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Major Article

Cleaning and disinfection in home care: A comparison of 2 commercial products with potentially different consequences for respiratory health

Nancy Goodyear PhD [a], Pia Markkanen ScD [b,*], Christian Beato-Melendez MSc [a], Hagir Mohamed MD, MSc [a], Rebecca Gore PhD [b], Catherine Galligan MSc [b], Susan Sama ScD [b], Margaret Quinn ScD, CIH [b]

[a] Department of Biomedical and Nutritional Sciences, College of Health Sciences, University of Massachusetts Lowell, Lowell, MA
[b] Department of Public Health, College of Health Sciences, University of Massachusetts Lowell, Lowell, MA

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Background: Home care aides perform personal care and homemaking services in client homes, including cleaning and disinfection (C&D). Although C&D are performed to remove soil and dust, they are increasingly performed for infection prevention. Many C&D products contain respiratory irritants. The objective of this study was to evaluate 2 commercial products for C&D effectiveness on common household surfaces in seniors' homes.

Methods: Two C&D visits were conducted in 46 seniors' homes. One visit applied a bleach-containing cleaning product and the other applied an environmentally preferable product. Before and after C&D, the study team performed organic soil bioluminometer measurements on surfaces and collected cotton swab and wipe samples for total bacteria count, *Staphylococcus aureus*, and *Clostridium difficile* identification.

Results: Both products removed microorganisms from tested surfaces. *S aureus* was found in 7 households, 1 strain of which was methicillin-resistant. Both products removed *S aureus* from all surfaces. Bleach-containing products removed somewhat more soil than environmentally preferable products, although results were statistically significant for only 1 surface.

Conclusions: The study showed similar, not identical, C&D performance for 2 cleaning products with potentially different consequences for respiratory health. Additional research is needed to develop robust recommendations for safe, effective C&D in home care.

The rapidly aging US population and increasingly complex medical conditions managed at home demand more home-based providers for medical and social assistance care. Home care (HC) aides, who work in 1 of the fastest growing occupations in the United States, perform a wide range of services, including personal care of clients (such as showering and bathing) and homemaking, particularly cleaning and disinfection (C&D).[1,2] Cleaning is a significant part of aides' work. In our recent survey in Massachusetts,[2] we found that 80% of nearly 3,500 HC aide visits involved cleaning a bathroom or kitchen with 24% of visits involving bleach and an additional 23% involving ammonia or other strong chemical.

Although cleaning tasks are performed to remove soil, dirt, and dust from home surfaces, they are also increasingly performed for infection prevention. One reason for the focus on disinfection is concern for infections in home health care[3] and the rise in prevalence of drug-resistant pathogens, such as methicillin-resistant *Staphylococcus aureus* (MRSA) both in hospitals and in the community.[4,5] *Clostridium difficile* is the major cause of enteric infections among elderly persons.[6] Patients returning home after exposures at facility-based health care settings can be carriers, which further compromises the health of home-based caregivers. Whereas cleaning removes soil, disinfection eliminates most recognized

* Address correspondence to Pia Markkanen, ScD, Department of Public Health, College of Health Sciences, University of Massachusetts Lowell, One University Ave, Lowell, MA 01854.
E-mail address: Pia_Markkanen@uml.edu (P. Markkanen).

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pathogenic microorganisms.[4,7,8] Increasingly, commercial products are formulated to accomplish C&D in 1 step. There are guidelines for C&D in hospitals and outpatient settings[7,8]; however, no guidelines exist for HC C&D.[9]

Complicating the choice of products to use for C&D, there is growing evidence that exposures to some common C&D products cause or exacerbate respiratory illnesses, including asthma and chronic bronchitis among janitors, domestic cleaners, and health care workers with regular exposure to cleaning products.[9-17] Indeed, cleaning products are among the leading causes of occupational asthma.[18-20] Because of high volatility, spray application, and use in small and poorly ventilated spaces, there is concern that some C&D product exposures may be sufficient to increase respiratory illness risks among HC aides who clean and disinfect clients' homes. This may at least partially explain the finding that HC aides in Massachusetts had twice the prevalence of asthma compared with all other workers (20% vs 10%) in the Behavioral Risk Factor Surveillance Survey, 2011-2014.[21]

