Laboratory and in-use assessment of methicillin-resistant *Staphylococcus aureus* contamination of ergonomic computer keyboards for ward use

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Background: An ideal computer keyboard for clinical use would be easily cleanable and cleaned by staff, meet acceptable levels of usability, and not attract hospital bacteria.
Methods: In vitro studies were performed to demonstrate bacterial transfer between keyboard surfaces and gloves. This was followed by a usability study and a controlled trial of keyboard contamination in an intensive care unit both with and without an alarm to indicate the need for cleaning. Eight cleanable keyboards were placed at random beds and compared with standard keyboards.
Results: Bacteria were most easily removed from a flat silicone-coated surface. The total viable count on flat keyboards with an alarm was lower than that on standard or other cleanable keyboards (median, 19 colony-forming units [cfu] (interquartile range, 7 to 40 cfu), n = 34; 65 cfu (33 to 140 cfu), n = 50; and 40 cfu (21 to 57 cfu), n = 80). Compliance with hand hygiene before touching the standard keyboard was 27%, but the alarmed keyboard was cleaned on 87% of occasions on which the alarm was triggered. The usability study found the flat profile of the cleanable keyboard did not interfere with routine use, except for touch-typing.
Conclusion: The flat keyboard with an alarm is easy to clean, and it use is associated with better cleaning compliance. (Am J Infect Control 2008;36:e19-e25.)

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With the advent of electronic patient records, the numbers of computer keyboards and mice in use in clinical areas are on the increase. Caregivers frequently touch keyboards immediately after patient-related procedures without first performing hand hygiene.[1] They then touch other keyboards without disinfecting their hands, possibly passing bacteria, including methicillin-resistant *Staphylococcus aureus* (MRSA), to other patients. Domestic workers do not clean electronic equipment, and compliance with cleaning by nurses is poor (9.3%).[1] Up to 25% of computer keyboards in wards are contaminated with MRSA and other pathogens, regardless of their design.[1-3] The hands of staff are believed to be the main vector for transfer of pathogens.[3] The aim of this study was to develop a user-friendly computer keyboard to which bacteria are not readily transferred (and can be easily removed) and that can be easily cleaned.

METHODS

Specifications for a functional keyboard surface that is smooth, impervious, and cleanable with a single wiping action yet can allow reasonably fast typing were sent to 3 keyboard manufacturers (herein designated A, B, and C) (Fig 1).

Preselection study

Experiment 1: Cleaning efficacy. Five existing keyboards were seeded with the 2 most common clinical

