Major Article

Bacterial contamination of the smartphones of healthcare workers in a German tertiary-care hospital before and during the COVID-19 pandemic

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A B S T R A C T

Background: Assuming that hygiene measures have improved significantly due to COVID-19, we aimed to investigate bacterial colonization on smartphones (SPs) owned by healthcare workers (HCWs) before and during the pandemic.
Methods: Employing a before-and-after study design, randomly selected HCWs were included. Devices underwent sampling under real-life conditions, without prior manipulation. Swabs were collected in 2012 (pre-pandemic) and 2021 to determine microbial colonization. Isolates were identified by MALDI-TOF mass spectrometry and underwent microbiological susceptibility testing.
Results: The final analysis included 295 HCWs (67% female, mean age 34 years) from 26 wards. Bacterial contamination was present on 293 of 295 SP screens (99.3%). The proportion of clinically relevant bacterial pathogens (eg *Staphylococcus aureus*, enterococci, *Enterobacterales,* non-fermenting bacteria) ranged from 21.2% in 2012 to 39.8% in 2021. Resistance profiles revealed a proportion of multidrug-resistant bacteria such as MRSA and VRE of less than 2%. The comparison of before-and-after sampling showed a significant increase in smartphone use during work from 2012 to 2021 with a simultaneous increase in cleaning intensity, probably as a result of the COVID-19 pandemic.
Conclusions: Bacterial contamination of SPs within the hospital is of concern and can serve as a source of cross-contamination. Hence, in addition to excellent hand hygiene, SPs must be carefully disinfected after handling in healthcare. Behavioral changes related to the COVID-19 pandemic could have a significant impact if implemented sustainably in everyday clinical practice.
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INTRODUCTION

Mobile communication devices, especially smartphones (SPs), have become an essential part of everyday life. The number of SP users in Germany exceeded 60 million in 2020.[1] Despite their frequent usage, most people, even healthcare workers (HCWs), often ignore the possibility of these devices accumulating and transmitting a variety of microorganisms, in particular during and after patient care.[2,3] In German hospitals, about 400,000 to 600,000 nosocomial infections occur annually, of which, according to large independent epidemiological studies, approximately 80,000 to 180,000 could be avoided every year.[4] Awareness of well-described risk factors such as

the use of catheters and other invasive equipment[5] and adherence to simple preventive measures, especially adequate hand hygiene,[6,7] can significantly limit the burden of disease. Given the importance that hospital surfaces play in the transmission of emerging pathogens in healthcare,[8-10] this underlines the role of SPs as a potential source of cross-contamination.

The ongoing coronavirus disease 2019 (COVID-19) pandemic has drawn tremendous public attention to improving basic hygiene.[11] General hygiene rules in the population in Germany have been established by the Robert Koch Institute and the Federal Ministry of Labor and Social Affairs.[12,13] Assuming that hygiene measures have improved significantly due to COVID-19, we aimed to investigate the frequency and intensity of bacterial colonization on SPs owned by HCWs before and during the pandemic at our institution, employing a before-and-after study design.

METHODS

Study design and participants

This prospective before-and-after study included HCWs who used private SPs during their daily clinical practice. All HCWs from clinical departments qualified for the study. The years 2012 (pre-pandemic cohort) and 2021 (during the second wave of the COVID-19 pandemic in Germany) were set as sampling periods.

Setting

The Hospital St. Georg in Leipzig, Saxony, Germany, is a large tertiary-care hospital with 1,066 beds and 25 different specialist areas and clinics, embedded in the structure of a modern academic teaching hospital. The healthcare personnel comprises approximately 3,400 employees.

Sampling and data collection

Sampling followed a standardized procedure (Fig 1). First, participants received detailed information about the study. After providing voluntary written informed consent, privately owned SPs, which were also used during work in the hospital, were retrieved for microbiological testing. In particular, no purification procedures were performed. All sampling was done by the same investigator to ensure consistency. After hygienic hand disinfection, the investigator wiped the SP screen with a COPAN eSwab (COPAN, Brescia, Italy) which was moistened with the Amies transport medium from the swab tube before. After this procedure, the swab was immediately transferred to a Brain-Heart-Infusion (BHI) tube (Merck, Darmstadt, Germany). At the same time, participants filled out a detailed questionnaire with information on age, gender, affiliation, focus of activity, SP use, and further professional biography details.

