A critical evaluation of methicillin-resistant *Staphylococcus aureus* and other bacteria of medical interest on commonly touched household surfaces in relation to household demographics

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Background: We sought to characterize and quantify bacteria of medical interest on commonly touched household surfaces and to evaluate predictors such as employment, day care attendance, and presence of infants and pets.
Methods: A convenience sample of 35 homes was recruited from the metro-Boston area, and up to 32 surfaces were sampled in kitchens, bathrooms, and living areas.
Results: Highest bacterial counts were associated with wet sites including hand/skin contact surfaces such as the tub, kitchen sink, and faucet handles. Surfaces were found to be contaminated with the bacteria of medical interest including species of *Enterobacteriaceae*, *Pseudomonas*, methicillin-sensitive *Staphyloccus aureus* (MSSA), and methicillin-resistant *Staphyloccus aureus* (MRSA).
Conclusion: A number of hand/skin contact surfaces were found to be frequently contaminated with one or more of the bacteria of medical interest. The presence of a cat in the home was found to be a strong predictor for the isolation of MRSA. This study provides further insight about microorganisms of medical interest on surfaces in American homes and the impact of factors that can influence bacterial contamination. The study may indicate that cleaning in private homes should be directed to the areas pinpointed by the study as very rich in bacteria of potential medical importance.
Key Words: Bacterial contamination; household surfaces; bacterial counts; MRSA; cats; hand-contact surfaces.

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Studies have shown that potential pathogens are found in the home environment, particularly in the kitchen and bathroom.[1] These bacteria are transmitted through a variety of means including direct person to person spread or contact with body fluids, contact with droplets or airborne spread by droplet nuclei, and indirect transmission through hand contact with a contaminated intermediate object.[2] Contaminated sites and surfaces in the home have been classified into 1 of 3 general categories (reservoirs, reservoir disseminators, and hand/food contact surfaces) for which the risks of contamination and cross contamination are higher.[3]

Bacteria can be introduced into the home via the human occupants, pets, and foodstuffs.[4] Day care attendance is a recognized risk factor for infectious diseases among children.[5-7] Of special concern is the increased possibility of the development of antimicrobial-resistant bacteria among these children. Day care-attending children have an increased relative risk for respiratory and gastrointestinal infections and double the risk of otitis media than non-day care-attending children. This increased risk is caused by increased contact between day care-attending children and subsequent increased exposure to infectious organisms.[8] Health care workers may be exposed to infectious materials including infectious body fluids, contaminated medical supplies and equipment, contaminated environmental surfaces, or contaminated air. Nosocomial transmission of infectious organisms, including methicillin-resistant *Staphyloccus aureus* (MRSA), occurs primarily through the hands of health care personnel, which may come into contact with colonized patients.[9] Health care workers infected with MRSA and other

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infectious microorganisms can serve as reservoirs and disseminators of MRSA within the hospital and outside within the community.[9] In addition to contaminated hands serving as a reservoir, studies implicate health care workers' contaminated clothing in the spread of MRSA and other infectious diseases.[10] More recently, MRSA outbreaks have occurred among athletes, military recruits, and prison inmates, and community-acquired MRSA (CA-MRSA) is emerging as a major cause of skin infections as reviewed in an International Scientific Forum on Home Hygeine expert report.[11] Only a small body of literature exists regarding the presence of potential pathogens in the home, and even fewer studies provide detailed information on bacterial counts at commonly touched surfaces. There is little or no data on predictors such as employment of household members in the health care field and day care attendance, as well the influence of infants, cats, and dogs living in the home and surface contamination.

The objectives of this study were to (1) describe bacterial colonization of 32 surfaces in residential homes and (2) determine whether homes of health care workers, or homes with children in day care, have MRSA detected on surfaces more often than homes without health care workers or children in day care.

METHODS

A convenience sample consisting of 35 homes in the metro-Boston area was selected. Potential subjects were recruited by word of mouth and through flyers. A screening tool was used to determine whether the home met inclusion criteria of having a child in diapers and a dog and/or a cat in the home. Simmons College Institutional Review Board (IRB) approval was obtained, and informed consent was required.