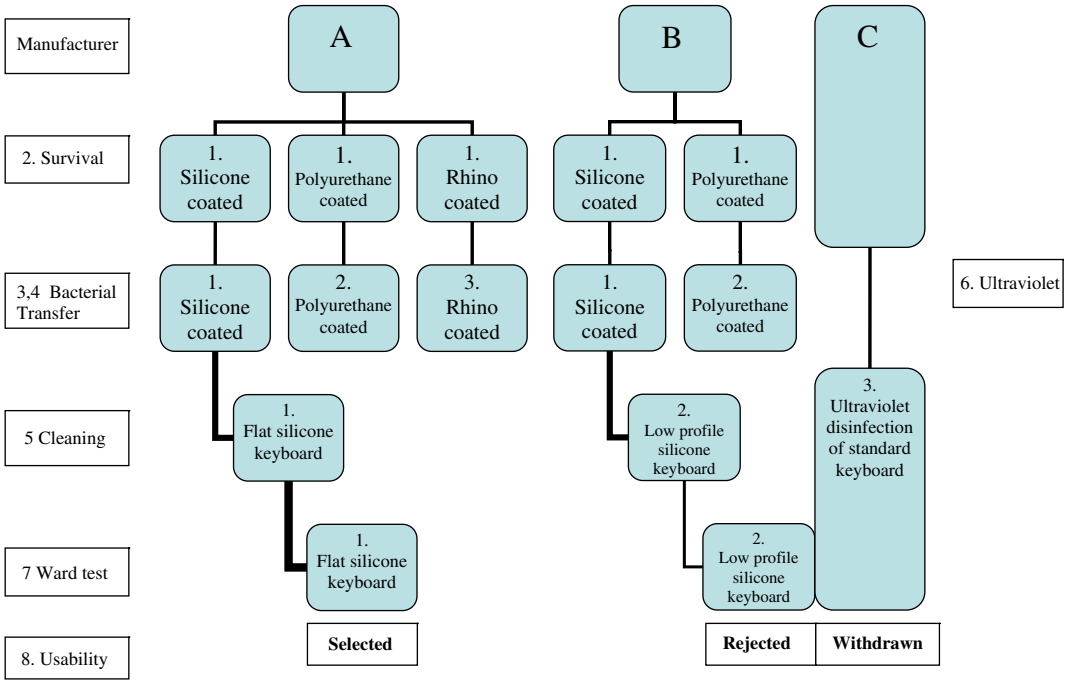

Fig 1. Flow diagram of the study work stream in keyboard design and selection. Number indicates rank at that stage of selection.

isolates of MRSA[4] (Table 1). The efficacy of wiping with isopropyl alcohol cloth or sterile water cloth was confirmed using contact plates.

Selection of coating

Experiment 2: Survival of MRSA on different elastomer surfaces. MRSA was inoculated onto 24 1 × 1 cm squares of elastomer coated with silicone or polyurethane (manufacturers A and B) or Rhino coat (manufacturer A) in artificial light at a temperature of 20°C and humidity level of 70% (Table 1). Three squares were removed at 8 time points over a 1-week period and pressed onto agar contact plates.

Experiment 3a: Transfer of MRSA from a glove to a surface. A glove tambour was inoculated and pressed against the same elastomer samples used in Experiment 2 (Table 1). In addition, their components were tested (painted [Ax1 and Bx2], laser-etched [Ax2], and raw elastomer). Contact plates were applied to all surfaces (replicates A3 and B6).

Experiment 3b: Transfer of MRSA from a surface to a glove. To demonstrate the transfer of countable numbers of MRSA to the glove tambour from a sample surface, an undiluted overnight broth culture was inoculated on the sample surface (as in Experiment 3a, omitting components of the B replicates). Contact plates were again used (5 replicates).

Experiment 4: Bacterial transfer to keyboard in the presence of lanolin. Lanolin was applied to the glove tambour to simulate an unwashed hand. Transfer from the glove tambour to the keyboard material was assessed as in Experiment 3a (3 replicates).

Keyboard testing

Manufacturers A and B provided silicone-coated prototypes. Keyboard A had a completely flat surface incorporating 2 cleaning sensors and a light alarm. Two resistive sensors detected the presence of 70% isopropyl alcohol (Table 1), and a third hidden sensor detected pressure, switching off the light alarm if detection occurred within 20 seconds. The alarm was activated at a fixed time point after cleaning. Manufacturer B supplied a keyboard with 1-mm-high keys but no alarm. Manufacturer C provided a standard keyboard and an ultraviolet light source (254 nm) as an automatic sterilizing system, but this system was later withdrawn due to production difficulties.

Experiment 5: Ease of cleaning. Fluorescent cream (Glo Germ, Moab, UT) was applied to both keyboards, and its removal by an alcohol-based wipe was assessed by UV photography.

Experiment 6: Ultraviolet light. A standard keyboard was inoculated evenly with a 1:50 dilution of a broth culture of EMRSA-16. One-sixth of the keyboard area, selected at random, was then exposed for 0, 10, 20, 30, 60, or 120 seconds (4 replicates).

Experiment 7: Ward testing of keyboards A and B. Manufacturer A supplied 8 keyboards and written

Table 1. Standard methods

Term	Method
Manufacturer A	Medigenic, Esterline, Coeur d'Alene, ID
Manufacturer B	Anonymous
Manufacturer C	Medisafe Technologies (Europe), Surrey, UK
MRSA	Clinical isolate EMRSA 16 ST36-MRSA-II[15] and EMRSA 15 ST22-MRSA-IV being the most common in the ICU
Inoculum	20 μL of broth culture (200 to 300 cfu) determined by a surface counting method. The inoculum was prepared by dilution in 10% serum brain heart infusion broth. For transfer using lanolin or alcohol-based gel, a higher inoculum (500 cfu) was used.
Sampling	Horse blood/Columbia agar contact plates of surface area 23.76 cm^2 (Oxoid, Basingstoke, UK)
Incubation	37°C for 24 hours aerobically. Growth was counted by colony type and Gram stain. MRSA was identified by subculture onto mannitol oxacillin salt agar and standard methods.
Cleaning with alcohol wipe	Cleaning of keyboard surface from right to left to cover the entire upper surface once, using a 70% isopropyl alcohol wipe
Cleaning with wet wipe	As above but using a sterile cloth and sterile water
Glove tambour	A sterile glove was stretched over an empty contact plate lid and secured. The flat glove surface over the lid was applied to the test surfaces.
Lanolin	Medical-grade lanolin (Lansioh Laboratories, Alexandria, VA)
Alcohol-based hand rub	Alcohol-based hand rub with emollient, 62% ethanol, 1000 ppm, no disinfectant, (Purell, Gojo, Akron, OH)
Silicone finger	Custom-made silicone rubber cast of a finger bearing a fingerprint (Body Double; Smooth-on, Easton, PA)