Microbiological approach

After transport to our microbiology laboratory on site, BHI tubes were incubated at 36°C for 24 hours. Clear BHI tubes were incubated for further 5 days. Aerobic and anaerobic subcultures were grown from turbid BHI tubes. Subculturing included media for aerobic bacteria, anaerobic spore formers, and fungi, comprising Columbia CNA agar (bioMérieux, Nürtingen, Germany), Gram-negative selective endo agar (Becton Dickinson, Heidelberg, Germany), Schaedler Kanamycin-Vancomycin (KV) anaerobic agar (Becton Dickinson), and Sabouraud Gentamicin-Chloramphenicol (SAB) agar (bioMérieux). In addition, selective plates were inoculated for the culturing of multidrug-resistant pathogens employing chromID MRSA/ESBL/VRE agars (bioMérieux) and Brilliance CRE agar (ThermoFisher Scientific, Waltham, Massachusetts, USA). Species were identified using VITEK Matrix Assisted Laser Desorption Ionization—Time of Flight Mass Spectrometry (MALDI-TOF-MS, bioMérieux) and VITEK 2 system (bioMérieux). For further typing, microscopic and biochemical methods (coagulase, catalase, and oxidase tests), an ESBL/AmpC test (MAST Diagnostica, Reinfeld, Germany), and specific polymerase chain reactions (PCR) for MRSA (Xpert MRSA NxG, detecting *mecA* and *mecC* genes) and VRE (Xpert van A/van B, detecting *vanA* and *vanB* genes) (both Cepheid, Sunnyvale, California, USA) were applied (Fig 1). All multidrug resistant isolates underwent semi-automated antimicrobial susceptibility testing using the VITEK 2 system (bioMérieux),
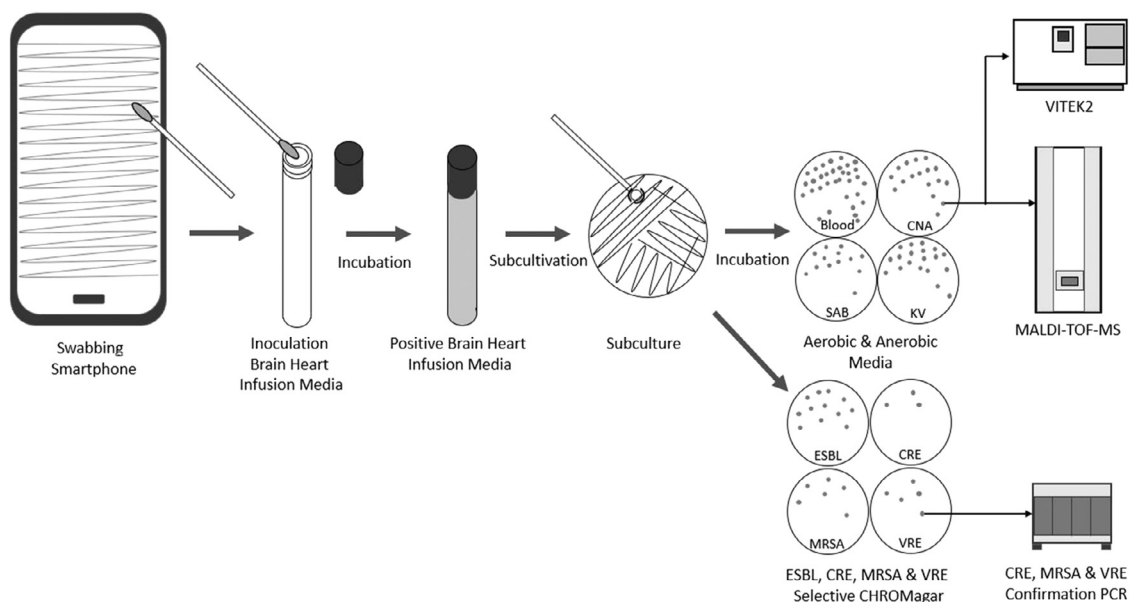
Fig 1. Flowchart for sample collection on SPs and microbiological processing of collected materials. First, the SP was swabbed with a COPAN brush. Second, a Brain-Heart-Infusion media tube was inoculated, followed by subculturing with a dilution spreading technique employing unselective and selective growth media. Species identification was performed by MALDI-TOF mass spectrometry, and multidrug-resistance was confirmed by specific PCR.

with respect of the current breakpoints according to EUCAST (European Committee on Antimicrobial Susceptibility Testing, www.eucast.org).[14]

Statistical analysis

The statistical analysis was performed using SPSS for Windows (SPSS 23.0, IBM Corporation, Armonk, New York, USA). Numerical variables were summarized as mean, and categorical variables were given as frequencies or proportions. Categorical data became dichotomized in case of more than two expressions and were analyzed by the Fisher's exact test. P values (two-sided) <.05 were considered statistically significant.