Environmental sampling

Homes were swabbed from January 2006 through March 2006. Environmental sampling was performed on 32 surfaces in each home using sterile swabs moistened in sterile buffer solution and sterile 25-cm^2 sampling templates. Swab sites included surfaces in the kitchen, bathroom, and home office.

Bacterial sample processing

Based on piloting studies[12] and the methods described by Cole et al 2003,[13] the following sample processing methodology was adopted. In the laboratory, swabs from each site were vortexed for 20 seconds, followed by serial dilution, with 0.1 mL inoculated onto trypticase soy agar, spread for counting, and incubated at 35°C for 36 hours. The remaining, undiluted portion from all swab samples was placed in 9 mL trypticase soy broth and incubated at 35°C for 24 hours for enrichment. The enriched sample was then streaked onto trypticase soy agar, mannitol salt agar, XLD agar, and pseudocel agar. Bacteria of medical interest, targeted in this study, included coagulase-negative (CN) *Staphylococcus* sp, methicillin-sensitive *Staphyloccus aureus* (MSSA) and MRSA, *Pseudomonas* sp, and members of the *Enterobacteriaceae.* Preliminary identification was based on colony morphology, pigmentation, Gram's stain reaction, oxidase reaction, and catalase test. Confirmation for MSSA and MRSA is previously described,[12] and API-20E test strips (bioMerieux Industry Inc., Hazelwood, MO) were used for species identification of *Pseudomonas* and *Enterobacteriaceae.*

Household questionnaire

Data were collected using a home characterization questionnaire that included participant-specific questions such as age, gender, race, ages of all family members, smoking, sport and/or gym attendance, and occupation; symptomatic-related questions such as the presence of a cough, fever, or rash and use of antibiotics or hospitalizations; day care-specific questions such as staff to student ratio and hours per week in day care; health care-specific questions such as specific job description and use of gowns, gloves, and frequency of handwashing; animal-specific questions such as number, type, and health of all pets; and cleaning- specific questions such as frequency of cleaning and type of cleaning products used.

Statistical methods

Independent variables of interest. The variable ''day care attendance'' was defined as any child who, by parent's report, attended day care during any part of the week (0 = no day care-attending children in the home or 1 = day care-attending children living in the home). The variable ''health care worker'' was coded as 0 = no health care worker living in the home or 1 = at least 1 health care worker living in the home. Data were analyzed at the house level; however, pertinent demographic data are displayed at the person level to clearly describe the subject population.

Dependent variables. The variable ''MRSA'' was dichotomized (0 = no MRSA detected on any surface in the home or 1= MRSA detected on any surface within the home). Median counts for each site together with the 25th and 75th percentiles were calculated. Total counts of zero were converted to 0.5 following standard statistical practice for handling zeros. There were only 4 counts recorded as $>10^8$, and these data were top censored to 10^8 for the purpose of analysis.

Table 1. Surfaces ranked by median count/sample area, with surface categorization as predominantly wet or dry and hand/skin contact indicated, and 25th and 75th percentiles are also given