instructions for cleaning the keyboard and mouse with an alcohol-based wipe whenever the alarm was activated. Manufacturer B supplied 8 keyboards and written instructions for cleaning with an alcohol-based wipe every 12 hours during the first week and every 3 to 4 hours during the second week. No specific cleaning instructions were provided for the control standard keyboards with covers (iNPACE, Oxfordshire, UK). The 28-bed medical-surgical intensive care unit (ICU) had keyboards at every bedside. Patients were routinely screened for MRSA colonization of the nose on admission, weekly, and on discharge from the ICU. Ethical approval for the experiment was not required.

Sampling 8 keyboards of each type on 10 days over a 2-week period (80 observations each) would detect a 50% reduction in total viable count of 100 cfu (standard deviation, 80 cfu) with a power of 0.8. Beds were selected by a computer randomization stratified for MRSA carriage. The alarm interval for keyboard A was 12 hours for 1 week, then 3 hours for 2 days, and finally 1.5 hours for 3 days. All keyboards were sampled 10 times and cleaned during each shift.

Two of the keyboards from manufacturer A were faulty; thus, 6 of these keyboards (23 patients; 8 empty-bed days) were compared with 9 standard keyboards (32 patients; 11 empty-bed days). Eight keyboards from manufacturer B (13 patients; 28 empty-bed days) were compared with 9 standard keyboards (24 patients; 21 empty-bed days). All patient groups had a median length of stay of 2 days. The keyboards were sampled between 11:00 AM and 12:00 noon each day using horse blood/Columbia agar contact plates (23.76 cm^2). Phage typing of MRSA was performed to assess transmission (Laboratory of Hospital Infection, HPA Colindale, London, UK). Patients identified as MRSA carriers were source-isolated but not moved.

During 16 unobtrusive 20-minute sessions, nursing staff maintained hand hygiene compliance before touching the keyboard or mouse.[5] Two keyboards from each manufacturer were sampled after 6 weeks of use without specific instructions and with the alarm turned off. After keyboard A had been in use in the ICU for another 6 months, the proportion with active alarms at 9:00 AM was noted daily for 16 weeks. After 2 months of use on general wards, a 1-day global audit was performed.

Experiment 8: Usability. The Institute of Occupational Ergonomics of the University of Nottingham convened a focus group to identify variation in keyboard use between hospital wards and outpatient clinics. Participants completed open-ended questionnaires consisting of 49 items related to operation, responsiveness, effort, comfort, shape, color, and accuracy rated on a 5-point scale. Ten users were observed by skilled observers and video recorded for 15 minutes using each keyboard in an ICU and a clinic with performing their normal work. All participants then completed a set task, typing random alphanumeric data and a set passage and using the mouse to arrange shapes, which took 12 minutes per keyboard to complete.

Postselection study

Experiment 9: Bacterial transfer on repeated contact. Keyboard A was inoculated with overnight broth culture (Table 1). A glove tambour or a silicone "finger" was wiped 4 times with an alcohol-based hand rub or once with lanolin or was left untreated (Table 1). The tambour and finger were then applied first to a part of the keyboard selected at random and then to 5 blood agar plates in sequence (3 replicates).