Concerns about adverse human and environmental health effects of C&D products have led to the development of so-called green cleaning products. In fact, there are several different terms used for these products by manufacturers, marketers, and environmental services professional groups, such as environmentally friendly, environmentally preferable, and green. It is important to note that there is still no accepted official definition of green. The 1998 US Executive Order 13101[22] defined environmentally preferable as "products or services that have a lesser or reduced effect on human health and the environment when compared with competing products or services that serve the same purpose." Despite the fact that there is no standard definition for the general concept of green, including a green cleaning product, this sector of the consumer products market is rapidly growing and some hospitals and other institutions have adopted initiatives such as green cleaning programs. Based on toxicologic screenings, there is limited evidence on how green cleaning products influence human health. Additionally, little is known about whether green cleaning products are as effective as conventional products for disinfecting as well as for cleaning in actual home and health care settings.[4,9] The American Society for Healthcare Environmental Services has recommended[23] that the green cleaning definition be expanded to address the efficacy of infection control and prevention "towards effective products with the fewest adverse effects on human health and the environment."

The objective of our study was to evaluate the effectiveness of alternative commercial products for C&D of common household touch points under conditions typical of a visit by an HC aide in the homes of residents in senior housing complexes. Two commonly available products were compared, a conventional cleaner containing chlorine bleach, and another marketed as green. For the purposes of this article, environmentally preferable will be used rather than green. The study was informed by a laboratory investigation that tested 3 products for C&D efficacy under controlled conditions with known sample contamination, including the 2 products used in this field study[4] and a qualitative investigation of 9 focus groups of HC aides and 7 in-depth interviews with HC managers to characterize HC C&D practices and products so that these could be applied in the present study. The findings of the qualitative study will be reported elsewhere.

METHODS

The sampling and culture methods of this study are based on previously published literature.[24-28] The study was approved by the University of Massachusetts Lowell Institutional Review Board. All participants signed an informed consent form. Three local senior housing complexes in Massachusetts were recruited as research study sites. With the assistance of the housing authorities, our study team recruited and visited 46 homes between January and September 2016.

A team of 3 researchers conducted 2 visits at each home, at least 1 week apart. During 1 visit, a bleach-containing (BC) product was used (Clorox Cleanup Cleaner + Bleach; The Clorox Company, Oakland, CA) and the other visit tested an environmentally preferable (EP) product (Seventh Generation Disinfecting Multi-Surface Cleaner; Seventh Generation Inc, Burlington, VT). The research team members have no relationship with the manufacturers of these products. The cleaning products were purchased at a local grocery store. The BC product was selected based on input from HC aides who participated in focus groups to identify commonly used C&D products. HC aides reported very infrequent use of green products and the EP product selected for this study was based on common availability in grocery stores. The efficacy of these 2 products was evaluated in an earlier laboratory pilot investigation, which has been reported elsewhere.[4] Residents were not told the names of the products or which type was applied during a visit. The order of product use (first visit vs second visit) was randomized.

Residents received a $40 cash incentive for the first visit and $60 for the second visit. A study visit lasted no more than 45 minutes. The team members wore disposable shoe covers during the entire study visit to protect residents' floors as well as gloves during sampling and cleaning to protect samples from hand contamination. Eight high-touch surfaces were sampled in each home: 4 surfaces in the kitchen (sink, counter, floor, and faucet) and 4 surfaces in the bathroom (tub or shower, toilet seat, floor, and faucet). Analyses included rapid measurements of organic soil (hereafter called soil), including bacteria, food residue, and human cells using an ATP luminometer (SystemSure Plus, Hygiena, Camarillo, CA); total aerobic plate counts (TAPC) as a measure of overall bacterial contamination and disinfection effectiveness; the presence of *S aureus*, differentiating MRSA and methicillin-susceptible *S aureus* (MSSA) strains after isolation, as an indicator of a significant pathogen; and the presence of *C difficile,* differentiating nontoxigenic and toxigenic strains.

