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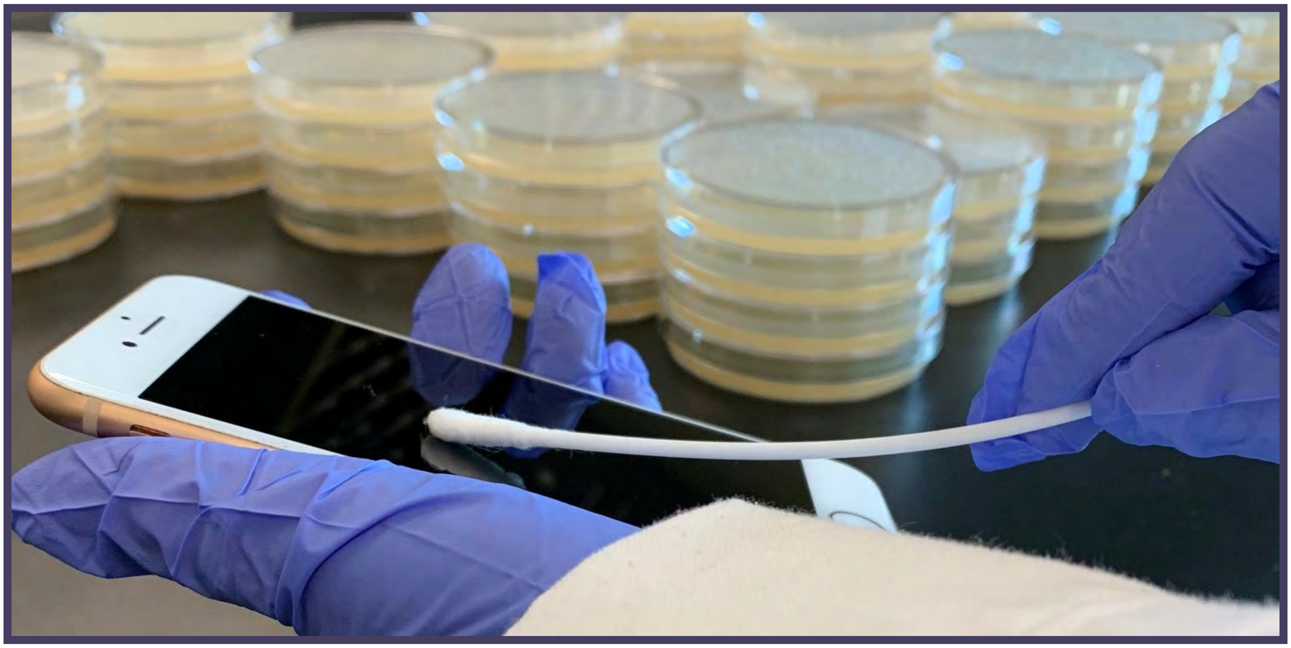

Prevalence and Control of Bacteria on Single-user Touchscreen Mobile Devices

ABSTRACT

Touchscreen mobile devices (TMD) are increasingly recognized as potential vehicles of disease transmission. This study aimed to i) characterize bacterial contamination of single-user TMDs and ii) evaluate the efficacy of two cleaning interventions. Additionally, study participants (n = 100) completed a survey on TMD use within food service establishments. Participants' TMDs were measured and divided vertically into sides A and B. Side A was swabbed to determine baseline levels of bacteria; side B was treated with a dry microfiber cloth or an isopropyl alcohol (IA) wipe and then swabbed. Swabs were spread on tryptic soy agar plates, which were then incubated. The average baseline bacterial concentration was 0.76 $\log_{10}$ (CFU/cm^2+1), with no difference between treatment groups (P = 0.183). There was a significant difference (P < 0.0001) between bacterial concentrations on side A and B, at 0.76 and 0.43 $\log_{10}$ (CFU/cm^2+1), respectively, regardless of treatment group. There was no significant difference (P = 0.132) in bacteria reductions between the two treatment groups. Data indicate that proper cleaning can reduce bacteria on TMDs by nearly 50%. More than 80% of participants expressed the belief that (i) TMDs can harbor harmful microorganisms; (ii) food service workers should clean their TMDs; and (iii) using a TMD while working with food is a potential health risk.

