American Journal of Infection Control 000 (2020) 1–4

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Methicillin-resistant *Staphylococcus aureus* contamination of hospital-use-only mobile phones and efficacy of 222-nm ultraviolet disinfection

Yuki Kaiki MD [a], Hiroki Kitagawa MD, PhD [a,b,c,*], Toshinori Hara MT [c,d], Toshihito Nomura MD, PhD [b], Keitaro Omori MD, PhD [b], Norifumi Shigemoto MD, PhD [a,b,c,e], Shinya Takahashi MD, PhD [a], Hiroki Ohge MD, PhD [b,c]

[a] *Department of Surgery, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, Japan*
[b] *Department of Infectious Diseases, Hiroshima University Hospital, Hiroshima, Japan*
[c] *Project Research Center for Nosocomial Infectious Diseases, Hiroshima University, Hiroshima, Japan*
[d] *Section of Infection Diseases Laboratory, Department of Clinical Support, Hiroshima University Hospital, Hiroshima, Japan*
[e] *Translational Research Center, Hiroshima University, Hiroshima, Japan*

Key Words:
Ultraviolet light
Antibiotic resistance
Infection control
Health care–associated infection
Bacterial contamination

Background: Mobile phones may be contaminated with nosocomial pathogens such as methicillin-resistant *Staphylococcus aureus* (MRSA). The aim of this study was to investigate the MRSA contamination rate on doctors' hospital-use-only mobile phones and the efficacy of 222-nm ultraviolet light (UV) disinfection.
Methods: We investigated the MRSA contamination rate of doctors' hospital-use-only mobile phones, as well as the reduction in MRSA counts on plastic plates and aerobic bacteria (AB) on mobile phones before and after exposure to 222-nm UV irradiation.
Results: Five (10%) of the 50 mobile phones investigated were contaminated with MRSA. Exposure to 0.1 mJ/cm^2 222-nm UVC irradiation for 1.5 and 2.5 min (9 and 15 mJ/cm^2) achieved mean $\log_{10}$ MRSA colony-forming units reductions of 2.91 and 3.95, respectively. Exposure to 9 mJ/cm^2 222-nm UVC irradiation (0.1 mW/cm^2 for 1.5 minutes) significantly reduced AB contamination on mobile phones ($P < .001$).
Conclusions: The use of 222-nm UV disinfection resulted in effective in vitro reduction of MRSA and significantly reduced AB contamination of mobile phone surfaces.

Effective disinfection of contaminated surfaces is essential for preventing the transmission of nosocomial pathogens, such as methicillin-resistant *Staphylococcus aureus* (MRSA) and *Clostridioides difficile*. Efforts to improve disinfection often focus primarily on high-touch surfaces in patient rooms. However, evidence suggests that portable equipment and other shared devices may also contribute to pathogen transmission.[1,2] Mobile phones are one of the most frequently used devices in hospitals, and studies have shown that, in clinical settings, they may become contaminated with the user's microbiome and nosocomial pathogens.[3,4]

Recently, ultraviolet (UV) light disinfection systems are being increasingly used in healthcare settings to limit the transmission of nosocomial pathogens and prevent healthcare-associated infections.[5] The most widely used UV disinfection system comprises of a germicidal lamp emitting 254-nm UV radiation C (UVC). However, since 254-nm UVC is harmful to the skin and eyes, UV disinfection systems are primarily used in unoccupied spaces. Previous reports had shown that 222-nm UVC light, which is part of the far-UVC light (207-222 nm) spectrum, also has highly effective germicidal properties, and is less harmful to the skin and eyes than 254-nm UVC.[6-11] However, only few reports exist regarding the efficacy of 222-nm UVC disinfection in clinical settings.[12] In this study, we investigated the extent of MRSA contamination in hospital-use-only mobile phones used by doctors, and the efficacy of 222-nm UVC disinfection on these devices.

METHODS

Ethics

The requirement of ethical approval was waived, since this study focused on the evaluation of MRSA contamination rate in mobile

* Address correspondence to Hiroki Kitagawa, MD, PhD, Department of Surgery, Graduate School of Biochemical and Health Sciences, Hiroshima University, 1-2-3 Kasumi, Minami-Ku, Hiroshima 734-8551, Japan.
E-mail address: hkitaga@hiroshima-u.ac.jp (H. Kitagawa).
Conflicts of interest: There are no conflicts of interest to declare.

https://doi.org/10.1016/j.ajic.2020.11.011
0196-6553/

phones and performance of 222-nm UV disinfection, and hence, did not require patient involvement or human sample collection.