The bathroom and kitchen faucets were sampled for TAPC and *S aureus* only, by rubbing the entire surface of the handle with a sterile swab premoistened with D/E Neutralization Broth (Becton, Dickinson and Company, Franklin Lakes, NJ) to stop the activity of any residual disinfectant.

The toilet seat and bathroom floor next to the toilet were sampled for *C difficile* only, using Swiffer Sweeper dry cloths (Procter & Gamble, Cincinnati, OH), which pick up dust and soil electrostatically.[27] The toilet seat was split into left and right sides and 1 entire side was wiped before and after cleaning. The floor next to the toilet was sampled using a template with 20 cm × 20 cm (400 cm^2 in total) sampling areas, 1 for precleaning and 1 for postcleaning. The entire template area was wiped with a Swiffer cloth.

The kitchen floor, counter, sink, and bathroom tub or shower were sampled for ATP, TAPC, and *S aureus*. A 4-section sampling template was used to define the sample area (20 × 20 cm), with separate areas for ATP and swab sampling, as well as precleaning and postcleaning. ATP luminometer measurements were performed using Ultrasnap ATP Test swabs (Hygiena) following the manufacturer's instructions. Sterile swabs, premoistened in D/E Broth were used for TAPC and *S aureus* sampling.

After all precleaning samples were taken, a brief spot cleaning was performed on all surfaces: cleaning product was sprayed directly on the surface and wiped immediately with a paper towel, to model actual home cleaning methods. After 10 minutes to allow the product to dry, postcleaning samples were taken. After sampling, swabs were placed in 1 mL D/E Neutralization Broth, Swiffers

were sealed in plastic bags, and all were transported on ice to the microbiology laboratory for culture. All samples were processed within 24 hours of collection. One study visit produced 16 precleaning and postcleaning samples in total.

TAPC

TAPC methods are based on previously published literature.[25] In the laboratory, TAPC were performed from the neutralizing broth in which swabs were transported. After vortex mixing for 10 seconds, serial 10-fold dilutions were made using phosphate-buffered saline and 100 µL was spread plated to duplicate tryptic soy agar plates (Becton, Dickinson and Company, Franklin Lakes, NJ) and incubated overnight at 37°C. Recovered colonies were visually inspected and counted.

S aureus *screening*

S aureus screening methods are based on previously published literature.[24,25,29] A 100-µL aliquot of the original neutralization broth was spread plated to duplicate mannitol salt agar plates (Becton, Dickinson and Company) and incubated overnight at 37°C. If growth was absent or insufficient, plates were reincubated for another 24 hours before final interpretation. In addition, the original swabs were placed in 3 mL *Staphylococcus* Broth (Becton, Dickinson and Company) and incubated at 37°C for 48 hours. Following incubation, a 100-µL aliquot of *Staphylococcus* Broth was inoculated in duplicate onto mannitol salt agar and incubated at 37°C overnight, with an additional 24 hours' incubation if growth was absent or minimal. Suspected *S aureus* colonies were identified by Gram stain, catalase test, and the Sure-Vue SELECT Staph ID Latex Slide Agglutination Test (Fisher Healthcare, Waltham, MA). Methicillin-resistant isolates were screened and confirmed using the PBP2a SA Culture Colony Test (Alere Inc, Waltham, MA).

C difficile *screening*

C difficile screening methods are based on previously published literature.[28] Phosphate-buffered saline (25 mL) was added to the sterile collection bag containing the Swiffer cloths. The bags were homogenized manually for approximately 1 minute by squeezing vigorously. This solution was inoculated in 25 mL tryptic soy broth (Becton, Dickinson, and Company) and incubated at 37°C for 48 hours. After incubation, broths were subjected to alcohol shock by adding 1 mL tryptic soy broth to 1 mL absolute ethanol. The mixture was incubated at room temperature for 1 hour and vortex mixed every 10 to 15 minutes. After treatment, 100 µL of the mixture was inoculated onto prereduced tryptic soy broth with 5% sheep blood agar (SBA) and *C difficile* selective agar (both from Becton, Dickinson and Company) and incubated anaerobically for 48 hours, with an additional 48-hour incubation for plates with no or minimal growth. Colonies on *C difficile* selective agar and SBA consistent with typical *C difficile* morphology were subcultured to SBA, and their identification was confirmed through Gram stain and the *C. diff* Quik Chek Complete Antigen Test (Alere Inc).