INTRODUCTION

Use of mobile devices (e.g., smartphones with touchscreens) has significantly increased in recent years, from 35% of American adults owning a smartphone in 2011 to 77% in 2018 *(15)*. The daily use of touchscreen mobile devices (TMD) by such a large proportion of the population has raised questions concerning the potential for TMDs to serve as reservoirs for human pathogens. Previous studies have reported on the microbial contamination of TMDs in high-risk environments such as clinical settings *(8, 10, 13)*. Meanwhile, few studies have been conducted on the microbial contamination of TMDs in non-clinical institutional settings, such as universities and food service establish-

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ments *(5)*. Previously, bacterial contamination on single-user TMDs in community settings have been evaluated *(1, 4)*.

Egert et al. investigated the microbial contamination of single-user TMDs at a German university *(5)*. Using contact agar plates, the authors sampled 20 TMDs and reported that all of them were contaminated with less than 2 $\log_{10}$ bacteria per cm^2. In another study, in which researchers sampled single-user TMDs in a community setting for bacterial contamination *(4)*, the authors reported that 145 of 192 TMDs had minimal contamination (1 to 5 CFU), while 23 (13.1%) and eight (4.5%) of the TMDs sampled had 'moderate' (6 to 10 CFU) and 'heavy' contamination (> 15 CFU) of microorganisms, respectively. These two studies demonstrate the potential for single-user TMDs to serve as vehicles of pathogen transmission outside of clinical settings.

Because of the potential public health risks related to contaminated TMDs, investigations on cleaning and disinfection practices have also been conducted. Akinyemi et al. split volunteers into four categories on the basis of occupation before testing their TMDs for bacterial contamination *(1)*. The authors found that 92% of TMDs from the group of marketers/food vendors were contaminated with bacteria, whereas only 42% of TMDs from the group of hospital workers were contaminated. Additionally, TMDs of public servants and lecturer/students were found to have contamination rates of 39% and 73%, respectively. Akinyemi and co-authors speculated that the difference in the prevalence of bacterial contamination could have been due to the disinfection practices utilized by hospital workers *(1)*. In turn, questions on the sanitation habits of food vendors and food service employees were raised, and data from the subsequent studies show the potential for cross-contamination via TMDs in the food industry, potentially contributing to the incidence of foodborne illness.

Other studies have examined at the efficacy of popular disinfecting products. Howell et al. contaminated iPads (Apple, Cupertino, CA) with methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus*, and *Clostridium difficile* in order to compare different disinfectant methods with wiping with a plain, lint-free cloth *(9)*. The data indicated that Sanigen 2% chlorhexidine gluconate wipes (70% alcohol and 2% chlorhexidine) and Clorox wipes (alcohol and alkyl dimethyl benzyl ammonium chloride-based) were significantly more effective than the plain cloth in reducing bacteria on iPads. Additionally, White et al. reported that alcohol-based wipes resulted in a 2.3 log reduction on the back of the iPad and a 3.3 log reduction on the front surface. Both of these studies highlight simple and effective means of decontaminating touchscreen devices that can be utilized by anyone *(19)*.

On the basis of these and similar studies investigating bacterial contamination of TMDs, the present study was designed to determine the levels of microbial contamination on single-user TMDs and to compare the efficacy of two cleaning methods for reduction of bacteria. We also aimed to identify, by means of a survey of participants, potential risk factors related to the use and cleaning of TMDs as well as opinions on risks associated with TMD use in general and within food service establishments. The combination of the two objectives present a novel approach to further understanding the risks related to microbial contamination of TMDs.