Ethics approval

The study was conducted in accordance with the ethical guidelines of the 1964 Declaration of Helsinki and its later amendments and was approved by the local ethics committee (Saxonian Board of Physicians, Dresden, Germany, vote EK-BR-18/21-1).

RESULTS

Sociodemographic data

Two hundred and ninety-five HCWs (67% female; mean age 34 years) from 26 wards comprising 19 different specialties were included in the final analysis (Fig 2, Table 1).

The participation rate of 63.4% (196 of 309) in the pandemic year 2021 was significantly higher than in 2012 (101 of 624, 16.2%; P <.001).

Microbiological contamination of SPs

A microbiological analysis was carried out on a total of 295 SPs from fully evaluable participants (99 in 2012, and 196 in 2021), supplemented by 4 negative controls which were freshly decontaminated before the analysis. Bacterial growth was detected on 293 out of 295 devices analyzed (99.3%). No microorganisms were detected on the 4 SPs serving as controls. Coagulase-negative staphylococci

Table 1
Baseline data of the participants and responses to questionnaires in 2012 and 2021

	2012	2021	P value
Number of investigated SPs	101	196	
Number of SPs from fully evaluable participants (%)	99 (98)	196 (100)	
Females (%)	60 (60.6)	138 (70.4)	.115
Median age (range)	30 (18-63)	36 (18-63)	
18−25 ys (%)	30 (30.3)	39 (19.9)	.001
26−35 ys (%)	37 (37.4)	51 (26)	
36−45 ys (%)	17 (17.2)	46 (23.5)	
46−55 ys (%)	14 (14.1)	38 (19.4)	
>55 ys (%)	1 (1)	22 (11.2)	
Peripheral ward (%)	22 (22.2)	83 (42.3)	.001
ICU/IMC/stroke unit (%)	43 (43.4)	46 (23.5)	
Multiple locations (%)	15 (15.2)	29 (14.8)	
Other clinical areas (%)	19 (19.2)	38 (19.4)	
Nurse (%)	60 (60.6)	130 (66.3)	.488
Physician (%)	29 (29.3)	45 (23)	
Other professions (%)	10 (10.1)	21 (10.7)	
Internal medicine (%)	48 (48.5)	93 (47.4)	.01
Surgical disciplines (%)	32 (32.3)	38 (19.4)	
Interdisciplinary (%)	19 (19.2)	65 (33.2)	
SP cleaning at a fixed interval, daily or more frequently (%)	23 (23.2)	90 (45.9)	<.001
SP cleaning without a fixed interval (%)	68 (68.7)	99 (50.5)	
No SP cleaning (%)	8 (8.1)	7 (3.6)	
SP storage in a workwear pocket (%)	39 (39.4)	136 (69.4)	<.001
SP storage on the ward (%)	50 (50.5)	56 (28.6)	
SP storage not on the ward (%)	10 (10.1)	4 (2)	

(CNS) were the most common isolate group detected in both study periods (Fig 3).

