

ORIGINAL ARTICLE

Bacterial Contamination of Keyboards: Efficacy and Functional Impact of Disinfectants

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BACKGROUND. Computers are ubiquitous in the healthcare setting and have been shown to be contaminated with potentially pathogenic microorganisms. This study was performed to determine the degree of microbial contamination, the efficacy of different disinfectants, and the cosmetic and functional effects of the disinfectants on the computer keyboards.

METHODS. We assessed the effectiveness of 6 different disinfectants (1 each containing chlorine, alcohol, or phenol and 3 containing quaternary ammonium) against 3 test organisms (oxacillin-resistant *Staphylococcus aureus* [ORSA], *Pseudomonas aeruginosa*, and vancomycin-resistant *Enterococcus* species) inoculated onto study computer keyboards. We also assessed the computer keyboards for functional and cosmetic damage after disinfectant use.

RESULTS. Potential pathogens cultured from more than 50% of the computers included coagulase-negative staphylococci (100% of keyboards), diphtheroids (80%), *Micrococcus* species (72%), and *Bacillus* species (64%). Other pathogens cultured included ORSA (4% of keyboards), OSSA (4%), vancomycin-susceptible *Enterococcus* species (12%), and nonfermentative gram-negative rods (36%). All disinfectants, as well as the sterile water control, were effective at removing or inactivating more than 95% of the test bacteria. No functional or cosmetic damage to the computer keyboards was observed after 300 disinfection cycles.

CONCLUSIONS. Our data suggest that microbial contamination of keyboards is prevalent and that keyboards may be successfully decontaminated with disinfectants. Keyboards should be disinfected daily or when visibly soiled or if they become contaminated with blood.

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Healthcare-associated infections are an important cause of morbidity and mortality in hospitals. Each year more than 2 million patients acquire healthcare-associated infections, resulting in 90,000 deaths and healthcare costs that are estimated to exceed \$5 billion.¹ Some investigators have suggested that computer keyboards may contribute to cross-transmission because of acquisition of transient hand carriage by healthcare personnel during contact with the contaminated computer keyboard surface.^{2,3}

Keyboards have become reservoirs for pathogens because of the increased use of computers in patient areas.²⁻⁷ The risk of transmission of pathogens from computer keyboards to patients would be prevented by compliance with current hand hygiene guidelines. Unfortunately, 34 studies have demonstrated that the mean rate of compliance with the Centers for Disease Control and Prevention guidelines on hand hygiene is approximately 40% among healthcare workers,⁸ which is a likely explanation for the frequent contamination of computer keyboards. This study was performed to determine the degree of microbial contamination, the efficacy of different

disinfectants, and the cosmetic and functional effects of the disinfectants on the computer keyboards.

METHODS

Degree of Bacterial Contamination on Computer Keyboards

The study was conducted at the University of North Carolina (UNC) Health Care System, where there are approximately 3,500 computers in use in such areas as nursing stations, patient rooms, intensive care units, operating rooms, the emergency department, and a burn unit.

Specimens were collected from 25 computers that were located in the burn intensive care unit, cardiothoracic intensive care unit, and 6 nursing units housing patients receiving short-term care. To determine the level of microbial contamination for the disinfection efficacy testing, a single sterile swab moistened with trypticase soy broth (TSB) was wiped over the entire keyboard surface. The swab was placed in 2 mL of TSB and immediately transported to the laboratory.

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TABLE 1. Microbial Contamination of Computer Keyboards in Patient Care Areas Before Disinfection

Microorganism	No. (%) of Keyboards Positive for Contamination (n = 25)	Degree of Contamination, No. of Keyboards			Mean No. of cfu per Keyboard (Median)
		20-100 cfu	101-1,000 cfu	>1,000 cfu	
OSSA	1 (4)	...	...	1	2,880 (NA)
ORSA	1 (4)	...	1	...	300 (NA)
VSE	3 (12)	3	...	...	40 (20)
VRE	0 (0)	...	...	...	NA
CoNS	25 (100)	4	11	10	1,045 (560)
Diphtheroids	20 (80)	7	12	1	489 (180)
<i>Micrococcus</i> species	18 (72)	13	4	1	280 (60)
<i>Bacillus</i> species	16 (64)	15	1	...	89 (40)
NF-GNR	9 (36)	6	3	...	211 (40)
Propionibacteria	7 (28)	2	5	...	197 (200)
Alpha streptococci	6 (21)	6	...	...	80 (100)
Viridans streptococci	2 (8)	2	...	...	90 (90)
<i>Aspergillus niger</i>	5 (20)	5	...	...	44 (20)
<i>Aspergillus flavus</i>	1 (4)	1	...	...	60 (NA)