Sites	n	Wet (W), Dry (D) Hand/skincontact (H)	25th Percentile	Median	75th Percentile
Kitchen drain	35	W	0	1.0×10^5	1.4×10^6
Sponge or cloth	33	W, H	1.9×10^4	1.3×10^5	3.7×10^5
Tub	35	W, H	0	2.3×10^4	3.2×10^5
Toilet floor	35	D	1.6×10^2	7×10^2	3.4×10^3
Kitchen faucet handle	35	D, H	7×10^2	6.7×10^2	2.1×10^3
Kitchen floor	35	D	1.7×10^2	6.1×10^2	1.7×10^3
Child training potty	10	D, H	0	5.9×10^2	8.9×10^2
Kitchen table top	35	D, H	1.1×10^2	3.9×10^2	9.0×10^2
Pet food dish	35	D, H	0	3.9×10^2	1.5×10^3
Bathroom sink	34	W, H	0	3.7×10^2	1.7×10^3
Dish towel	31	D, H	8×10^1	3×10^2	9.9×10^2
Toy	34	D, H	3×10^1	2.8×10^2	2.3×10^3
Kitchen counter top	35	D, H	0	2.5×10^2	9.8×10^2
Bathroom counter top	33	D, H	6×10^1	1.5×10^2	1.1×10^3
Keyboard	32	D, H	0	1.5×10^2	3.3×10^2
Infant changing mat	24	D, H	1	1×10^2	6.8×10^2
Refrigerator door handle	34	D, H	0	7×10^1	5.4×10^2
TV remote	34	D, H	1×10^1	6.5×10^1	2.1×10^2
Bathroom faucet handle	35	D, H	0	6×10^1	6.8×10^2
Microwave touch screen	34	D, H	0	5.5×10^1	2.2×10^2
Light switch bathroom	34	D, H	1×10^1	5×10^1	2×10^2
Phone, home office	22	D, H	0	5×10^1	5.9×10^2
Infant high chair	26	D, H	0	5×10^1	5×10^2
Phone, kitchen	32	D, H	0	4×10^1	4.5×10^2
Chopping board	32	D, H	0	4×10^1	6×10^2
Door handle, inside	34	D, H	0	4×10^1	1.45×10^2
Flush handle	35	D, H	0	3×10^1	1×10^2
Computer mouse	31	D, H	0	2×10^1	2.1×10^2
Kitchen sink	35	W	0	0	2.1×10^3
Garbage bin	35	D	0	0	3.8×10^1
Toilet seat	35	D, H	0	0	8×10^1
Toilet bowl	32	W	0	0	4.7×10^6

NOTE. Median counts were calculated by converting zero counts to 0.5 and converting all counts $>10^8$ to a count of 10^8.

Potential confounders explored included the use of a public gym, presence of a cat or dog in the home, and use of antibacterial hand soap or cleaner in the home, which were dichotomized as yes/no variables. The number of pets in the home, number of people in the house, and ages of family members were also collected.

Statistical analysis was performed with SPSS version 15, (SPSS Inc, Chicago, IL) for Windows and Microsoft Excel 2003 for Windows (Microsoft Corp, Redmond, WA). Appropriate descriptive statistics for the data were conducted including frequency percentages for categorical data and mean, median, mode, and standard deviation for continuous data. The χ^2 test (for large samples) or Fisher exact test (for small samples) was used to assess the relationship between dichotomized variables and the presence of MRSA in the home. Multivariate logistic regression was used to explore the relationship between day care attendance or health care worker and the presence of MRSA in the home after adjusting for appropriate biologic or statistical confounders. Statistical confounding in regression model development was defined as a change of at least 10% in the β coefficient for the outcome variable.

RESULTS

Bacterial counts

Sites ranked by median aerobic total count are shown in Table 1. Highest median counts were observed at the kitchen drain, sponge, tub, toilet floor, and kitchen faucet handles. All of these sites constitute wet sites, with the exception of the faucet handles and floor. It was found that counts at these surfaces ranged from zero to maximum counts of 10^7. Lowest median counts (10^0) were recorded from the toilet seat and toilet bowl. Maximum counts recorded at hand contact surfaces ranged from 10^3 at surfaces such as the phones to 10^6 at the kitchen faucet handle and sponge. Statistical analysis using the Wilcoxon signed rank test of the median hand contact surface counts in the kitchen (faucet handle, dish towel, phone, refrigerator

Table 2. The percentage frequency of occurrence of MSSA, MRSA, CN *Staphylococcus* sp, Pseudomonads, and *Enterobacteriaceae* at kitchen and bathroom surfaces from 35 homes

	MSSA	MRSA	CN *Staphylococcus* sp	Pseudomonads	*Enterobacteriaceae*
	%	%	%	%	%
Kitchen surface					
Phone	15	0	68	11	14
Sink	23	3	63	24	83
Chopping board	0	0	75	12	56
Refrigerator door handle	12	0	71	19	58
Faucet handle	12	6	83	7	59
Sponge or counter wiping cloth	30	3	52	39	79
Table top	14	0	71	24	55
Counter top	12	3	68	11	67
Garbage bin	6	3	47	17	46
Drain	20	3	63	40	80
Dish towel	27	7	77	13	71
Microwave touch screen	7	0	59	10	52
Kitchen floor	18	0	66	27	53
Bathroom surface					
Sink	17	3	60	21	28
Toilet floor	11	0	69	17	46
Toilet seat	14	0	77	14	22
Toilet bowl	15	0	56	32	36
Tub	26	3	66	47	43
Counter top	12	0	88	30	25
Flush handle	3	0	59	22	36
Faucet handle	11	3	86	24	31
Door handle	12	3	68	19	44
Child training potty	0	0	89	17	25
Light switch	9	0	65	15	31

CN, coagulase negative.