Statistical methods

The Mann-Whitney U-test was used to compare colony counts between test and control surfaces, and the Kruskal-Wallis rank-sum test was used to compare colony counts between more than 2 groups. Count data from 2 × 2 tables was analysed using Fisher's exact test. Survival of MRSA (Experiment 2) was analyzed

by fitting a generalized linear model for overdispersed Poisson data to the actual colony count data. The repeated-measures data from Experiment 9 were analyzed with a Poisson model, using a generalized estimating equations approach with a first-order autoregressive correlation structure to account for dependencies between consecutive contacts. With y_{ij} representing the cfu count resulting from the ith application of the finger or tambour to the keyboard and the jth subsequent contact with a blood agar plate, the following model was used:

$$\log\left(y_{ij}\right) = a_0 + a_1 * alc_i + a_2 * lan_i + a_3 \times contact_i + a_4 \times alc_i \times contact_j + a_5 \times lan_i \times contact_j + \varepsilon_{ij,}$$

where alc_i and lan_i are indicator variables that take the value 1 when alcohol or lanolin are used, respectively; $contact_j$, with j = 1…5, represents the sequence number of the contact with the blood agar plate; and ϵ_{ij} is the error term. The parameter estimates for a_0 to a_5 represent, respectively, the predicted initial colony count in the untreated arm, the initial effects of alcohol and lanolin on bacterial transfer, the rate of exponential decline in colony counts on consecutive contacts, and interaction terms reflecting to the degree to which alcohol or lanolin modified the exponential rate of colony count decline on subsequent contacts. Analyses were performed using Microsoft Excel (Microsoft, Redmond, WA) and Stata 8.0 (StataCorp, College Station, TX).

RESULTS

Experiment 1: Cleaning efficacy

With a single exception (6 cfu MRSA after wet wiping), alcohol and wet wipes completely decontaminated all surfaces.

Experiment 2: Survival of MRSA on surfaces

The survival half-life of EMRSA-16 did not differ significantly among the surfaces.

Experiment 3a: Bacterial transfer

Using a glove inoculated with 200 cfu, in almost all cases, no organisms were recovered from the samples from the keyboards of manufacturer A. The exceptions were 1 cfu in single replicates from the paint and silicone surfaces. A median of 73 cfu (interquartile range [IQR], 34 to 110 cfu) was recovered from the glove. For the keyboards of manufacturer B, no organisms were recovered from any of the samples except for 1 and 16 cfu from the raw elastomer. A median of 50 cfu (IQR, 40 to 65 cfu) was recovered from the glove.

Experiment 3b: Transfer of MRSA from surface to glove

Application of a sterile glove to an inoculated confluent surface provided very strong evidence to reject the null hypothesis that transfer was similar for all surfaces ($\chi^2 = 26$; degrees of freedom = 6; $P = .0002$). Fewer organisms were picked up from the Rhino (median, 1 cfu [IQR, 0 to 8 cfu]) and polyurethane (4 cfu [IQR, 1 to 13 cfu]) coatings of manufacturer A than from the painted elastomer (> 100 cfu [IQR, 18 to >100 cfu]) or silicone (33 cfu [IQR, 4 to >100 cfu]) coatings. For manufacturer B, removal from polyurethane was similarly lower than from silicone (median, 4 cfu [1 to 55 cfu] vs 247 cfu [155 to 1120 cfu]), but the difference was not statistically significant ($P = .10$). Bacterial transfer onto all surfaces was low, with the fewest bacteria retained on silicone.

Experiment 4: Transfer in the presence of lanolin

A median of 68% to 83% of organisms was transferred from the glove tambour to the samples, but there was no evidence of differences between materials or manufacturers ($P = .55$).

Experiment 5: Ease of cleaning

Fluorescence remained on keyboard A only around the positioning marks in the keyboard. On keyboard B, considerable residual liquid remained around the keys despite their low profile.

Experiment 6: Ultraviolet light

With a single exception, MRSA did not survive on any plate after just 10 seconds of exposure to UV light (0 to 1 cfu of 234 to 617 cfu) (> 2 log-kill).

Experiment 7: Ward tests

A median of 23% of beds on the ward were occupied by MRSA-positive patients, of whom 33% carried EMRSA-15, 38% carried EMRSA-16, and 29% carried other phage types.[6] Phage typing was performed on 8 isolates (3 EMRSA-16, 1 EMRSA-15, 3 sporadic). The total viable counts (predominantly coagulase-negative staphylococci) on the keyboards from manufacturer A cleaned every 1.5, 3, or 12 hours were lower than the simultaneous counts on the standard keyboards (Table 2). The total viable count on the keyboards from manufacturer B did not differ significantly from that on the standard keyboards. For keyboard A, 6 patients (4 keyboard A, 2 standard keyboards) were MRSA carriers at the start