NOTE. All cultures yielded at least 2 microorganisms. CFU = colony-forming units; CoNS = coagulase-negative staphylococci; NA = not applicable; NF-GNR = nonfermentative gram-negative rods; OSSA = oxacillin-susceptible *Staphylococcus aureus*; ORSA = oxacillin-resistant *S. aureus*; VRE = vancomycin-resistant *Enterococcus* species; VSE = vancomycin-susceptible *Enterococcus* species.

After the swab in the TSB was vortexed for 1 minute in the Fisher Vortex Genie 2 on the highest (ie, number 8) setting, 100 μ L of the specimen was plated onto trypticase soy agar with 5% sheep blood by use of the spread plate technique. The specimens were incubated at 37°C for 48 hours. Isolates were identified on the basis of Gram stain findings, colony morphology, detection of hemolysis on sheep blood agar, and colony pigmentation, as well as results of the tube coagulase test (for *Staphylococcus* species), detection of NaCl and results of the bile esculin test (for *Enterococcus* species), and detection of conidia by microscopy (for *Aspergillus* species). Susceptibility testing was performed on *Staphylococcus aureus* and enterococcal isolates by use of antibiotic-containing agars (6 μ g/mL for oxacillin and 6 μ g/mL for vancomycin).

Efficacy and Compatibility of Disinfectants

Seven IBM ThinkPad laptop computers were used to evaluate the effectiveness of sterile water-containing wipes (Abbott Laboratories) in comparison with that of the following 6 disinfectants: wipes containing alkaline phenolic cleaner (Vesphene II SE; Steris Corporation), 70% isopropyl alcohol (HUMCO), or chlorine (The Clorox Company) and the quaternary ammonium-containing disinfectants Sani-Cloth Plus (PDI), CaviWipes (Metrex), and Clorox Disinfecting Wipes (The Clorox Company). The chemical compositions of the hospital disinfectants were as follows: alkaline phenolic wipes, 9.09% *o*-phenylphenol and 7.66% *p*-tertiary amylphenol (dilution, 1 : 128); 70% isopropyl alcohol wipes, 70% isopropyl alcohol by volume; chlorine wipes, chlorine concentration of

80 ppm; Sani-Cloth Plus wipes, 14.85% isopropyl alcohol, 0.125% *n*-alkyl (68% C₁₂ and 32% C₁₄) dimethyl ethylbenzyl ammonium chlorides, and 0.125% *n*-alkyl (60% C₁₄, 30% C₁₆, 5% C₁₂, and 5% C₁₈) dimethyl benzyl ammonium chlorides; CaviWipes, 14.30% isopropanol and 0.23% di-isobutylphenoxyethoxyethyl dimethyl benzyl ammonium chloride; and Clorox Disinfecting Wipes, 0.145% *n*-alkyl (60% C₁₄, 30% C₁₆, 5% C₁₂, 5% C₁₈) dimethyl benzyl ammonium chloride and 0.145% *n*-alkyl (68% C₁₂ and 32% C₁₄) dimethyl ethylbenzyl ammonium chloride. Wipes containing alkaline phenolic cleaner, alcohol, and water were created by applying 15 mL of the respective liquid to a 14 × 14-cm paper towel (Brawny; Georgia-Pacific) folded into fourths and lightly squeezing until the towel was no longer dripping but still remained wet.

Before experiments were conducted, each laptop was tested for proper functionality, and the laptops were photographed to document any possible bleaching or discoloring of the letters on the keys by the disinfecting agents. Each keyboard was wiped from side to side 300 times (25 times per day for 12 days) with its respective disinfecting agent. The keyboards were evaluated before commencement of the experiment, and no keys had discolored or faded letters. A medical photographer photographed the keyboard of each computer after 0, 50, 100, 150, 200, 250, and 300 wipes.