Table 3. The percentage frequency of occurrence of MSSA, MRSA, CN *Staphylococcus* sp, Pseudomonads, and *Enterobacteriaceae* at home office and other surfaces from 35 homes

	MSSA	MRSA	CN *Staphylococcus* sp	Pseudomonads	*Enterobacteriaceae*
	%	%	%	%	%
Home office surface					
Keyboard	3	0	84	11	28
Mouse	10	0	68	12	8
Phone	13	0	88	6	25
TV remote control	12	0	79	4	27
Other surfaces					
Infant high chair	29	4	38	11	42
Infant changing mat	23	0	59	0	11
Toy	34	0	63	20	33
Pet food dish	15	3	74	18	36

CN, coagulase negative.

door handle, microwave touch pad) compared with hand contact surface counts in the bathroom (faucet handle, light switch, door handle, flush handle) indicated no significant difference ($P = .06$). Although not found to be statistically significant, there were some indication of factors that trended toward higher counts at surfaces, including having a child in day care, and the presence of a cat.

Identification of target organisms

The prevalence of bacteria of medical interest at kitchen, bathroom, home office, and other surfaces is shown in Tables 2 and 3, respectively. As previously reported,[12] MSSA was found in 34 of the 35 homes, and MRSA was found in 9 of the 35 homes. MSSA was isolated on all surfaces in one or more homes, with the

exception of the chopping board and the training potty. Thirteen surfaces in these 9 homes tested positive for MRSA. Ten of these surfaces can be classified as hand contact surfaces, or skin contact in the case of the tub, and only 5 can be classified as wet surfaces. Only 2 surfaces, the dish towel and kitchen faucet, tested positive in more than 1 home. Although MRSA was isolated from some surfaces on which the frequency of occurrence of MSSA was also high, such as the sponge, tub, and high chair, MRSA was not isolated from the toy, which was the site most frequently contaminated with MSSA. MRSA was also isolated from some surfaces with low frequency of occurrence of MSSA, such as the garbage bin, counter top, and faucet handle.

Gram-negative bacteria belonging to the families of *Enterobacteriaceae* and *Pseudomonadaceae* were isolated from all 32 sites in 1 or more homes. In general, species of *Enterobacteriaceae* were isolated more frequently than pseudomonads. For the most part, wet sites were more frequently contaminated than dry. The kitchen sites were always more frequently contaminated than the bathroom and other areas. In all but 2 kitchen surfaces, *Enterobacteriaceae* were found to be present in more than 50% of samples and at 83%, 80%, and 79% of sink, drain, and sponge samples, respectively. The highest frequency of occurrence in the bathroom was on floors (46%), door handle (44%), and tub (43%). Occurrence was also relatively high on high chairs (42%) and toys (33%). Many hand contact surfaces in kitchen, bathroom, and other areas were found to be frequently contaminated with *Enterobacteriaceae*. Pseudomonads were isolated from all surfaces in 1 or more homes, except for the infant changing mat. Pseudomonads were most frequently isolated from the drain (40%) and sponge (39%) in the kitchen, from the tub (47%) and toilet bowl (32%) in the bathroom, and also from the toy (20%). In total, 486 gram-negative samples were isolated and identified, including the different gram-negative species shown in Table 4. *Enterobacter* was the predominant species and was isolated from all surfaces in 1 or more homes, except for the infant changing mat. Species of *Salmonella* were isolated on 2 occasions from the toilet bowl and once from the bathroom tub. *Shigella* sp was isolated on only 1 occasion from the kitchen counter. Species of *Escherichia* were rarely isolated and were only found at the kitchen sink, bathroom floor, and infant high chair.

