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Innovative compounds to reduce β-D-glucans, endotoxin, and allergens newly discovered on smartphones

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Abstract

Background: Eight-four percent of people own smartphones and view them 14 billion times daily, making them potential vectors for environmental hazards such as allergens, β-D-glucans (BDGs), and endotoxin. Whether these toxins are prevalent and the effectiveness of cleaning solutions targeting these agents on smartphones have not been studied.

Objective: We sought to determine (1) whether phones are reservoirs of allergen, endotoxin, and BDGs and (2) if present, whether their levels can be effectively reduced by using specific cleaning methods.

Methods: Electrostatic wipes used to wipe the phones of 15 volunteers were tested to determine their allergen, BDG, and endotoxin levels. Cleaning interventions were done on simulated phone models; 70% isopropyl alcohol, 0.184% benzyl and ethyl benzyl ammonium chloride (Clorox nonbleach [The Chlorox Company, Oakland, Calif]), 0.12% chlorhexidine, 0.05% cetylpyridinium, 3% benzyl benzoate, and 3% tannic acid wipes were used and compared with wipes with no solution (the control).

Results: The smartphones showed high and variable levels of BDG and endotoxin. Cat and dog allergens were found mostly on the smartphones of pet owners. The combination of chlorhexidine and cetylpyridinium significantly reduced BDG levels (mean 269 ng/wipe vs 1930 ng/wipe for the control [$P < .05$]) and endotoxin, (mean 349 vs 1320 endotoxin units/wipe for the control [$P < .05$]). The combination of benzyl benzoate and tannic acid significantly reduced the levels of cat and dog allergens (dog, mean level of 14 ng/wipe versus 407 ng/wipe for the control [$P < .001$]; cat, mean level of 55 ng/wipe versus 1550 ng/wipe for the control [$P < .001$]). The combination mixture solutions had the greatest reductions compared with the control.

Conclusions: There are elevated levels of BDG, allergens, and endotoxin on smartphones. The combination of chlorhexidine and cetylpyridinium was the most effective in reducing BDG and endotoxin levels, and the combination of benzyl benzoate and tannic acid was most effective in reducing cat and dog allergen levels on smartphones.

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Keywords

Allergens; environmental exposures; smartphones; endotoxin; β-D-glucans; cleaning solution

INTRODUCTION

More than 84% of people own a smartphone,[1] view them 14 billion times a day, and touch them up to 5400 times a day in a variety of locations and settings.[2] Environmental biologic agents act as triggers of inflammation and allergy, leading to adverse health outcomes, reducing the quality of life for many, and costing the health care system billions of dollars.[3] Allergens are the main drivers of atopic asthma and allergic rhinitis, which affect more than 50% of the population.[4] Endotoxin from gram-negative bacteria and β-D-glucans (BDGs) from fungi have also been found ubiquitously in the environment, including in homes and schools. They are triggers of inflammation and produce acute and chronic airway irritation.[5-7] Because smartphones are handled so often, they are potentially important fomites for exposures to allergens, *BDG*s, and endotoxins. Strategies to reduce these exposures on smartphones could potentially improve the health and lives of millions of people.

The Apple (Cupertino, Calif) and Samsung (Suwon-si, South Korea) smartphone companies recommend 70% isopropyl alcohol and 0.184% benzyl and ethyl benzyl ammonium chloride (Clorox nonbleach [The Chlorox Company, Oakland, Calif]) wipes to clean their products.[8] Chlorhexidine and cetylpyridinium have been shown to reduce mold and bacterial growth in other settings,[9] making a compound of these 2 chemicals a rational solution for reducing BDG and endotoxin levels. Benzyl benzoate[10] and tannic acid are known to break down animal and dust mite allergen in carpets and furniture,[11,12] thus making a compound of these chemicals a rational solution for reducing allergen levels. We had 2 research objectives: (1) to determine the prevalence of BDGs, endotoxins, and allergens on smartphone surfaces and (2) to test whether smartphone-recommended cleaning solutions and compounded cleaning solutions of chlorhexidine and cetylpyridinium were effective in reducing BDG and endotoxin levels and whether compounded cleaning solutions of benzyl benzoate and tannic acid were effective in reducing the levels of allergens found on smartphones.