Five test keys (“Q,” “F,” “M,” “Enter,” and “.”) and one nontreated key (“Esc”) were contaminated with 10 μ L of inoculum of one test organism (10² dilution of a 0.5 McFarland of *Pseudomonas aeruginosa* [10⁶ organisms/mL], 10³ dilution

TABLE 2. Effectiveness of Disinfectants at Removing and/or Inactivating Test Organisms on Computer Keyboards

Disinfectant, Test Organism	No. of Trials	Mean Decrease in No. of cfu After Disinfection, % ^a
Alcohol		
All organisms	14	97.03
ORSA	8	95.29
PA	3	99.99
VRE	3	98.71
CaviWipes		
All organisms	9	99.85
ORSA	3	99.87
PA	3	99.69
VRE	3	100.00
Chlorine		
All organisms	14	99.80
ORSA	8	99.73
PA	3	100.00
VRE	3	99.78
Clorox Disinfecting Wipes		
All organisms	9	99.96
ORSA	3	100.00
PA	3	99.89
VRE	3	100.00
Sani-Cloth Plus		
All organisms	9	99.99
ORSA	3	99.97
PA	3	100.00
VRE	3	100.00
Vesphene II SE		
All organisms	12	99.95
ORSA	6	99.90
PA	3	100.00
VRE	3	100.00
Sterile water		
All organisms	14	99.05
ORSA	8	98.58
PA	3	99.75
VRE	3	99.61

NOTE. CFU = colony-forming units; ORSA = oxacillin-resistant *S. aureus*; PA = *Pseudomonas aeruginosa*; VRE = vancomycin-resistant *Enterococcus* species.

^a Calculated as the percentage difference in the number of colony-forming units on the treated keys, compared with the number of colony-forming units on the control keys.

of a 0.5 McFarland of oxacillin-resistant *S. aureus* [ORSA; 10^5 organisms/mL], and 10^3 dilution of a 0.5 McFarland of vancomycin-resistant *Enterococcus* species [VRE; 10^5 organisms/mL]). The following strains of test microbes were obtained from the American Type Culture Collection (ATCC; Rockville, MD): ORSA ATCC strain 43300, *P. aeruginosa* ATCC strain 27853, and VRE ATCC strain 51299.

Because of the dilutions, mean of 173 colony-forming units (cfu) per key of each inoculum were deposited. After drying for 45 minutes, each keyboard (except for the "Esc" key) was

wiped with its respective disinfectant for 5 seconds and allowed to air dry. Once dry, the test keys were swabbed using a sterile applicator tipped with polyester fiber (Fisherbrand; Fisher Scientific) moistened with D/E neutralizing broth (Becton, Dickinson, and Company). The applicator was placed in 1 mL of the D/E neutralizing broth and vortexed for 1 minute at high speed, and 100 μ L of the solution was plated on 2 culture plates with trypticase soy agar containing 5% sheep blood. Plates for detection of ORSA and VRE were incubated at 37°C for 48 hours, and colony-forming units were counted; plates for detection of *P. aeruginosa* were incubated at 37°C and analyzed after 24 hours. The efficacy of the disinfectant was determined by calculating the percent reduction achieved using the following formula: [no. of colony-forming units on the control key – no. of colony-forming units on the test key] / no. of colony-forming units on the control key. The mean number of colony-forming units on the 2 plates for each analysis were calculated, and then the mean number of colony-forming units for all analyses that involved the same disinfectant and test organism were determined. There were too many colony-forming units to count on 2 plates. For these 2 plates, mean values were estimated on the basis of the maximum number of colonies that could be counted.

Each day after the contamination experiment was completed, the entire keyboards were wiped 25 times with their respective disinfecting agents. Wiping was performed for 5 seconds in a side to side manner on the key surfaces of the entire keyboard, and 10 minutes of drying time was allowed between wiping episodes.

Because of the residual antimicrobial activity of the quaternary ammonium compounds, no growth or limited growth was observed on the control keys of the keyboards treated with these compounds. To remove the residual disinfectant, the keyboards were washed 3 times at the end of each day with 15 mL of a soapy solution (1 : 50 Dawn Ultra Concentrated; Proctor & Gamble). The solution was applied to a laparotomy sponge, which was squeezed to remove excess liquid. Between each wash, the keyboard was dried with a fresh laparotomy sponge. After all washes, the keyboards were rinsed 5 times with a laparotomy sponge containing 15 mL of sterile water and were allowed to air dry. On 3 different days, the 7 control keys (the "Esc" key on each keyboard) were swabbed after 25 wipes, and swab specimens were cultured in trypticase soy broth to ensure that all microorganism had been removed or inactivated by the disinfectant.