Table 2. Experiment 7: Total viable count isolated from keyboards in ward tests

Manufacturer	Cleaning alarm interval (hours)	Number of samples*	Median cfu (IQR)	*P* (Mann-Whitney U test)
A				
Test	12	34	19 (7 to 40)	
Standard		50	65 (33 to 140)	<.0001
Test	3	18	11 (4 to 19)	
Standard		29	49 (34 to 97)	<.0001
Test	1.5	26	5 (2 to 14)	
Standard		40	38 (24 to 56)	<.0001
B				
Test		80	40 (21 to 57)	
Standard		81	52 (26 to 79)	.11

*Each pair of samples was collected together.

of the study, but none acquired MRSA. MRSA was isolated from 4 keyboards, 2 keyboard A and 2 standard (median, 3 cfu [IQR, 1 to 21 cfu]). The MRSA on 1 keyboard and patient was of a similar phage type. *Acinetobacter* species were isolated from 5 keyboards (3 keyboard A, 2 standard) and 1 patient.

For keyboard B, 2 patients (1 keyboard B, 1 standard) were already MRSA-positive, and 1 patient acquired MRSA (keyboard B). MRSA was not isolated from any keyboard, but methicillin-sensitive *S aureus* was isolated from 1 standard keyboard. *Acinetobacter* spp were isolated from 2 keyboards (1 keyboard B, 1 standard) but from no patients.

On average, the keyboard or mouse was touched after patient/environmental contact 15.7 times per hour, 4.7 times with gloved hands and 11.0 times with ungloved hands. Hand hygiene was performed before keyboard or mouse contact 4.3 times/hour, for a compliance rate of 27%. There was no significant difference in hand hygiene compliance with any keyboard in the absence of an activated alarm (9/48 [18.8%] vs 8/28 [28.6%]; $\chi^2 = 0.98$; $P = .32$). Keyboard disinfection was not observed, but the keyboard cleaning alarm on keyboard A was activated on only 10 of 78 occasions (12.8%), indicating a high level of compliance. One of the authors then deliberately cleaned the keyboards from manufacturer B every 12 hours for 2 days (100% compliance). Contact samples were obtained according to a randomized schedule during the 12-hour interval to ensure that no systematic bias was introduced. The median total viable count was reduced to 13 cfu (IQR, 6 to 34 cfu), substantially lower than that found without cleaning (40 cfu [IQR, 21 to 57 cfu]) and similar to the median count for keyboard A.

After 6 weeks of use without an alarm, total viable counts were 47 and 51 cfu on A keyboards compared with 63 and 77 cfu on B keyboards. No *S aureus* was isolated. After 6 months of using keyboard A in the ICU, a median of 2 of 30 (6.7%) bedside keyboards (range, 0 to 5) showed the alarm on 115 days (alarms set at 3 hours); however, a median of 1 of 6 (17%) communal keyboards (range, 1 to 4) remained uncleaned. Of 290 keyboards examined on a single day after 2 months on 13 other wards (mean, 22 each; range, 7 to 50), medians of 33% (range, 25% to100%) in bed bays and 29% (range, 0 to 100%) in communal areas showed alarms (alarms set at 12 hours).

Experiment 8: Usability

In the ICU, 10 users (9 female and 1 male nurses) participated. All subjects were right-handed. The median age was 30 years (range, 26 to 34 years). In the outpatient clinic, 10 users (8 females and 2 males) participated. Eight of these users were right-handed, and 2 were left-handed. The median age was 28 years (range, 23 to 58 years). The users included senior and junior nurses, a consultant, a health care assistant, and clinic coordinators. Only 1 user rated keyboard B as satisfactory, whereas 6 clinic users and 10 ICU users rated keyboard A as satisfactory, easy to use, and/or comfortable. Five clinic users and 7 ICU users rated mouse A as satisfactory, compared with 3 clinic users and 3 ICU users for mouse B. Although both keyboards were rated as simple to use, only 2 clinic users and no ICU users judged that keyboard B could be operated without excessive force, compared with 5 clinic users and 10 ICU users for keyboard A. Only 1 clinic user and 1 ICU user reported the ability to type effectively using keyboard B, compared with 7 clinic users and 10 ICU users for keyboard A. Three clinic users and 3 ICU users made mistakes with mouse B, but no user made mistakes with mouse A. Both mouses were judged easy to clean (> 6 users each).