MATERIALS AND METHODS

Study design

One hundred university students, faculty, and staff were recruited to participate in this study. All were required to have a single-user TMD. University of Arkansas Institutional Review Board approval (Protocol 17-06-753) was received prior to study commencement. The study was conducted during August 2017. Participants were assigned to alternate treatment groups based on recruitment order—Treatment 1, Treatment 2, Treatment 1, etc.

Survey

All participants completed a short survey prior to TMD sampling. The survey was completed on an iPad, using Qualtrics web-based survey software (Qualtrics, Provo, UT). Participants were given an ID number that they were required to enter before starting the survey, in order to protect their confidentiality. The survey consisted of questions on basic demographic information, participants' TMD cleaning habits, and their opinions on the risks associated with TMD contamination in general and within retail food service establishments. The construct related to participant opinions on TMD contamination risks was measured by a five-point Likert scale (1 = definitely not, 5 = definitely yes).

Sampling TMDs

The dimensions of each participant's TMD were measured in centimeters, and the presence or absence of a protective case and screen protector was noted. When a protective case and/or screen protector were present, they remained on the TMD during sampling, as these are not removed by the participant during daily use. The TMD was then divided in half vertically to distinguish side A and side B prior to swabbing *(Fig. 1)*. Side A represents the non-treated side (front and back surface) of the TMD, and side B represents the treatment side (front and back surface). Treatment 1 was a dry microfiber wipe (Kimtech, Roswell, GA) and treatment 2 was a pre-moistened isopropyl alcohol (IA) wipe (CareTouch, Future Diagnostics LLC, Brooklyn, NY). Fifty participants were in the treatment 1 group, and 50 were in the treatment 2 group.

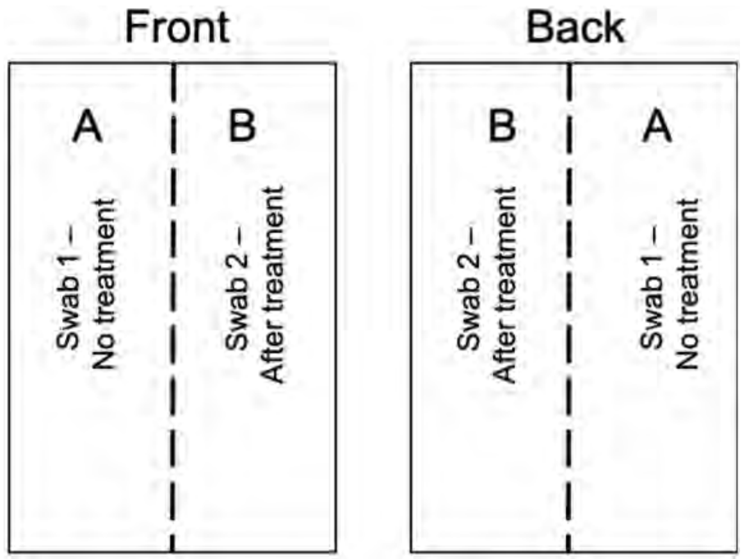

Figure 1. Schematic of the division of a TMD into sides A and B.

Recovery and detection of microorganisms

A dry cotton-tipped swab (Puritan Medical Products Co. LLC, Guilford, ME) was used to recover bacteria from the TMD. Side A was swabbed first, and the swab was immediately spread onto two tryptic soy agar (TSA; Hardy Diagnostics, Santa Maria, CA) plates. This method was chosen to reduce participant concerns about applying a solution to the TMD surface that is not specifically for cleaning or disinfection purposes. Prior to swabbing side B, either treatment 1 or treatment 2 was applied to the TMD. For treatment 2, the TMD was allowed to dry completely prior to swabbing. After swabbing side B, the swab was spread onto two TSA plates. Two negative control TSA plates were also incubated to ensure that no outside contamination had occurred. The plates were incubated at 37°C for 48 h, after which bacterial CFU were counted. For each TMD, an average CFU count was calculated separately for side A and B. Using the surface area of the TMD, the bacterial concentrations in CFU/cm^2 were determined.