In 2012, 80 of 99 SPs (80.8%), and in 2021, 147 of 196 SPs (75%) carried this group of bacteria (P = .307). Frequently detected representatives of this group were *Staphylococcus (S.) lugdunensis, S. hominis, S. epidermidis, S. warneri, S. capitis,* and *S. haemolyticus.* Spore-forming aerobic bacteria represented the second largest group of bacteria detected on SPs. Among them, *Bacillus cereus* was identified most frequently, followed by *Lysinibacillus fusiformis* and *Lysinibacillus sphaericus.* In contrast to CNS, significantly more spore-forming aerobic bacteria were detected in 2021 (130 of 196, 66.3%) than in
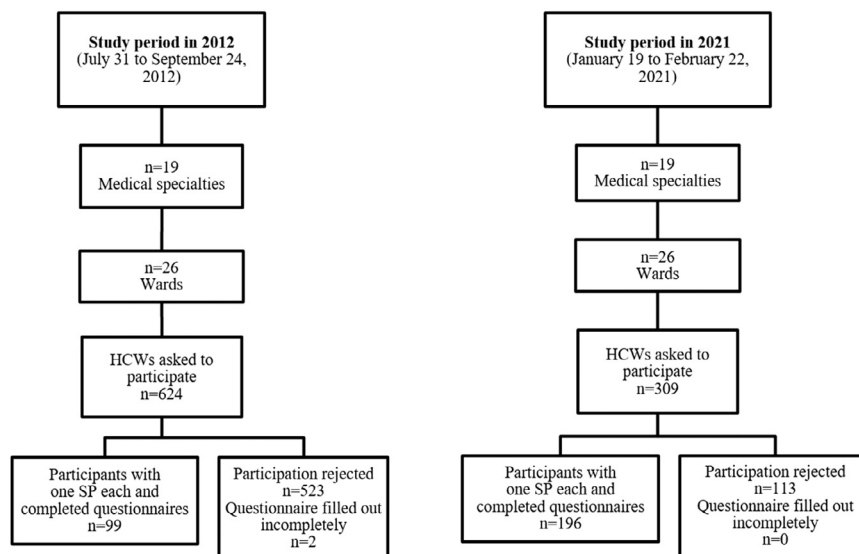

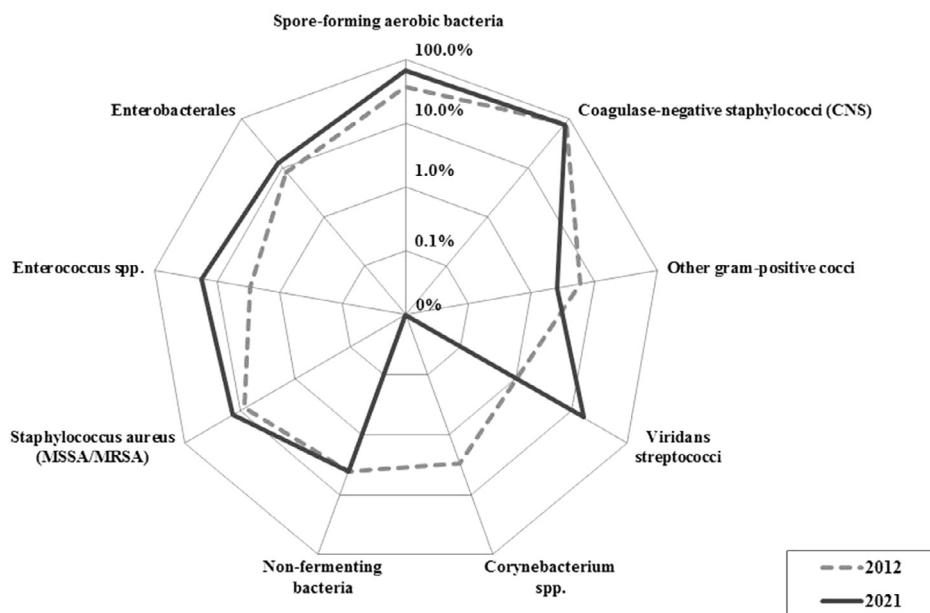**Fig 2.** Flowchart of the study population.

Fig 3. Comparison of bacterial contamination of SPs in 2012 versus 2021 (during the second wave of the COVID-19 pandemic).

2012 (37 of 99, 37.4%; *P* <.001). Polymicrobial contamination was detected on 54 of 99 SPs (54.5%) in 2012, and on 155 of 196 SPs (79.1%) in 2021 (*P* =.003) (Table 2).

In principle, almost all bacteria detected can cause infections in critically ill patients, especially those with immunosuppression. As clinically relevant pathogens, we defined bacteria that are not expected to be detectable on SP screens and whose presence is likely due to smear infection, (eg enterococci, *Enterobacterales,* and non-fermenting bacteria), but also bacteria well known to cause severe infections in critically ill patients, such as *S. aureus.* In 2012, the proportion of SPs with detection of clinically relevant pathogens (21 of 99, 21.2%) was significantly lower than in 2021 (78 of 196, 39.8%; *P* =.002) (Fig 4).