Experiment 9: Repeated contact

During repeated contacts, 49% (95% confidence interval [CI], 34% to 64%) of the inoculum was

Table 3. Experiment 9: Regression coefficients for bacterial transfer on repeated contacts

S	Coefficient	95% CI	*P* value
Glove tambour			
Alcohol a1	1.41	0.45 to 2.36	.004
Lanolin a2	1.777	0.84 to 2.71	.000
Time a3	−1.37	−2.19 to -0.55	.001
Alcohol by time a4	0.63	−0.21 to 1.47	.142
Lanolin by time a5	0.88	0.05 to 1.71	.037
Contacts a0	2.76	1.84 to 3.67	.000
Silicone finger			
Alcohol a1	0.23	−0.32 to 0.78	.409
Lanolin a2	−1.53	−2.50 to -0.55	.002
Time a3	−0.39	−0.55 to -0.23	.000
Alcohol by time a4	−0.13	−0.37 to 0.11	.286
Lanolin by time a5	−0.09	−0.52 to 0.35	.689
Contacts a0	2.85	2.45 to 3.25	.000

See the Statistical methods section for an explanation of terms.

transferred after application and drying of alcohol-based hand rub on the glove, compared with 36% (95% CI, 27% to 46%) after application of lanolin (n = 3) (Table 3). Up to 5 subsequent surfaces were contaminated after application of lanolin or alcohol-based gel, compared with at most 2 surfaces with the untreated glove. Both lanolin and alcohol-based gel were associated with significantly higher initial counts for glove transfer. Unlike alcohol-based gel, lanolin was associated with a slower rate of decline on subsequent contacts (Fig 2A). On the silicone finger, neither alcohol-based gel nor lanolin affected the rate of decline of bacterial counts (Fig 2B).

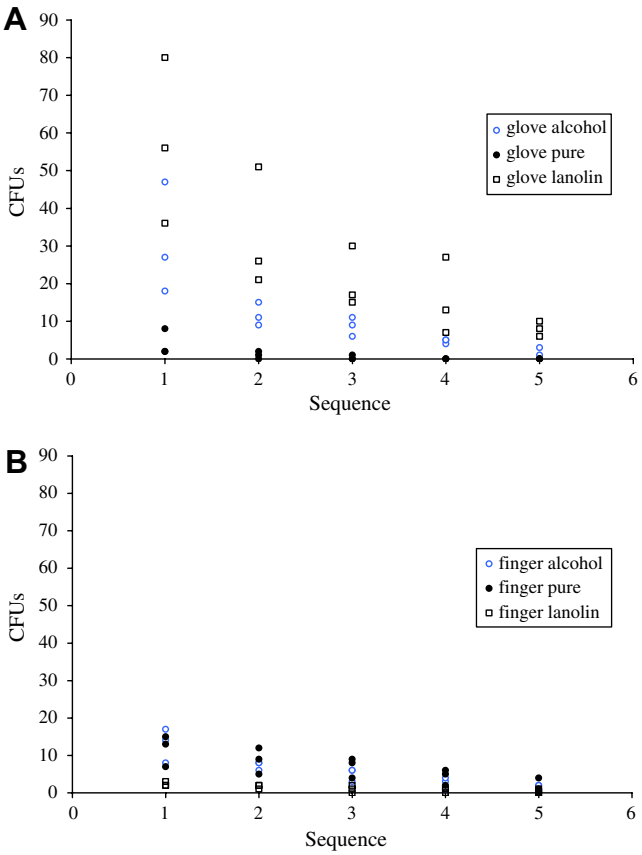

Fig 2. Experiment 1. Total viable count isolates on a contact plate after application of a glove tambour (A) and a silicone cast finger (B) to an inoculated silicone keyboard surface and then to 5 contact plates. The glove was used dry ("pure"), with lanolin or alcohol-based hand rub. (The alcohol was allowed to evaporate.)