For each TMD, up to 10 colonies were randomly selected from the two TSA plates for both side A and B, to differentiate between Gram-positive and Gram-negative bacteria. To do this, a simple, non-staining potassium hydroxide (KOH) test was used, as outlined by Suslow et al. *(17)*. A sterile loop was used to place one colony on a sterile glass slide. One drop of 3% KOH was added to the top of each colony, and the mixture was incubated at room temperature for one minute. The mixture was then slowly drawn upward with a loop. If the mixture contained viscous strings attached to the loop, the colony was marked as Gram-negative. If there was no change in the viscosity of the mixture after one minute, the colony was categorized as Gram-positive.

Statistical analysis

Prior to data analysis, all microbial data were log-transformed (e.g., $\log_{10}$ CFU/cm^2+1) for visual convenience without loss of generality in statistical results, as described previously *(6)*. More specifically, in some instances, the log value would be negative because the CFU/cm^2 is < 1 but > 0; by adding one to the CFU/cm^2 prior to log transformation for all samples, all values are positive. Descriptive statistics were performed to determine the mean and standard deviation for bacterial concentrations on each side within each treatment group. Thereafter, one-way analysis of variance (ANOVA) was performed to compare treatments and to identify any statistically significant differences, as defined by $P \leq 0.05$. Multiple comparisons of the means were performed using the Steel-Dwass method, because of the lack of normality in the data. For the survey data, Likert item data were treated as nominal data on a continuous scale, and descriptive statistics were used to calculate the mean and standard deviation for responses to each question. In addition, ANOVA was performed to compare bacterial concentrations on Side A (i.e., prior to treatment) with self-reported cleaning habits. JMP® Pro 13 (SAS, Cary, NC) statistical analysis software was used for all data analysis.

RESULTS

Survey

The demographic information collected from the survey revealed that of 100 participants, nine were faculty, 36 were graduate students, 43 were staff, four were undergraduate students, and five were "other." Three participants answered that they were not affiliated with the University of Arkansas. It was also noted whether or not the participant had a protective case and/or a screen cover on their TMD. Of 100 participants, 82 had a protective case, and 28 had a screen cover. When asked about their TMD usage frequency, 85% of participants indicated that they check their TMD at least once an hour, and 35% stated that they check their TMD more than three times per hour. Participants were also asked several questions about their perceptions of cleaning practices for single-user TMDs and the perceived contamination risks associated with single-user TMDs within food service establishments. *Table 1* indicates that, based on a mean response of > 4, most participants believe that (i) TMDs can harbor harmful microorganisms; (ii) food service workers should clean their TMD; and (iii) using a TMD while working with food is a potential health risk. Conversely, participants were not completely convinced that requiring food service employees to clean their TMD would reduce potential transmission of harmful pathogens, with a mean response of 3.78 *(Table 1)*.

Characterization of bacteria on TMDs

The results from the bacteria recovery revealed that every TMD was contaminated with bacteria, with a greater prevalence of Gram-positive bacteria than of Gram-negative bacteria. Most of the colonies tested were Gram-positive and were reduced by both cleaning interventions. Gram-positive bacteria represented 94.5% of bacteria on both side A and B of the TMDs; this is likely due to the Gram-positive nature of the human epidermis microbiota *(16)*. The baseline bacterial concentration on Side A was 0.76 $\log_{10}$ (CFU/cm^2+1), with no significant difference between the treatment groups ($P = 0.183$). A comparison of the bacterial concentration on the TMDs revealed a statistically significant difference ($P < 0.0001$) between bacterial concentrations on Side A and Side B regardless of the treatment type, at 0.76 and 0.43 $\log_{10}$ (CFU/cm^2+1) difference, respectively *(Fig. 2)*. There was no difference ($P = 0.644$) in bacterial concentrations on Side B by treatment type. Moreover, there was no significant difference ($P = 0.132$) in mean log reductions between treatment groups, with 0.28 and 0.38 $\log_{10}$ (CFU/cm^2+1) for dry microfiber cloths and IA wipes, respectively.