Methicillin-resistant *S. aureus* (MRSA) was not detected in 2012, but on 3 SPs (1.5%) in 2021. Also a higher rate of enterococci were detected on SPs in 2021 (35 out of 196, 17.8%) compared to 2012 (3 out of 99, 3.3%; *P* <.001). In the 2012 study period, no vancomycin-resistant enterococci (VRE) were detected either, but in 2 of 196 SPs (1%) in 2021. No yeasts were detected on Sabouraud agar plates in 2012 or 2021, respectively. Furthermore, there was no detection of anaerobically growing bacteria on Schaedler plates, as well as no microbiological evidence of Gram-negative bacteria producing extended spectrum beta-lactamases (ESBLs) in either period of study.

Data from questionnaires

The responses to the questionnaires showed a statistically relevant difference between the surveys in 2012 and 2021 with regard to the storage behavior of SPs during working hours (Table 1). In 2012, 39 out of 99 respondents (39.4%) stated that they always carry the SP with them while working compared to 136 out of 196 (69.4%; *P* <.001) in 2021. In 2012, only 23 out of 99 respondents (23.2%) said they cleaned their SP on a daily or less frequent basis. In 2021, the number rose significantly to 90 of 196 (45.9%; *P* <.001). In 2012, 68 out of 99 participants (68.7%) stated to clean their SP only when it is obviously contaminated. In 2021, the respective number dropped to 99 from 196 (50.5%; *P* <.001). In 2012, 8 out of 99 respondents (8.1%) reported no cleaning procedures at all, and in 2021 the respective numbers were 7 out of 196 (3.6%; *P* <.001).

No statistically relevant differences could be found within different subgroups.

DISCUSSION

In this study among 295 HCWs from 26 different wards, we could show that 99.3% of SP screens were bacterially contaminated. The proportion of clinically relevant bacterial pathogens ranged from 21.2% in 2012 to 39.8% in 2021. The comparison of before-and-after sampling showed a significant increase in smartphone use during work from 2012 to 2021 with a simultaneous increase in cleaning intensity, probably as a result of the COVID-19 pandemic.

Our study yielded data comparable to previous studies with regard to the contamination rate as well as the bacterial spectrum.[15] The questionnaire evaluation regarding hand hygiene and specific SP hygiene showed that careful disinfecting cleaning of SPs in 2012 was internalized by two thirds of the study participants as not necessary if there was no visible contamination. By repeating sampling in the same cohort during the second wave of the COVID-19 pandemic, we were able to demonstrate the effects of improved general hygiene measures. The significantly increased participation rate during the pandemic (63.4% in 2021 vs 16.2% in 2012; *P* <.001) also fits in with this improved awareness.

As predicted in 2012, the popularity of smartphones has increased massively over the past ten years.[1] The Bring-Your-Own-Device (BYOD) concept to hospitals illustrates the implementation of these devices in everyday clinical practice. A wide range of applications, also for clinical questions in the medical field, is available (eg medical risk score calculators, antibiotics and medication guides, digital reference works).[16, 17] The increasing use of hospital-provided devices (Corporate Owned Personally Enabled [COPE] devices) connected to the hospital information system underscores their importance and shows that restricting the use of SPs and tablet computers would not work.[18,19] It is therefore not unexpected that a large number of our study participants stated that they also carry the SP with them at work, eg in pockets of their work clothing.

Fifty percent of the study participants stated, even under the conditions of the COVID-19 pandemic, that they only clean the SP screen

Table 2
Bacterial species detected on SP screens and their clinical relevance regarding nosocomial infections