To determine the levels of toxins on smartphones, we used an established method for collecting allergens, BDG, and endotoxin on other surfaces (not phones) using electrostatic wipes (ESWs).[13-16] The study was approved by the Hopkinton High School institutional review board, and informed consent was obtained. The volunteers were recruited from an equal number of pet owners and non–pet owners. The ESWs were wrapped in separate aluminum foil and protected in a zipper storage bag to prevent contamination. The ESWs were used to wipe the whole glass face and case surface of 15 cell phones in a standard protocol 3 times daily for 7 days and were then sent to the University of Iowa Human Toxicology and Exposomics Laboratory for analysis. Briefly, the wipes were eluted on pyrogen-free water for endotoxin, pyrogen-free PBS with 0.05% Tween-20 for allergens, and 0.3 N sodium hydroxide for glucan. The wipe eluates were analyzed for endotoxin using the kinetic chromogenic LAL assay (Kinetic-QCL, Lonza, Inc, Walkersville, Md), as

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previously described.[15,16] BDG level was measured by using the Glucatell Endpoint Assay (GT003, Associates of Cape Cod, Inc, East Falmouth, Mass) as previously described.[16] Allergens were quantified by using a multiplex array with magnetic beads (MRA-M10) from Indoor Biotechnologies, Inc (Charlottesville, Va), including dust mites (*Dermatophagoides pteronyssinus* 1 and *Dermatophagoides farinae* 1); cat (*Felinus domesticus* [Fel d] 1]); dog (*Canus familiaris* [Can f] 1); molds (*Aspergillus fumigatus* 1 and *Alterneria alternata* 1); mouse (*Mus musculus* 1); cock-roach (*Blattella germanica* 2); Timothy grass (*Phleum pratense* 5); and ragweed (*Ambrosia artemisifolia* 1) [for the assay limits of detection, see Table E1 in the Online Repository at www.jaci-global.org]. Three blank wipes were tested as a control.

For the phone cleaning intervention experiments targeting BDG and endotoxin, we used 0.12% chlorhexidine (which was shown in other settings to inhibit fungal and bacterial growth by a factor of 4) and 0.05% cytlpridinium (which in other settings reduced bacterial and fungal growth by 50%).[9] Our test groups for BDG and endotoxin were as follows: (1) control wipe with no solution, (2) 70% isopropyl alcohol wipe, (3) 0.184% benzyl and ethylbenzyl ammonium chloride (Clorox nonbleach wipe), (4) 0.12% chlorhexidine-only wipe, (5) 0.05% cetylpridinium chloride–only wipe, and (6) a combination 0.12% chlorhexidine and 0.05% cetylpyridinium chlorine wipe in a ratio of 1:1. To standardize exposure before our cleaning solution intervention, we used dust that had known concentrations of BDG and endotoxin (BDG in a concentration of 73.541 ng/mg and endotoxin in a concentration of 122.502 endotoxin units [EU]/mg). We weighed 30 mg of dust for each phone model sprinkled on each phone in standard fashion and did the same experiment 5 times for each of the solutions. Because of all the phones required, we used phone models rather than testing actual phones. These included a case and glass cover similar to those of a real phone without the hardware to mimic the surface of interest for testing. After the solution wipe, we collected the ESWs and sent them for BDG, allergen, and endotoxin analysis as described earlier.

For the phone cleaning intervention targeting allergens, we tested 3% benzyl benzoate and 3% tannic acid, which have in lower concentrations reduced dust mite and animal allergens in carpets and bedding.[10,12] To standardize exposure before our cleaning solution intervention, we used dust containing known concentrations of allergens (dust mite, *Dermatophagoides pteronyssinus* 1 [114.79 μg/g] and *Dermatophagoides farinae* 1 [41.95 μg/g]; cat, Fel d 1 [258.71 μg/g]; and dog, Can f 1 [46.62 μg/g] [Indoor Biotechnologics, Inc, Charlottesville, Va]). We weighed exactly 9.5 mg of dust for each phone model and did the same experiment 3 times for each of the solutions. Our test groups for allergens were as follows: (1) control wipe with no solution, (2) 70% isopropyl alcohol wipe, (3) 0.184% benzyl and ethylbenzyl ammonium chloride (Clorox nonbleach wipe), (4) 3% benzyl benzoate–only group, (5) 3% tannic acid–only wipe, and (6) a 1:1 combination of 3% benzyl benzoate and 3% tannic acid wipe.