Microbial concentration and TMD use

A comparison of the participant's role at the University of Arkansas with the $\log_{10}$ (CFU/cm^2+1) bacteria on their TMDs revealed that there was no statistically significant difference in bacterial concentrations among the roles. There was also no statistically significant difference in bacterial concentrations among frequency of use categories. Participants were also asked about their TMD cleaning habits; there was no statistically significant difference between bacterial concentrations and self-reported frequency of cleaning *(Table 2)*. Various cleaning methods for TMDs were reported, including tissues, moist cloths, "my shirt," and lens cleaning wipes. Most participants (n = 82) had a protective case on their TMD, and a smaller number (n = 28) had a screen cover. Comparing the mean $\log_{10}$ reductions revealed no significant difference in $\log_{10}$ reduction by treatment with respect to the presence or absence of a protective case or screen cover (data not shown).

DISCUSSION

Microbial contamination of TMDs has been reported previously, such as in a study by Egert et al. in which a similar population was investigated *(5)*. Specifically, the

TABLE 1. Responses to survey questions on TMD cleaning and health risks in general and in retail food service establishments

Survey Question	5-point Likert Scale[a] Mean Response (± SD)
Is it important for food service employees to regularly clean their TMD?	4.39 (0.82)
Are there health risks associated with using TMDs while working with food?	4.23 (0.93)
Can TMDs become contaminated with harmful germs that can make you sick?	4.36 (0.72)
If there were requirements for food service employees to clean TMDs, would the potential for transmission of harmful germs via contaminated TMDs decrease?	3.78 (0.89)

[a]definitely not = 1, probably not = 2, might or might not = 3, probably yes = 4, definitely yes = 5
SD = standard deviation.

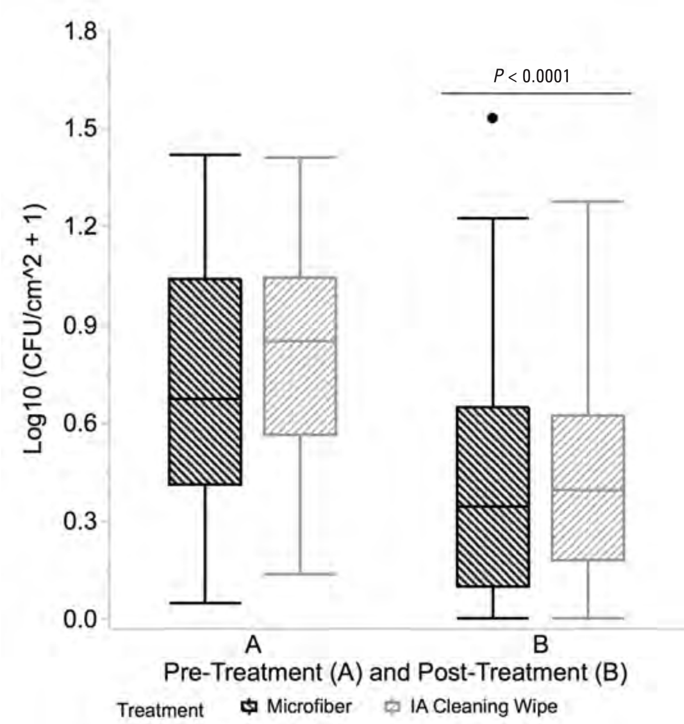

Figure 2. Distribution of bacteria concentrations recovered from side A and side B of TMDs by treatment type. Box plots show bacteria concentrations at pre-treatment (A) and post-treatment (B) by treatment type. The solid horizontal line within the box represents the median sample values while the box represents the interquartile range (IQR), or the 25th and 75th percentiles. The whiskers extending from the ends of the box represent the 1.5 × IQR, and outliers are shown as individual points beyond the whiskers.