	2012	2021	P value
Number of SPs from fully evaluable participants (%)	99 (98)	196 (100)	
Monomicrobial colonization (%)	44 (44.4)	40 (20.4)	<.001
Polymicrobial colonization, ≤3 species (%)	53 (53.5)	140 (71.5)	.003
Polymicrobial colonization, >3 species (%)	1 (1)	15 (7.6)	.002
No bacterial growth (%)	1 (1)	1 (0.5)	.0
Gram-positive bacteria (%)	97 (98)	194 (99)	.6
Gram-negative bacteria (%)	12 (12.1)	30 (15.3)	.6
Staphylococcus aureus (%)	8 (8.1)	26 (13.3)	.247
− MSSA	8 (8.1)	23 (11.7)	
− MRSA	0 (0)	3 (1.5)	
Coagulase-negative staphylococci (CNS) (%)	80 (80.8)	147 (75)	.307
Other Gram-positive cocci (%)	6 (6.1)	5 (2.6)	.19
− Lactococcus lactis	0 (0)	4 (2.0)	
− Micrococcus spp.	6 (6.1)	1 (0.5)	
Viridans streptococci (%)	1 (1.0)	34 (17.3)	<.001
− S. sanguinis	1 (1.0)	12 (6.1)	
− S. parasanguinis	0 (0)	13 (6.6)	
− S. mitis	0 (0)	8 (4.1)	
− S. suis	0 (0)	1 (0.5)	
Streptococcus agalactiae (%)	0 (0)	1 (0.5)	.0
Enterococcus spp. (%)	3 (3)	35 (17.8)	<.001
− E. faecalis	2 (2)	27 (13.8)	
− E. durans	1 (1)	0 (0)	
− E. faecium	0 (0)	6 (3.1)	
− E. faecalis (VRE)	0 (0)	1 (0.5)	
− E. faecium (VRE)	0 (0)	1 (0.5)	
Spore-forming aerobic bacteria (%)	37 (37.4)	130 (66.3)	<.001
Enterobacterales (%)	8 (8.1)	25 (12.7)	.616
− Enterobacter cloacae	1 (1.0)	4 (2.0)	
− Enterobacter spp.	0 (0)	2 (1.0)	
− Escherichia coli	0 (0)	4 (2)	
− Klebsiella oxytoca	0 (0)	2 (1)	
− Pantoea spp.	4 (4)	12 (8.1)	
− Leclercia adecarboxylata	3 (3)	1 (0.5)	
Non-fermenting bacteria (%)	4 (4)	8 (4.1)	.0
− Pseudomonas spp.	0 (0)	2 (1)	
− Acinetobacter baumannii	3 (3)	6 (3.1)	
− Sphingomonas paucimobilis	1 (1)	0 (0)	
SPs with detection of clinically relevant pathogens (%)	21 (21.2)	78 (39.8)	.002
Staphylococcus aureus (MRSA/MSSA)	8 (8.1)	26 (13.3)	
Enterococci	3 (3)	35 (17.8)	
Enterobacterales	8 (8.1)	25 (12.7)	
Non-fermenting bacteria	4 (4)	8 (4.1)	
SPs with detection of commensal bacteria (%)	94 (94.9)	183 (93.4)	.8
Coagulase-negative staphylococci (CNS)	80 (80.8)	147 (75)	
Spore-forming aerobic bacteria	37 (37.4)	130 (66.3)	
Corynebacterium spp.	3 (3)	0 (0)	
Viridans streptococci	1 (0)	34 (17.3)	
Streptococcus agalactiae	0 (0)	1 (0.5)	
Other Gram-positive cocci	6 (6.1)	5 (2.6)	

when it is clearly contaminated. This information from questionnaires indicates that SP hygiene is not sufficiently integrated into basic hygiene measures yet. Nevertheless, the rate of participants who stated that they did not clean their device at regular intervals in 2021 fell by more than 22% compared to 2012. At this time, according to manufacturer's recommendations, a dry microfiber fabric was often used to clean the SP surface, especially taking into account that electronic devices are subject to technical protection standards such as susceptibility to liquids. Since the liquid tightness of SPs has improved significantly since 2012, it is now less difficult to clean and disinfect a SP. Modern devices with special seals even withstand

treatment with disinfectant solutions. In addition, special surface treatments, eg metal oxide solutions with antibacterial properties, are available. Smart alternative options, such as UV light for disinfection, however, are not generally in use.[20]

Bacterial contamination of SP surfaces is affected by various factors such as sebum, sweat, saliva, fat, food residues, and make-up.[15,21] When comparing both study periods, the spectrum of bacteria was very similar. However, bacteria known for airborne transmission were detected more frequently in 2021, as well as polymicrobial contamination. In addition, the increased colonization rate with clinically relevant pathogens in 2021 may be attributed to different usage behavior and increased storage in a coat pocket during work itself. For instance, compared to the pre-pandemic study period, the rate of viridans streptococci was much higher in 2021. Taking into account that voice assistants have become a mega-trend in recent years,[22] a growing detection rate for oral streptococci is not unexpected. However, wearing a mask while using the SP is a new condition under pandemic circumstances, suggesting that people are removing their face masks to make calls or record voice messages. Carrying the SP close to the body and high frequency of use lead to a possible increase in the temperature of the device, which is associated with an improvement in the replication conditions for bacteria. A recent study also analyzed the posterior surface of SPs. Interestingly, Kuriyama et al. found an even higher colonization rate on the posterior side of the SPs.[23] This underlines the immense importance of an adequate and complete cleaning at fixed intervals. This fact should be taken into account in future hygiene analyses of handheld devices.