Data analysis

Paired differences were used to calculate the change in precleaning minus postcleaning levels for both ATP readings and $\log_{10}$ TAPC. Thus, positive values represent decreases in mean levels, indicating that the treatment reduced soil or bacteria, respectively. Pairing was done by sampling site within a home visit. Paired differences of pre–post change within a home by sampling site were calculated to represent the comparative efficacy of the BC product compared with the EP product. Thus a positive difference indicated that the BC product was more effective than the EP product. Box plots[30] were produced for both ATP measurements and $\log_{10}$ TAPC by site and by cleaning product. All calculations were performed using SAS version 9.4 software for Windows (SAS Institute Inc, Cary NC).

Table 1
Household characteristics in a cleaning and disinfection in home care study, January-September 2016

All participating households (n = 46)	n	%
Household makeup		
1-person households	45	98
2-person households*	1	2
Gender of the household participant		
Female	35	76
Male	11	24
Age of household participant, y		
< 50	1	2
50-69	14	31
70-89	28	61
≥ 90	3	7
Households with pets	10	22
Households receiving home care services	14	30
Household receiving cleaning services	5	11
Hospitalization within 3 mo	7	15

*Only 1 member of this household participated in the study.

RESULTS

Population characteristics

Measurements were completed in 46 households (Table 1). Forty-five households had a single resident who enrolled as the study participant. One household had 2 adult residents; however, only 1 member of this household was registered as the study participant. The age range of participants was 46-95 years, average age was 75 years, and median age was 77.5 years. Most participants were women (76%), and only 1 resident self-identified as nonwhite. Ten participating households (22%) had pets (7 cats, 1 dog, and 2 birds); 14 households (30%) received some type of HC services, including homemaking assistance; and 5 households (11%) received other cleaning services. Seven participants had had an overnight hospitalization during the 3 months before the study visit.

ATP bioluminescence

An ATP luminometer was used to measure organic soil on specific household surfaces in relative light units (RLUs) of bioluminescence per 400 cm^2 in each household before and after cleaning with each product (Table 2 and Fig 1). Precleaning, the highest average soil levels were found in the kitchen sink (1,718 RLU/400 cm^2 from the BC product sample sites and 1,752 from the EP product sample sites). The other 3 sample sites, kitchen counter, bathroom tub/shower, and kitchen floor had considerably less organic soil on average before the study cleaning began. Of the 4 sampling sites, in only 1—the tub—was the pre–post reduction significantly larger (ie, more clean) using the BC product compared with the EP product (Table 2). There was wide variability in soil levels among the samples, notably for the tub and kitchen sink (Fig 1).

TAPC

Both products reduced the TAPC of microorganisms on all surfaces (Fig 2). The BC product achieved an overall average 2.26 $\log_{10}$

Table 2
Comparison of cleaning effectiveness* of a bleach-containing (BC) versus an environmentally preferable (EP) product applied in senior housing, January-September 2016

	BC product			EP product			BC – EP†
Sampling site (N = 46)	Pre- cleaning average	Post- cleaning average	Mean change	Pre-cleaning average	Post- cleaning average	Mean change	Mean (95% confidence interval)
Bathroom tub (n = 46)	745	58	687	398	299	98	589 (27 to 1,150)
Kitchen counter (n = 46)	550	84	465	602	289	313	152 (–141 to 447)
Kitchen floor (n = 46)	502	71	431	596	177	418	13 (–175 to 200)
Kitchen sink (n = 46)	1718	882	836	1757	1378	379	458 (–486 to 1,402)

*Organic soil levels measured as ATP relative light units of bioluminescence/400 cm^2 of a specific household surface.
†Difference in mean pre–post cleaning change, comparing BC with EP products.

reduction on all surfaces (range, 2.20-2.74 log_{10}) and the EP product achieved an overall average reduction of 1.65 log_{10} (range, 1.42-1.84 log_{10}). These reductions correspond to 90% or better reductions in median TAPC using either product.