TABLE 2. Mean log bacteria by self-reported frequency of cleaning

Frequency of Cleaning (Response No., n = 100)		Concentration of Bacteria [log (CFU/cm^2+1)]
		Mean (± SD)
Always	1	1.22 (-)
Most of the time	6	0.80 (0.35)
About half the time	14	0.80 (0.36)
Sometimes	52	0.76 (0.38)
Never	27	0.79 (0.32)

SD = standard deviation.

authors reported bacterial contamination on the TMDs of German university students (n = 60) as well as evaluating treatment methods. However, as opposed to using each student's TMD as its own baseline and treatment, the authors separated the TMDs into three groups of 20: uncleaned, cleaned with dry microfabric cloth, and cleaned with alcohol-based (ethanol and isopropanol) wipes. The average baseline concentration of bacteria recovered from untreated TMDs was 0.37 $\log_{10}$ CFU/cm^2+1, approximately half of the baseline level (0.76 $\log_{10}$ CFU/cm^2+1) reported in the present study. This difference in baseline contamination could be due to differences in TMD use habits and behaviors, but the sampling method—contact agar plates versus swabbing—is likely to be a major contributing factor. Although $\log_{10}$-reduction values were not explicitly reported, Egert and co-authors reported that 0.28 and 0.34 $\log_{10}$ (CFU/cm^2+1) reductions were achieved after treatment with microfabric cloths and alcohol-based wipes, respectively *(5)*. However, given the difference in baseline concentrations between the present study and Egert et al., these $\log_{10}$ reduction values are comparable to those reported for microfiber and IA treatment groups in the present study at 0.28 and 0.38 $\log_{10}$ (CFU/cm^2+1), respectively.

Basol et al. also evaluated the efficacy of alcohol-based wipes in reducing bacteria on shared mobile phones within a clinical setting *(3)*. Specifically, both isopropyl alcohol wipes and ethyl alcohol wipes were investigated with respect to the reduction of bacteria. The treatments were equally effective in reducing resident microflora on the shared mobile devices (from an initial prevalence of 64% down to 12–15% for cleaned devices with detectable bacteria). However, it is unclear whether these devices were touchscreen devices or mobile phones with a small screen and keypad. Kiedrowski et al. also evaluated disinfection methods for shared devices in clinical settings *(10)*. The researchers inoculated iPads with 4.18-$\log_{10}$ *C. difficile* spores or MRSA and then applied one of three treatments: 50% isopropyl alcohol pads, 0.6% hypochlorite bleach wipes, or moistened microfiber cloths. All treatments completely eliminated MRSA from the iPads, whereas the removal of *C. difficile* spores varied across treatments, with bleach wipes being most effective (100% reduction), followed by microfiber cloths and then isopropyl alcohol pads. Interestingly, the manufacturer of iPads recommends cleaning these TMDs with only a slightly damp, lint-free cloth, with no reference to actual disinfection *(2)*.

Other researchers have also investigated the difference in contamination risk between touchscreen versus non-touchscreen mobile devices. Lee et al. assessed the prevalence of bacterial contamination on TMDs (n = 115) and non-TMDs (n = 88) used by healthcare workers *(11)*. While all phones were contaminated with bacteria, probable pathogens were more frequently isolated from TMDs (34.8%) than from non-TMDs (20.5%). These data reveal a potential risk related to touchscreen devices in general.