Table 4. Gram-negative bacterial species belonging to the *Enterobacteriaceae* and pseudomonads isolated from household surfaces

Enterobacteriaceae (n)
Citrobacter sp (1)
C braakii (1)
C koseri/farmeri (1)
Enterobacter sp (29)
E amnigenus (3)
E sakazakii (22)
E aerogenes (4)
E gergoviae (1)
E cloacae (108)
Serratia sp (4)
S marcescens (6)
S odorifera (5)
S rubidaea (1)
S plymuthica (1)
S liquefaciens (1)
Klebsiella sp (5)
K oxytoca (16)
K ornithinolytica (8)
K terrigena (1)
K pneumoniae (17)
Kluyvera sp (1)
Shigella sp (1)
Salmonella arizonae (3)
Proteus mirabilis (5)
Other enterobacterial species (6)
Ewingella americana (2)
Pantoea sp (1)
Pantoea subsp 2 (1)
Pantoea subsp 3 (67)
Pantoea subsp 4 (3)
Pseudomonads
P seudomonas sp (84)
P aeruginosa (25)
P fluorescens (7)
P luteola (22)
P oryzihabitans (17)
Stenotrophomonas maltophilia (6)

Questionnaire data analysis

Questionnaire data were gathered from a householder in each of the 35 homes. The population in the homes was almost exclusively of white ethnicity with the largest group being adults over the age of 18 (53%), followed by children 2 years of age or younger (23%), and the smallest group was school-aged children from 6 to 17 years of age (3%).

There were 131 people living in the 35 homes. The majority of homes consisted of 2 adults and 2 children. Most of the 62 children were infants and toddlers not in school programs (69.4%), and most of the 69 adults were college graduates (47.8%) or had graduate or postgraduate degrees (29.0%), as shown in Table 5. Fifty-six percent of the population was male, whereas 44% was female.

Health care worker and MRSA

Thirty-seven percent of homes had at least 1 person in the home working in health care. Analyses revealed that, of the 9 homes that were positive for MRSA, 2 were homes of health care workers. Fisher exact test

Table 5. Household demographics

	Demographic		Number	Percent of population
Level of education				
Children, n = 62	Infant/toddler, no school		43	69.4
	Preschool-kindergarten		17	27.4
	Elementary-high school		2	3.2
Adult, n = 69	High school/some college/ associates/tech school		16	23.2
	College graduate		33	47.8
	Graduate/postgraduate		20	29.0
Race				
	White		126	96
	Non-white		5	4
Sex				
	Male adults	n = 37	73	56
	Male children	n = 36		
	Female adults	n = 32	58	44
	Female children	n = 26		

revealed no significant difference in MRSA contamination among homes with or without health care workers (*P* value = .43). Additionally, there was no association between health care workers presence in the home and such variables as cats or dogs in the home; number of people in the home; gym use; or use of antibacterial hand soap, kitchen cleaner, or bathroom cleaner.

Day care attendance and MRSA

Of the 35 homes, 43% had at least 1 child in the home attending day care. Whether or not a home had a child in day care was not associated with such variables as cats or dogs in the home; number of people in the home; gym use; or use of antibacterial hand soap, kitchen cleaner, or bathroom cleaner. Of the 9 homes that were positive for MRSA, 4 were homes in which children attended day care, whereas 5 were not. Fisher exact test revealed no significant difference in MRSA contamination among homes with or without day care attendance (*P* value = 1.0).

MRSA and other covariates

Gym use, antibacterial hand soap use, kitchen antibacterial cleaner use, bathroom antibacterial cleaner use, number of people in a home, and presence of a dog in the home were not associated with MRSA presence on home surfaces (*P* values all greater than .05). However, as has been reported previously,[12] a cat in the home was a strong predictor of the presence of MRSA on surfaces. Forty-three percent of homes surveyed had 1 or more cats in the home. The data showed that 7 homes with cats (46.7%) had 1 or more surfaces positive for MRSA, whereas only 2 homes without cats (10%) had MRSA present (*P* value = .02). Whether or not a cat lived in the home was not associated with such variables as health care workers; a child in day care; number of people in the home; gym use; or use of antibacterial hand soap, kitchen cleaner, or bathroom cleaner but was significantly associated with dogs, ie, most cat owners did not own dogs (*P* value $< .001$).

