface. This issue is also of concern in previous studies of transfer efficiencies but has not been addressed in the existing literature. To evaluate the influence of measurement error from different surface types, we measured CFU that could be directly recovered from each of the surface types used in our primary experiments when no transfer event occurs (Table 3). Latex gloves have a higher mean direct CFU recovery (0.05%) compared with all other material surface types (0.01%), including the fingerpad ($P < .001$), suggesting a possible bias in our fomite to fingerpad and fingerpad to fomite comparison for gloves. However, the significant differences by direction are also seen for fingerpad-fomite transfers where the direct CFU recoveries for these surfaces are the same. Therefore, recovery fractions do not appear to explain the differences we measure by direction indicating that, although measurement biases exist, they are not sufficient enough to explain the differences we measure by direction. Finally, we validated our results further using a multivariate logistic regression analysis that included both the variation in the initial inoculum and the maximum theoretical recovery for all surfaces, which confirmed the same significant results as reported in Table 1. Collectively, these results suggest that the differences in transfer efficiencies seem likely to persist in the face of potential biases.

In summary, the results of this transfer efficiency investigation show that the fomite-to-fingerpad transfer efficiency of *A baumannii* was significantly higher than the fingerpad-to-fomite transfer efficiency, regardless of glove use, and suggest the importance of using appropriate fomite-to-fingerpad and fingerpad-to-fomite transfer efficiencies in the mathematical modeling of bacterial transmission. In addition, we show that bacterial transfer efficiencies are significantly reduced, but not eliminated, by glove use, stressing the important role of glove use with frequent changes during patient care for the reduction of the transfer of pathogens. We recommend that the standard precautions set by the Centers for Disease Control and Prevention for glove use should also apply to hospital personnel who are in contact with patient environments and that glove changes should always occur immediately after direct physical contact with the patient if possible. Finally, our results suggest that the variations between nonporous fomite material types do not significantly affect transfer efficiency in either direction. Of the 6 material types tested, only rubber showed trends of having an influence on the transfer efficiency of *A baumannii* in either direction. Further investigation into the interactions between rubber and microbial attachment and the effect of rubber on the transfer efficiency of pathogens is needed. Results from our study will help improve the accuracy of mathematical estimation of environmental mediated infectious disease transmission and serve to strengthen current guidelines for control of hospital-acquired infections.

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