There were 24 sampling site pairs where neither precleaning nor postcleaning samples had any bacterial growth, and 50 sampling site pairs (9%) where 1 reading (pre or post) was above the limit of detection. In these 74 cases, TAPC reduction calculations could not be performed. This occurred most frequently with the kitchen sink, with 19 instances (38%) followed by 10 for the tub or shower (20%), 6 each for the kitchen counter and kitchen floor (2%), 5 for the bathroom faucet (10%), and 4 for the kitchen faucet (8%).

Identification of S aureus *and* C difficile

There were only 7 households in which *S aureus* was found—6 MSSA and 1 MRSA strain (Table 3). Kitchen surfaces, in particular the kitchen sink, were the most common surfaces where *S aureus* was found. All MSSA and MRSA were identified precleaning only; no *S aureus* was identified in any postcleaning sample. Both products removed *S aureus* from all surfaces sampled. *C difficile* was found in only 1 household visit, on the toilet seat, in both precleaning and postcleaning samples. In this household, *C difficile* was found in only 1 of the 2 visits. Two of the 8 households where either *S aureus* or *C difficile* was found received HC services.

DISCUSSION

Soil, measured by ATP RLUs

Both cleaning products removed organic soil on all tested surfaces, based on the study precleaning and postcleaning ATP luminometer measurements. ATP levels reflect the presence of organic material such as living cells and cellular material that is no longer viable, but not inorganic soils (eg, sand or dust). Overall, we found that the BC product removed somewhat more organic soil than the EP product, although the difference was modest and statistically significant at only 1 sampling site. The ATP luminometer is used in foodservice and commercial facilities to monitor general cleaning effectiveness and for training purposes. There are no guidelines or targets for what levels constitute clean enough for home cleaning. Thus it is difficult to judge the health influence of the modest differences we observed between products.

We designed the study's cleaning protocol to model what is typically done in actual home cleaning rather than following the manufacturers' instructions, which recommend leaving the EP product on the surface for 10 minutes before wiping it off. The shorter contact time may have reduced the effectiveness of the EP product. Our previous pilot study in a laboratory setting showed that this same EP product, when used as directed, worked as effectively as the BC product for cleaning and disinfecting a stainless steel surface, and when disinfecting a ceramic surface.[4]

In this study overall, the kitchen sink surface had the most organic soil and was the hardest to clean; neither product achieved a 50% or greater reduction in RLUs/400 cm^2 readings. The area around the drain, where sampling occurred, can be difficult to access and the stainless steel surface may become scratched over time, allowing microorganisms and food residue to remain. In addition, the sink is a wet surface, which may support organisms better than the dry floor and counter surfaces. The bathtub or shower, also a frequently wet surface, had the second highest maximum readings, although the means were similar to the kitchen counter and floor. The BC product performed best on the bathtub or shower, whereas the EP product performed best on the floor.