Descriptive statistics were used to calculate mean exposure levels. All levels were adjusted for any trace levels found on the blank ESWs as controls by subtracting any trace levels in our calculations. Pairwise *t* tests were conducted between each intervention compared with the control. All tests were 2 tailed, and α was set at 0.05.

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RESULTS AND DISCUSSION

Table I shows the levels of BDG, endotoxin, and allergens found on the smartphones. We demonstrated that smartphones have high and variable levels of both BDG (mean 944, range 6.06-3240 ng/phone) and endotoxin (mean 311, range 0.06-919 EU/phone). Some phones had high levels of cat and dog allergens, and 1 phone had a detectable level of dust mite allergen. The high levels of pet allergens were mostly found on the smartphones of pet owners, although the phones of 2 dog owners did not yield detectable dog allergen. Interestingly, however, 1 phone also had dust mite and cat allergen even though the household was a reported non–pet owner.

Table II shows the mean residual spiked BDG and endotoxin levels after each intervention compared with the control wipe with no solution. The combination of chlorhexidine and cetylpyridinium significantly reduced BDG levels (a mean 269 ng/wipe for the combination vs 1930 ng/wipe for the control [$P = .02$]) and endotoxin levels (a mean of 349 EU/wipe for the combination vs 1320 EU/wipe for the control [$P < .05$]). The mean BDG levels after each intervention are shown in Fig 1. The combination wipe of 0.12% chlorhexidine plus 0.05% cetylpyridinium had the largest mean reduction in BDG level. The 0.184% benzyl and ethyl benzyl ammonium chloride (Clorox wipe) alone and the combination wipe of cetylpyridinium and chlorhexidine solution significantly reduced endotoxin levels compared with the controls (a mean of 436 EU/wipe for the 0.184% benzyl and ethyl benzyl ammonium chloride [Clorox] versus1320 EU/wipe for the control [$P = .04$]) (Table II).

Table III shows the results of the mean allergen level after each cleaning solution wipe compared with the control. The combination of benzyl benzoate and tannic acid significantly reduced cat and dog allergens (Can f 1, 14 ng/wipe for the combination vs 407 ng/wipe for the control [$P = .0005$]; Fel d 1, (55 ng/wipe for the combination vs 1550 ng/wipe for the control [$P < .0001$]). Comparisons of all the interventions for Fel d 1 and Can f 1 are shown in Fig 2. Benzyl benzoate alone was not effective in reducing cat and dog allergen levels. The combination wipe of 3% benzyl benzoate and 3% tannic acid had the largest mean reduction in Fel d1 and Can f 1 levels ($P < .0001$).

To our knowledge, this is the first study to evaluate BDG, endotoxin and allergen levels on smartphones and test novel solutions to reduce these exposures. We found levels of BDG, endotoxin, and allergens at levels that are potentially clinically relevant.[6,7,17-21] Although there are no other published smart-phone allergen studies, the cat allergen levels in our study were higher than those seen on wipes of tables used by urban schoolchildren, which were correlated with dust levels known to cause sensitization.[21] The widespread use of mobile phones in the worldwide population suggests that these findings are important. We demonstrated that the smartphone company–recommended cleaning wipes did not significantly reduce BDG, although 0.184% benzyl plus ethyl benzyl ammonium chloride (Clorox) was helpful in reducing dog allergen and endotoxin levels. It is interesting to note that the combination solutions seemed most effective and that cetylpyridinium alone and benzyl benzoate alone did not seem to provide any benefit.

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Our study has potential limitations. The prevalence of exposures may be different in other groups and in a larger sample. Simulated phone model experiments may not hold true in a real-world setting. Future studies could refine the optimum concentrations and combinations before embarking in a larger real-world population.

We conclude that smartphones carry biologic agents with the potential to contribute to adverse health outcomes and that our combination solutions may be effective for reducing exposures. This strategy deserves further study, and efforts to reduce harmful exposures on phones could improve public health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations used

BDG	β-D-glucan
Can f	*Canus familiaris*
ESW	Electrostatic wipe
EU	Endotoxin unit
Fel d	*Felinus domesticus*