Evaluation of Sustained Disinfectant Efficacy

We evaluated the sustained antimicrobial effectiveness of disinfectant wipes over a 48-hour interval for inactivation of *P. aeruginosa* and VRE that were inoculated onto keys. Sani-Cloth Plus wipes, CaviWipes, Clorox Disinfecting wipes, and an alcohol wipe were tested. The alcohol and sterile water wipes were made by applying 15 mL of the respective liquid to a

TABLE 3. Sustained Efficacy of Disinfectants Applied to Keyboard Against Vancomycin-Resistant *Enterococcus* Species

Disinfectant	Efficacy of Disinfectant, by Time of Microbial Challenge and Duration of Disinfectant Exposure, %					
	Challenge at 6 Hours		Challenge at 24 Hours		Challenge at 48 Hours	
	10-min Exposure	60-min Exposure	10-min Exposure	60-min Exposure	10-min Exposure	60-min Exposure
Alcohol	3.05	5.67	12.58	3.31	10.89	5.59
CaviWipes	100.00	100.00	100.00	100.00	100.00	100.00
Clorox Disinfecting Wipes	100.00	100.00	100.00	100.00	100.00	100.00
Sani-Cloth Plus	100.00	100.00	100.00	100.00	100.00	100.00
Sterile water	0.00	0.28	9.69	0.00	0.00	9.09

NOTE. Efficacy was calculated as the percentage difference in the number of colony-forming units on the treated keys, compared with the number of colony-forming units on the control keys. Challenge times are hours since disinfectant exposure.

14 × 14-cm paper towel (Brawny) folded into fourths and lightly squeezing until the towel was no longer dripping but still remained wet. At the initiation of the experiments, the keyboards were wiped 5 times for 5 seconds each time. The keyboard was allowed to air dry between each application.

Individual keys were challenged with the test organisms 6, 24, and 48 hours after disinfectant application. Different pairs of keys on each keyboard were designated as control or test keys for each period. The challenge consisted of inoculating test keys with 10 µL of VRE or *P. aeruginosa* to achieve, on average, an inoculum of approximately 80 cfu/key (mean values, 70 cfu/key for VRE and 86 cfu/key for *P. aeruginosa*). The keys were then swabbed when dry (after approximately 10 minutes) and 60 minutes after the application of the test inoculum. This protocol allowed us to assess both the sustained efficacy of the disinfectant for short (ie, 10 minutes) and long (ie, 60 minutes) contact times.

The degree of contamination on keys was assessed by swabbing keys with a sterile applicator tipped with polyester fiber that was then placed in 1 mL of D/E neutralizing broth,

vortexed for 1 minute at high speed, and cultured quantitatively. The efficacy of each disinfectant was calculated as the percentage difference in the number of colony-forming units on the treated keys, compared with the number of colony-forming units on the control keys.

RESULTS

Of the 25 cultures performed for keyboards before disinfection, all had growth of 2 or more microorganisms (Table 1). Many keyboards tested positive for skin organisms, including coagulase-negative staphylococci (100% of keyboards), diphtheroids (80%), *Micrococcus* species (72%), *Bacillus* species (64%), nonfermentative gram-negative rods (36%), propionibacteria (28%), alpha streptococci (21%), *Aspergillus niger* (20%), and viridans streptococci (8%). Pathogenic microbes recovered from cultures of keyboard swab specimens included *Aspergillus flavus*, *A. niger*, ORSA, and vancomycin-susceptible *Enterococcus* species. The keyboard swab specimens yielded a mean number of 1,995 cfu of pathogens on culture (median, 1,180 cfu

TABLE 4. Sustained Efficacy of Disinfectants Applied to Keyboard Against *Pseudomonas aeruginosa*