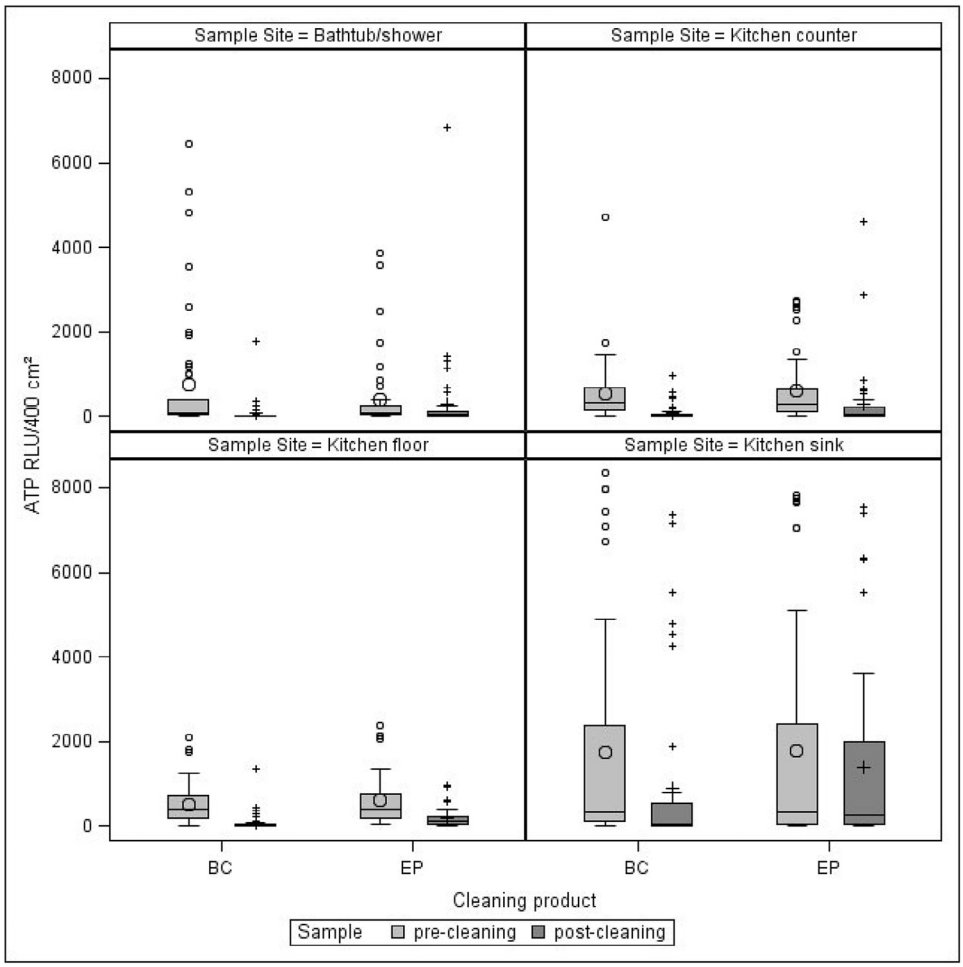

Fig 1. Box plot comparison of organic soil levels comparing bleach-containing (BC) versus environmentally preferable (EP) cleaning products applied in senior housing, January-September 2016. Organic soil levels were measured as ATP relative light units of bioluminescence/400 cm^2 of specific household surface.

TAPC

A real-world evaluation of the effectiveness of disinfectants is necessarily limited by the presence of microorganisms before cleaning—if the concentrations are low, it is not possible to observe a large reduction in counts regardless of the product. The participants of this study were asked to not clean the kitchen and bathroom surfaces for 2 days before the team's sampling and cleaning visit, and at the start of each visit, the participants were asked to confirm this. Nonetheless, in our study not all sampled surfaces had precleaning TAPC of microorganisms ≥3.00 $\log_{10}$. The 3.00 $\log_{10}$ TAPC reduction meets the Environmental Protection Agency standard for nonfood contact surface disinfection requirement; that is, the commonly accepted threshold defining disinfection.[31] In this study's 160 complete sampling pairs, where the precleaning TAPC was ≥3.00 $\log_{10}$, the BC product achieved at least a 3.00 $\log_{10}$ reduction 52 times and EP product 18 times. No guidelines exist for home environment disinfection effectiveness.

When our study sampling pairs are expressed as percent reduction in TAPC, the BC product achieved an overall median microorganism reduction of 100% and the EP product achieved a 99% reduction. For the general population without extensive knowledge in microbiology, percent TAPC reductions are a more understandable disinfection effectiveness concept than $\log_{10}$ reductions.

Our previous lab study[4] showed that with a 30-second wet contact time, the BC and EP products were equally effective at killing *Escherichia coli* and MSSA organisms (≥5 $\log_{10}$ reduction) on common household surfaces dosed with these common bacteria.