REFERENCES

1. How many smartphones are there in the world? December 2022 user statistics. Bank my cell. Available at: https://www.bankmycell.com/blog/how-many-phones-are-in-the-world#. Accessed December 2022.
2. Naftulin J. Here's how many times we touch our phones every day. Business Insider July 13,2016; Available at: https://www.businessinsider.com/dscout-research-people-touch-cell-phones-2617-times-a-day-2016-7#:~:text=The%20typical%20cellphone%20user%20touches,more%20than%205%2C400%20times%20daily. Accessed July 13, 2016.
3. Wolf M, Lai PS. Indoor microbial exposures and chronic lung disease: from microbial toxins to the microbiome. Clin Chest Med 2020;41:777–96. [PubMed: 33153695]
4. Akar-Ghibril N, Phipatanakul W. The indoor environment and childhood asthma. Curr Allergy Asthma Rep 2020;20:43. [PubMed: 32548675]
5. Lai P, Sheehan WJ, Petty C, Coull B, Christiani DC, DR G, et al. School endotoxin exposure is associated with increased asthma morbidity. Amer J Respir Crit Care Med 2014;155:S35.
6. Krop EJ, Jacobs JH, Sander I, Raulf-Heimsoth M, Heederik DJ. Allergens and beta-glucans in dutch homes and schools: characterizing airborne levels. PloS One 2014;9:e88871. [PubMed: 24551183]

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7. Oluwole O, Rennie DC, Senthilselvan A, Dyck R, Afanasieva A, Kirychuk S, et al. The association between endotoxin and beta-(1–>3)-D-glucan in house dust with asthma severity among school children. Respir Med 2018;138:38–46. [PubMed: 29724391]
8. Webster S. How to clean your phones 2022: effectiver ways to clean your filthy phone. Verified News Explorer Network. 2022. Available at: https://vnexplorer.net/how-to-clean-your-phones-2022-effective-ways-to-clean-your-filthy-phone-s1013109.html. Accessed April 17, 2022.
9. Fathilah AR, Himratul-Aznita WH, Fatheen AR, Suriani KR. The antifungal properties of chlorhexidine digluconate and cetylpyrinidinium chloride on oral Candida. J Dent 2012;40:609–15. [PubMed: 22521700]
10. Hayden ML, Rose G, Diduch KB, Domson P, Chapman MD, Heymann PW, et al. Benzyl benzoate moist powder: investigation of acaricidal [correction of acarical] activity in cultures and reduction of dust mite allergens in carpets. J Allergy Clin Immunol 1992;89:536–45. [PubMed: 1740584]
11. Woodfolk JA, Hayden ML, Couture N, Platts-Mills TA. Chemical treatment of carpets to reduce allergen: comparison of the effects of tannic acid and other treatments on proteins derived from dust mites and cats. J Allergy Clin Immunol 1995;96:325–33. [PubMed: 7560634]
12. Lau S, Wahn J, Schulz G, Sommerfeld C, Wahn U. Placebo-controlled study of the mite allergen-reducing effect of tannic acid plus benzyl benzoate on carpets in homes of children with house dust mite sensitization and asthma. Pediatr Allergy Immunol 2002;13:31–6. [PubMed: 12000496]
13. Kanchongkittiphon W, Mendell MJ, Gaffin JM, Wang G, Phipatanakul W. Indoor environmental exposures and exacerbation of asthma: an update to the 2000 review by the Institute of Medicine. Environ Health Perspect 2015;123:6–20. [PubMed: 25303775]
14. Arbes SJ Jr, Sever M, Vaughn B, Mehta J, Lynch JT, Mitchell H, et al. Feasibility of using subject-collected dust samples in epidemiologic and clinical studies of indoor allergens. Environ Health Perspect 2005;113:665–9. [PubMed: 15929886]
15. Kilburg-Basnyat B, Metwali N, Thorne PS. Effect of deployment time on endotoxin and allergen exposure assessment using electrostatic dust collectors. Ann Occup Hyg 2015;59:104–15. [PubMed: 25187036]
16. Sauve JF, Locke SJ, Josse PR, Stapleton EM, Metwali N, Altmaier RW, et al. Characterization of inhalable endotoxin, glucan, and dust exposures in Iowa farmers. Int J Hyg Environ Health 2020;228:113525. [PubMed: 32311660]
17. Lai PS, Sheehan WJ, Gaffin JM, Petty CR, Coull BA, Gold DR, et al. School endotoxin exposure and asthma morbidity in inner-city children. Chest 2015;148:1251–8. [PubMed: 26087201]
18. Maheswaran D, Zeng Y, Chan-Yeung M, Scott J, Osornio-Vargas A, Becker AB, et al. Exposure to beta-(1,3)-D-glucan in house dust at age 7–10 is associated with airway hyperresponsiveness and atopic asthma by age 11-14. PloS One 2014;9:e98878. [PubMed: 24905346]
19. Bertelsen RJ, Carlsen KC, Carlsen KH, Granum B, Doekes G, Haland G, et al. Childhood asthma and early life exposure to indoor allergens, endotoxin and beta(1,3)-glucans. Clin Exp Allergy 2010;40:307–16. [PubMed: 20210808]
20. Jacobs JH, Krop EJ, Borras-Santos A, Zock JP, Taubel M, Hyvarinnen A, et al. Endotoxin levels in settled airborne dust in European schools: the HITEA school study. Indoor Air 2013;24:148–57. [PubMed: 23927557]
21. Kanchongkittiphon W, Sheehan WJ, Friedlander J, Chapman MD, King EM, Martirosyan K, et al. Allergens on desktop surfaces in preschools and elementary schools of urban children with asthma. Allergy 2014;69:960–3. [PubMed: 24750034]