The fact that no yeasts could be detected in our study suggests that they are not part of the normal skin flora. Multidrug-resistant Gram-positive pathogens such as MRSA and VRE were detected in less than 2% of the isolates, and Gram-negative ESBL-producers were not detected at all. This could indicate that hygiene measures are particularly consistently adhered to when patients are known to be colonized with multidrug-resistant organisms.

Limitations

The main limitations of this study result from the monocentric design and the medium-sized cohort (n = 295) with limited statistical power. Due to the eight-year interval between the two study periods, there were changes in the baseline characteristics of the two cohorts analyzed. These differences mainly result from the fact that the majority of the study participants were the same in both study periods, but 8 years older. In addition, there was no control group outside the hospital. Thus, our findings are rather descriptive. Since only bacterial and fungal contamination was investigated, no statement can be made about the viral load on SP screens. Furthermore, compliance with hand hygiene in HCWs in the study cohort was only queried, but not systematically observed. Social desirability as a possible influencing factor has to be considered when questionnaires were filled out directly.

Depending on the SP manufacturer, type of SP, material, software and usage behavior, there are differently frequented areas on SP touchscreens, which is why we opted for a semi-quantitative identification process by wiping the entire touchscreen and culturing in BHI. Due to the different growth behavior, suboptimal growth of anaerobic bacteria is possible and must be taken into account. A possible quantitative bias in the bacterial load is conceivable due to the enlarged surface structure of the COPAN brushes used in 2021. Improved routine usage of MALDI-TOF mass spectrometry for bacterial identification could have led to a qualitative bias in differentiation down to the species level in 2021. Only the front screens of SPs were analyzed. No statements can be made about hygienically relevant colonization rates on the posterior side of the SPs.
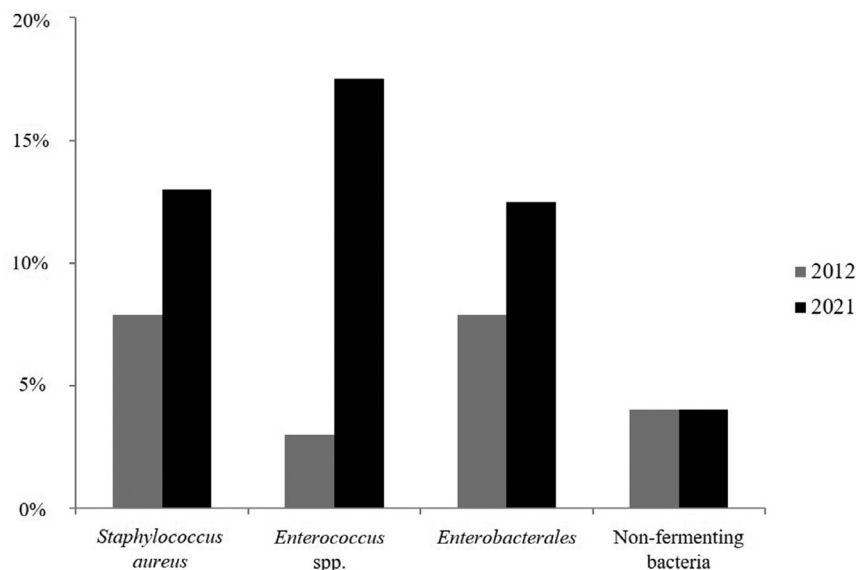
Fig 4. Detection of clinically relevant bacterial pathogens with high relevance for nosocomial infections on SPs.

CONCLUSION

Bacterial contamination of SPs occurs before and after patient contact and can serve as a source of cross-contamination. Hence, in addition to excellent hand hygiene, SPs must be carefully disinfected after handling in healthcare. Behavioral changes related to the COVID-19 pandemic could have a significant impact if implemented sustainably in everyday clinical practice.

Acknowledgments

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