While cleaning and disinfecting TMDs is effective in decreasing the risk of cross-contamination, the actual practice is not routinely implemented. Mark et al. included a survey in their study on the contamination of TMDs in a clinical setting *(13)*. The authors reported that out of 100 medical professionals, nurses, and allied professionals, 95% admitted to never disinfecting their TMDs with alcohol wipes, and 68% never washed their hands prior to using TMDs. Another study, by White et al., examined mobile device cleaning policies in the National Health Service in England and found that out of 265 organizations, 22% had no policy in place *(18)*. Furthermore, when policies were in place, the majority advocated only the use of general purpose/universal detergent wipes. Some organizations even responded that hand decontamination practices were adequate and a TMD decontamination policy was therefore not warranted. Overall, these studies indicate that although TMDs are known to harbor microorganisms, including potential human pathogens, more research is needed to investigate and validate appropriate cleaning protocols for implementation in service-oriented settings as well as by the general population. This is especially important to consider as the use of TMDs in shared retail spaces increases.

For instance, in 2018, McDonald's Corporation began an expansion of stationary touchscreen devices so that customers could order directly by using a touchscreen interface *(12)*. The company said that the addition of self-service kiosks would be approximately 1,000 each quarter for the next two years, changing the way consumers order food in a retail setting. In addition to the self-service kiosks in fast food establishments, the implementation of tableside touchscreen tablets is increasing. According to one manufacturer of tableside tablets, Ziosk, over 170,000 touchscreen devices have been installed at tables in restaurants across the U.S. *(20)*, and over 750 million guests are served annually using these devices in the U.S. alone *(20)*. Overall, the rapid rise of touchscreen technology raises concern about the sanitary habits of both food service employees and consumers in a shared setting.

Another aspect of the present study aimed to survey the participants' opinions on the importance of disinfection practices in the food service industry, a critical environment for preventing the transmission of human pathogens. Most participants (n = 89) answered that employees in retail food service establishments should regularly clean their TMDs (≥ 4) and that there is a definite probability that TMDs can be contaminated with "harmful germs" *(Table 1)*. The majority (63%) also indicated that if cleaning protocols for TMDs were put in place in the food service industry, the potential for transmission of pathogens would probably be decreased; however, 29% were not sure. A few studies have explored the idea of pathogen transmission through TMDs in food service. Green et al. reported that of 81 foodborne disease outbreaks attributed to food contaminated by food workers, 89% involved the transmission of pathogens to food by workers' hands *(7)*. Here, the transmission of pathogens from TMD to hands is a distinct possibility. For instance, Meadow et al. investigated the link between the microbiome of a person's hands and that of their TMD *(14)* and observed that about 22% of the bacterial flora on the participants' fingers were also present on their TMDs. These findings illustrate the potential for cross-contamination between the person and the TMD and the importance of appropriate cleaning and disinfection protocols.

As with most research, it is important to recognize some limitations in the present study. From an epidemiological perspective, the present study likely captured human microbiota from the human epidermis on the TMDs. While this study does not further classify the bacteria captured, it does demonstrate the ability of microorganisms, which could include pathogenic bacteria, to survive on the surface of TMDs. Based on this information, future studies should include the further classification of microorganisms recovered from the TMDs, beyond Gram-positive or negative. In addition, the authors chose to use a dry swab for recovery of microorganisms from TMDs, knowing that it may not be as effective as a pre-moistened swab. This approach is in line with a study by Egert et al. (5), who used contact agar plates to sample their mobile devices. However, additional studies may consider further characterizing the role of factors such as microbial concentration, drying time, and sampling approach (dry versus wet swab) on the recovery of microorganisms from TMDs.

CONCLUSIONS

Overall, this study aimed to determine the concentration of bacteria on single-user TMDs before and after treatment, while also using a survey to identify participants' opinions on potential risk factors associated with TMD cleaning habits. The authors found that all devices tested were contaminated with bacteria and that both treatment methods were effective in the reduction of bacteria on TMDs. Although good handling practices are required by employees in food service establishments, future research should focus on the role of single-user and multi-user TMDs in the intermediate transmission of microbes within retail food service settings as well as on practical cleaning and disinfecting strategies. In addition, future studies could include a comprehensive survey of TMD use policies as well as cleaning and disinfection standard operating procedures within retail food service establishments.

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