Disinfectant	Efficacy of Disinfectant, by Time of Microbial Challenge and Duration of Disinfectant Exposure, %					
	Challenge at 6 Hours		Challenge at 24 Hours		Challenge at 48 Hours	
	10-min Exposure	60-min Exposure	10-min Exposure	60-min Exposure	10-min Exposure	60-min Exposure
Alcohol	0.00	0.00	10.28	0.00	1.07	0.00
CaviWipes	61.33	48.32	83.96	79.47	73.40	32.22
Clorox Disinfecting Wipes	69.99	59.43	69.45	74.70	79.81	55.62
Sani-Cloth Plus	68.91	70.54	91.75	90.41	86.71	85.86
Sterile water	16.58	27.76	34.75	40.85	16.51	17.74

NOTE. Efficacy was calculated as the percentage difference in the number of colony-forming units on the treated keys, compared with the number of colony-forming units on the control keys. Challenge times are hours since disinfectant exposure.

[range, 80-7340 cfu]). With the exception of coagulase-negative staphylococci, the count of almost all other microorganisms was less than 1,000 cfu per keyboard.

All disinfectants were highly effective at removing and/or inactivating ORSA, *P. aeruginosa*, and VRE (Table 2). The water control was excellent at removing the pathogens. None of the disinfectants had any visible effect on the appearance of the letters or the keyboard. In addition, all laptop computers worked without any functional problems.

All 3 quaternary ammonium compounds demonstrated excellent sustained activity against VRE, and antimicrobial activity was maintained over the entire 48-hour test period (Table 3). In contrast, alcohol failed to demonstrate any clinically relevant sustained activity. Similarly, all 3 quaternary ammonium compounds demonstrated sustained activity against *P. aeruginosa* but at a level less than that for VRE (Table 4). However, the efficacy of the 3 compounds had not decreased at the time points sampled (ie, 6 hours, 24 hours, and 48 hours after disinfectant application). As with VRE, alcohol did not demonstrate any clinically relevant sustained activity against *P. aeruginosa*.

DISCUSSION

Computers are ubiquitous in medical settings where laboratory test results are accessed, radiologic findings are viewed, and computerized physician order entry is performed. Several investigations have evaluated the degree of microbial contamination and the types of contaminating organisms on computer keyboards.²⁻⁷ Concern has been raised that contact with contaminated computer keyboards might serve as a mechanism for contaminating the hands of healthcare workers with potential pathogens, thereby leading to cross-contamination of patients. Of special concern is transmission of pathogens that have been demonstrated to be present on environmental surfaces in proximity to colonized or infected patients, including ORSA, VRE, and *Clostridium difficile*. Two studies have provided suggestive evidence linking computer use to cross-contamination of patients.^{2,3}

Our study also demonstrated that microbial contamination of computer keyboards was prevalent and that commensal skin organisms were the most common contaminating microbes.⁶ We also found that contamination with ORSA and with potential pathogens, such as *Aspergillus* species, was less frequent than has been reported previously.^{4,5} However, the degree of contamination we observed was high enough to potentially allow transmission via contaminated hands.

All disinfectants tested were highly effective at removing or inactivating pathogens, including ORSA, VRE, and *P. aeruginosa*, after a 5-second application with a wipe. Importantly, all 3 quaternary ammonium-containing products demonstrated excellent sustained activity against VRE and good sustained activity against *P. aeruginosa* for up to 48 hours after application. Quaternary ammonium compounds are recognized to have a more limited efficacy against *P. aeruginosa*.⁹

The risk of transmission from contaminated keyboards would be eliminated if staff performed hand hygiene after contact with inanimate objects in the patient care environment.⁸ Unfortunately, 34 studies have demonstrated low compliance (approximately 40%) with the Centers for Disease Control and Prevention guidelines on hand hygiene.⁸ Therefore, we agree with other investigators who have recommended that routine disinfection be performed on computer keyboards that are used in patient care areas.^{2,3,5,6,10} Computers in these areas should be disinfected daily and when visibly soiled. In an effort to prevent contamination of computers, health care personnel should not touch computer keyboards with contaminated hands. If a keyboard cover is used, we suggest that it should be disinfected using these same recommendations. Additionally, mobile computers used by patients should be disinfected between patient uses. Ideally, computers used by a patient under isolation precautions should remain in the patient's room until no longer needed and should then be disinfected before use by another person. Our data demonstrate that keyboards can be safely and successfully decontaminated with disinfectants, such as quaternary ammonium compounds.

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