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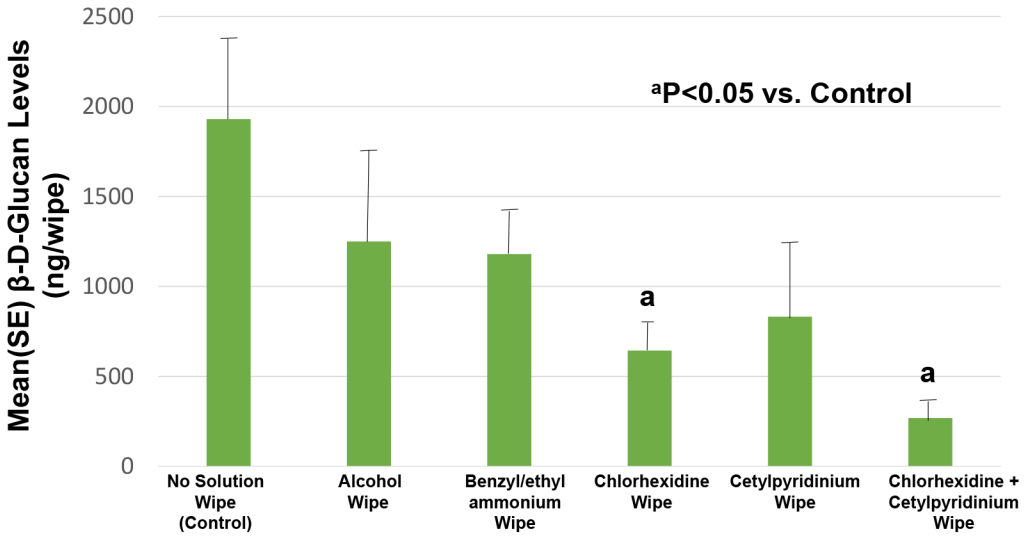

FIG 1.
Residual BDG levels by smartphone cleaning intervention compared with the control.

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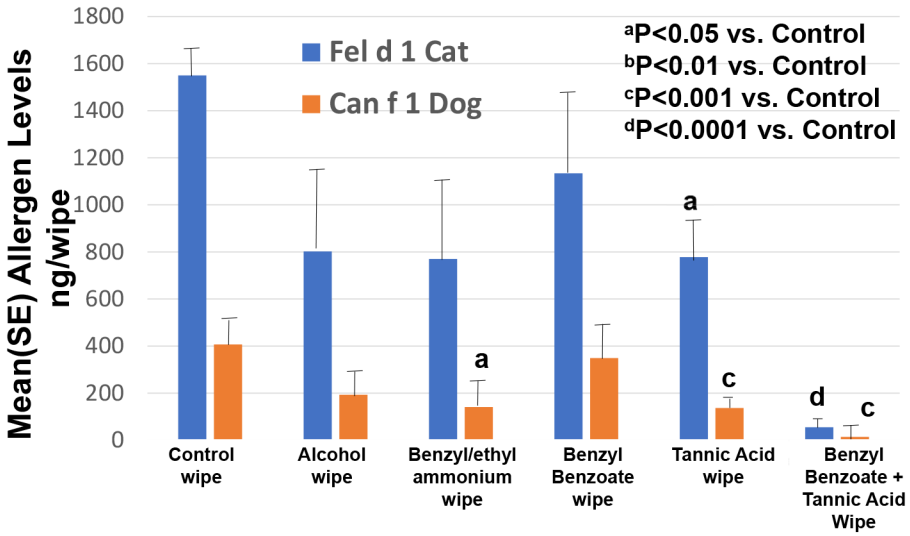

FIG 2.