With such a small sample, exploration of potential confounding factors in a multivariate logistic regression model was limited. The odds of having MRSA on 1 or more surfaces in a home were 7.9 times higher (95% confidence interval (CI) 1.3-46.6; *P* = .02) in homes with a cat than homes without a cat. The best fitting model was adjusted for just 1 variable, the number of people in the home, and was correctly able to classify 66.7% of the homes with MRSA and 85% of the homes without MRSA. The odds of MRSA on at least 1 surface in the home was 8.1 times higher (95% CI: 1.30-51.1; *P* = .025) in homes with a cat compared with homes without cats after adjustment for the number of people in the home.

Exploratory analysis was also run to explore further the relationship between cats and the presence of MRSA. However, there was no association between anyone in the home having a recent infection or using antibiotics, anyone in the home recently being admitted to the hospital or being seen as an outpatient, or any pet in the home being ill or on medication including antibiotics.

DISCUSSION

This study confirms and extends the results of previous studies analyzing the bacterial content of the home.[13,14] The count data ranged from zero to 10^8, indicating the extreme ranges of bacterial counts that can occur on surfaces in the home and the influence of moisture on total counts.

MSSA was found at 14% of all sites sampled in the 35 homes compared with 31% of sites in a larger study of some 70 surfaces in 201 homes,[14] although hand/skin contact was a common surface factor for contamination in both studies. In our study, MRSA was isolated in 9 of the 35 homes, and the majority of sites contaminated with MRSA correspond to hand contact surfaces, as has been indicated in the literature.[15] To our knowledge, this is the first report of a study to isolate MRSA in ''healthy homes,'' ie, homes without a history of infection or antibiotic use. The association between MRSA and cats is discussed previously.[12] Our data suggest that having a health care worker in the home or a child in day care is not a significant predictor of whether MRSA will be found in the home or not.

Many of the gram-negative species identified in this study were also identified in an earlier study[13] and are either pathogens or opportunistic pathogens. The overall findings for gram-negative bacteria are consistent with previous studies with the exception of *Escherichia*

coli. A study of UK homes[14] found that 60% of all gram-negative isolates corresponded to *E coli*. This is significantly more than Cole et al,[13] who found that *E coli* represented approximately 5% of all the gram-negative target bacteria isolated. In the present study, there were no isolates of *E coli*. When speculating, it seems possible that these differences in *E coli* could be attributed to 1 or more of the following factors: differences in methodology, including the use of different selective agars and sample size across the 3 studies; differences between homes in the United Kingdom and United States; and also changes in household cleaning practices over the last 25 years.

In considering the overall results of this study as well as others, it is clear that many potential pathogens are still readily present in our homes. MSSA, a skin and wound pathogen, was found in nearly all homes in this study, and, to our knowledge, this is the first report of MRSA found in households without a history of infections or antibiotic use. Many of the isolated gram-negative bacteria are regarded as fecal coliforms and, as such, indicate fecal contamination. The source of this contamination is likely to be human for bathroom surfaces and a combination of human and raw foods for kitchen surfaces. The level of fecal coliforms on hand contact surfaces throughout the homes in our study indicates the potential for spread of fecal pathogens via hand contact surfaces.

A number of surfaces stand out in this study as being both heavily contaminated and also frequently contaminated with 1 or more of the bacteria of medical interest including MSSA, MRSA, and species of *Enterobacteriaceae* and *Pseudomonas*. Included are hand and skin contact surfaces such as faucet handles, the bathroom sink, and the tub; food contact surfaces such as the kitchen sink and kitchen sponge; and surfaces in contact with infants such as toys. All of these surfaces are recommended for targeted hygiene in the IFH Guidelines,[16] and this study again confirms the importance of regular and effective cleaning and disinfection at targeted surfaces in the home. Further investigation is required to determine whether MRSA cross contamination is occurring among pets, humans, and surfaces, which may have implications for medical management of at-risk patients.

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