C difficile, *MRSA, and MSSA*

C difficile was found only in 1 home and MRSA in 1 other home. MSSA was found in about 6% of visits. As mentioned, 2 of the 8 households where these pathogens were found received HC services. Pets, cleaning services, and overnight hospitalizations had either no or very minimal association in identification of these organisms; however, the study population was relatively small and with a larger sample size an association could have been possible. The prevalences of these pathogens were lower than other researchers have reported for home-based studies. Scott et al[25] studied a sample of 35 random homes in the Boston metropolitan area and collected wipe samples from 32 surfaces in each. MRSA was found in 26% of these homes, and MSSA was found in all but 1 of the homes. In comparison to our study, Scott et al[25] sampled more surfaces, including dish cloths and sponges, toys, pet food dishes, and others.[25] Alam et al[28] found *C difficile* in 32% of 30 Houston area homes, with greatest prevalence from shoe bottom swab samples (40%), bathroom or toilet surfaces (33%), and house floor dust (33%). A possible explanation is that all but 1 of the 46 households participating in

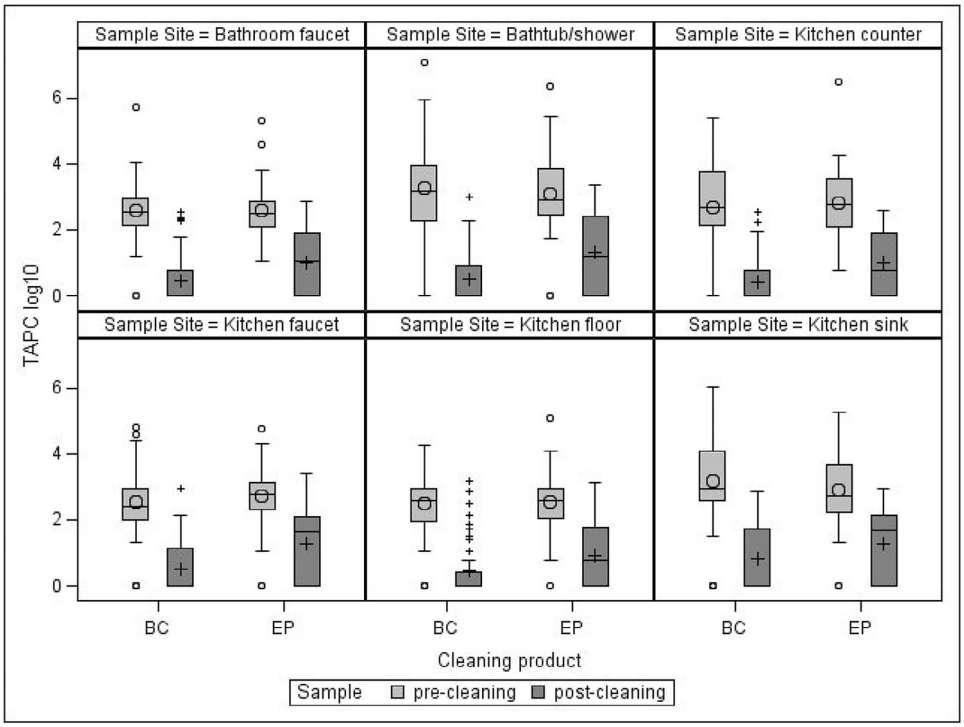

Fig 2. Total precleaning and postcleaning results for bleach-containing (BC) product versus environmentally preferable (EP) product applied in senior housing, January-September 2016. *TAPC*, total aerobic plate counts.

Table 3
Identification of *Staphylococcus aureus* pathogens in precleaning samples. Pathogens were not found in any postcleaning samples collected in senior housing units, January-September 2016

Household visited	Pathogen found	Sampling sites where pathogen was found
1	MSSA	Kitchen sink, counter and floor
2	MSSA	Kitchen sink
3	MSSA	Kitchen sink
4	MSSA	Bathroom tub
5	MSSA	Kitchen counter
6	MSSA	Kitchen sink
7	MRSA	Kitchen sink

MRSA, methicillin resistant *Staphylococcus aureus*; *MSSA*, methicillin susceptible *Staphylococcus aureus*.

our study had only 1 resident and all residents were adults, many with limited mobility and thus with limited opportunities for transporting soil and microorganisms from the outside environment into the home.

CONCLUSIONS

C&D of environmental surfaces are key components of infection prevention in health care, including at home. This study found similar, but not identical performance of C&D for 2 different cleaning products with potentially different consequences for respiratory health. We encourage additional research with other cleaning products and in a larger number of homes to develop a more robust database for recommendations of safe and effective C&D in HC settings.

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