DISCUSSION

A completely flat profile, a cleaning alarm, and a silicone-coated surface were the most important features in achieving low bacterial counts on high-contact keyboards. Keyboard A most closely met the design requirements while offering acceptable usability. Both keyboards were tolerant to disinfectants (eg, chlorine, alcohol, phenol, detergent in water).[7] Polyurethane and silicone surfaces can support the growth of staphylococci, especially in the presence of bovine serum albumin.[8] Transfer of *S aureus* to silicone surfaces in vitro is lower than that to Teflon and depends on incubation time and temperature, bacterial concentration, slime production, and hydrophobicity.[9] Strains of *S aureus* that strongly adhere to silicone may be more pathogenic.[10] Transfer to polyurethane is variable and is increased in the presence of fibrinogen.[11] Only 3% of organisms are transferred from the glove to the clean keyboard surface, even though MRSA is found on the hands of 7.5% of staff and throughout the environment and keyboards are touched frequently.[12] Both lanolin and emollient from alcohol-based gel increase the risk of bacterial transfer to other surfaces.

Although flat surfaces are the easiest to decontaminate, staff still need to be reminded to clean the device. Although existing membrane keyboards are almost flat, they require excessive force on the keys.[1] In contrast, the usability study found that keyboard A allowed a near-normal rate of data entry.

Keyboards are a potential source of cross-infection.[1-3] With the cost of each MRSA infection exceeding $7600 (£4000),[13] prevention of just a few such infections would justify the extra cost of the keyboard and mouse and alcohol wipes. Our data suggest that the keyboard of manufacturer A had the best characteristics for minimizing transfer of MRSA; consequently, 9500 of these keyboards have been purchased for the National Health Service. Further reinforcement of cleaning, in the form of

visual screen reminders and remote monitoring, is currently under development.

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References

1. Wilson AP, Hayman S, Folan P, Ostro PT, Birkett A, Batson S, et al. Computer keyboards and the spread of MRSA. J Hosp Infect 2006;62:390-2.
2. Devine J, Cooke RP, Wright EP. Is methicillin-resistant *Staphylococcus aureus* (MRSA) contamination of ward-based computer terminals a surrogate marker for nosocomial MRSA transmission and handwashing compliance? J Hosp Infect 2001;48:72-5.
3. Bures S, Fishbain JT, Uyehara CF, Parker JM, Berg BW. Computer keyboards and faucet handles as reservoirs of nosocomial pathogens in the intensive care unit. Am J Infect Control 2000;28:465-71.
4. Cookson BD, Robinson DA, Monk AB, Murchan S, Deplano A, de Ryck R, et al. Evaluation of molecular typing methods in characterizing a European collection of epidemic methicillin-resistant *Staphylococcus aureus* strains: The HARMONY collection. J Clin Microbiol 2007;45:1830-7.
5. Pittet D, Hugonnet S, Harbarth S, Mourouga P, Sauvan V, Touveneau S, et al. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. Infection Control Programme. Lancet 2000; 356:1307-12.
6. Cepeda JA, Whitehouse T, Cooper B, Hails J, Jones K, Kwaku F, et al. Isolation of patients in single rooms or cohorts to reduce spread of MRSA in intensive-care units: Prospective two-centre study. Lancet 2005;365:295-304.
7. Rutala WA, White MS, Gergen MF, Weber DJ. Bacterial contamination of keyboards: Efficacy and functional impact of disinfectants. Infect Control Hosp Epidemiol 2006;27:372-7.
8. Flemming RG, Capelli CC, Cooper SL, Proctor RA. Bacterial colonization of functionalized polyurethanes. Biomaterials 2000;21: 273-81.
9. Livni G, Yuhas Y, Ashkenazi S, Michowiz S. In vitro bacterial adherence to ventriculoperitoneal shunts. Pediatr Neurosurg 2004;40:64-9.
10. Kreft B, Ilic S, Ziebuhr W, Kahl A, Frei U, Sack K, et al. Adherence of *Staphylococcus aureus* isolated in peritoneal dialysis–related exit-site infections to HEp-2 cells and silicone peritoneal catheter materials. Nephrol Dial Transplant 1998;13:3160-4.
11. Flemming RG, Proctor RA, Cooper SL. Bacterial adhesion to functionalized polyurethanes. J Biomater Sci Polym Ed 1999;10: 679-97.
12. Wilson AP, Hayman S, Whitehouse T, Cepeda J, Kibbler C, Shaw S, et al. Importance of the environment for patient acquisition of methicillin-resistant *Staphylococcus aureus* in the intensive care unit: A baseline study. Crit Care Med 2007;35:2275-9.
13. Wilson AP, Hodgson B, Liu M, Plummer D, Taylor I, Roberts J, et al. Reduction in wound infection rates by wound surveillance with post-discharge follow-up and feedback. Br J Surg 2006;93:630-8.