Residual allergen levels by smartphone cleaning intervention compared with the control.

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TABLE I.

BDGs, endotoxin, and allergen levels discovered on smartphones

Phone sample	BDG level, ng/phone	Endotoxin level, EU/phone	*Fel d 1* (cat) level, ng/sample	*Can f 1* (dog) level, ng/sample	*Der P 1* (dust mite) level, ng/sample
1	988	251	<LLOD	<LLOD	<LLOD
2	2030	463	<LLOD	<LLOD	<LLOD
3	1510	508	<LLOD	<LLOD†	<LLOD
4	629	865	<LLOD	<LLOD†	<LLOD
5	1520	907	3.51	<LLOD	154
6	372	101	<LLOD	<LLOD	<LLOD
7	63.2	28.8	69.1*	<LLOD	<LLOD
8	90.0	1.47	21.9*	<LLOD	<LLOD
9	134	380	<LLOD	11800†	<LLOD
10	2710	919	<LLOD	4810†	<LLOD
11	3240	150	<LLOD	2020†	<LLOD
12	18.3	43.4	<LLOD	2160†	<LLOD
13	6.06	0.06	<LLOD	<LLOD	<LLOD
14	144	5.01	<LLOD	<LLOD	<LLOD
15	715	36.7	<LLOD	<LLOD	<LLOD

Levels have been corrected for any small amounts found on blank ESWs. All other allergens tested (ie, *Dermatophagoides farinae 1* [dust mite], Der *P* 2 [dust mite], *Mus musculus* 1 [mouse], *Blattella germanica* 2 [cockroach], *Rattus norvegicus* 1 [rat], *Phleum pratense* 5 [grass], *Ambrosia artemisifolia* [ragweed], and *Betula verrucosa* 1 [birch] were found at levels less than the LLOD.

Der *P*, *Dermatophagoides pteronyssinus*; *LLOD*, lower limit of detection.

*Smartphone of a cat owner.

†Smartphone of a dog owner.

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TABLE II.

Residual BDG and endotoxin levels by smartphone cleaning intervention compared with the control

Cleaning intervention	BDG level (ng/wipe), mean (SE)	*P* value	Endotoxin level (EU/wipe), mean (SE)	*P* value
Control wipe (no solution)	1930 (523)	—	1320 (219)	—
Alcohol	1250 (577)	.40	907 (371)	.49
Benzyl ethyl ammonium (Clorox)	1180 (305)	.25	436 (80)	.04
Chlorhexidine	644 (103)	.04	502 (103)	.06
Cetylpyridinium	832 (372)	.10	1500 (1114)	.40
Combination chlorhexidine + cetylpyridinium	269 (55)	.02	349 (90)	.03

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TABLE III.

Residual allergen level by smartphone cleaning intervention compared with the control

Cleaning intervention	*Der P 1* (dust mite) level (ng/wipe), mean (SE)	*P* value	*Der f 1* (dust mite) level (ng/wipe), mean (SE)	*P* value	*Der P 2* (dust mite) level (ng/wipe), mean (SE)	*P* value	*Fel d 1* (cat) level (ng/wipe), mean (SE)	*P* value	*Can f 1* (dog) level (ng/wipe), mean (SE)	*P* value
Control	1390 (88)	—	538 (22)	—	407 (3)	—	1550 (68)		407 (39)	
Alcohol	538 (151)	.04	208 (122)	.04	193 (25)	.12	802 (385)	.12	193 (97)	.11
Benzyl ethyl ammonium (Clorox)	467 (279)	.04	179 (58)	.03	141 (32)	.03	770 (391)	.10	141 (70)	.03
Benzyl benzoate	1060 (300)	.61	362 (110)	.410	349 (36)	.09	1134 (283)	.45	349 (116)	.79
Tannic acid	377 (126)	.001	115 (14)	.0007	137 (8)	.0002	778 (166)	.01	137 (18)	.005
Combination benzyl benzoate + tannic acid	39 (11)	.0001	15 (4)	.0001	14 (3)	<.0001	55 (14)	<.0001	14 (3)	.0005

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