Sample collection from mobile phones

From March to May 2020, 50 hospital-use-only mobile phones, used by doctors, were sampled for bacterial contamination at Hiroshima University Hospital, Hiroshima, Japan, which is a 746-bed tertiary care hospital. Sampling was performed using 25-cm^2 trypticase soy agar (TSA) with lecithin and polysorbate replicate organism detection and counting (RODAC) contact plates (25 cm^2; Nippon Becton Dickinson Co., Ltd., Tokyo, Japan). The RODAC plate was firmly pressed onto the surface of the mobile phone keypad for 10 seconds for sample collection.

Bacterial culture and identification

After sample collection, the contact plates were immediately transferred to the clinical laboratory at Hiroshima University Hospital and aerobically incubated for 48 hours at 37°C. Plate counts were conducted to estimate the total number of colony-forming units (CFUs) for all aerobic bacteria (AB) present in each sample. Putative MRSA colonies on the sample plates were identified according to their unique color, morphology, and *S. aureus*-selective latex agglutination test results (PS Latex; Eiken Chemical Co., Tokyo, Japan). These were then subcultured and identified using standard microbiological methods[13]; CFU counts for MRSA were estimated for each sample.

UVC light source

A 222-nm UVC-emitting Kr-Cl excimer lamp module (Care222, Ushio Inc. Tokyo, Japan) was used in this study. This lamp comprised of an optical filter with a restricted light emission range of 200-230 nm, with a maximum output wavelength of 222 nm (Fig 1).[6,9,11] For 222-nm UVC irradiation, the emission window of Care222 was 24 cm above the surface of the plate or mobile phone, and radiation intensity at the surface was 0.1 mW/cm^2, as measured with an S-172/UIT250 UV meter (Ushio Inc., Tokyo, Japan).

In vitro disinfection of MRSA

MRSA clinical isolates were grown overnight at 37°C on blood agar plates. The isolates were suspended in physiological saline and adjusted to 0.5 McFarland standards using a nephelometer (MM-1000, Koden Industry, Tokyo, Japan). Next, 50 μL bacterial suspension was inoculated onto 9-cm plastic plates and spread into a circle of diameter approximately 7 cm. The inocula were allowed to dry at ambient temperature under sterile laminar flow in a biosafety cabinet. A total of 5 plates were prepared, 1 used as a control and 4 subjected to 222-nm UVC irradiation for 1.5, 2.5, 5, and 10 minutes, separately. After 222-nm UVC irradiation, the control and treated plastic plates were swabbed for sample collection using sterile cotton swabs moistened with phosphate-buffered saline in a zigzag motion. Each swab was placed in a 15-mL conical tube containing 2 mL sterile phosphate-buffered saline. The tubes were vortexed vigorously for 2 minutes, and 100 μL was inoculated on 5% sheep blood agar plates, which were incubated aerobically for 48 hours at 37°C. The control plate samples were enumerated via serial dilution and inoculated on 5% sheep blood agar plates, before incubating aerobically for 48 hours at 37°C. The MRSA CFUs, on each plate, were counted and the total number on the control and treated plastic plates was calculated. Log_{10} CFU reductions were calculated by comparing log_{10} CFUs recovered from carriers after 222-nm UV disinfection and from untreated controls. This experiment was repeated thrice on different days.

Efficacy of Care222 disinfection in mobile phones

To assess the actual efficacy of Care222, we collected samples from 40 hospital-use-only mobile phones used by doctors, before and after 222-nm UVC disinfection (performed for 1.5 minutes on each mobile phone) and cultured them. The back sides of 20 mobile phones were sampled before disinfection and the front keypads were sampled after 222-nm UVC disinfection. In the remaining 20 mobile phones, the front keypads were sampled before disinfection and back sides were sampled after 222-nm UVC disinfection. For sampling, RODAC plates were pressed firmly onto the surface of the mobile phone keypads or on the back sides for 10 seconds. The sampling

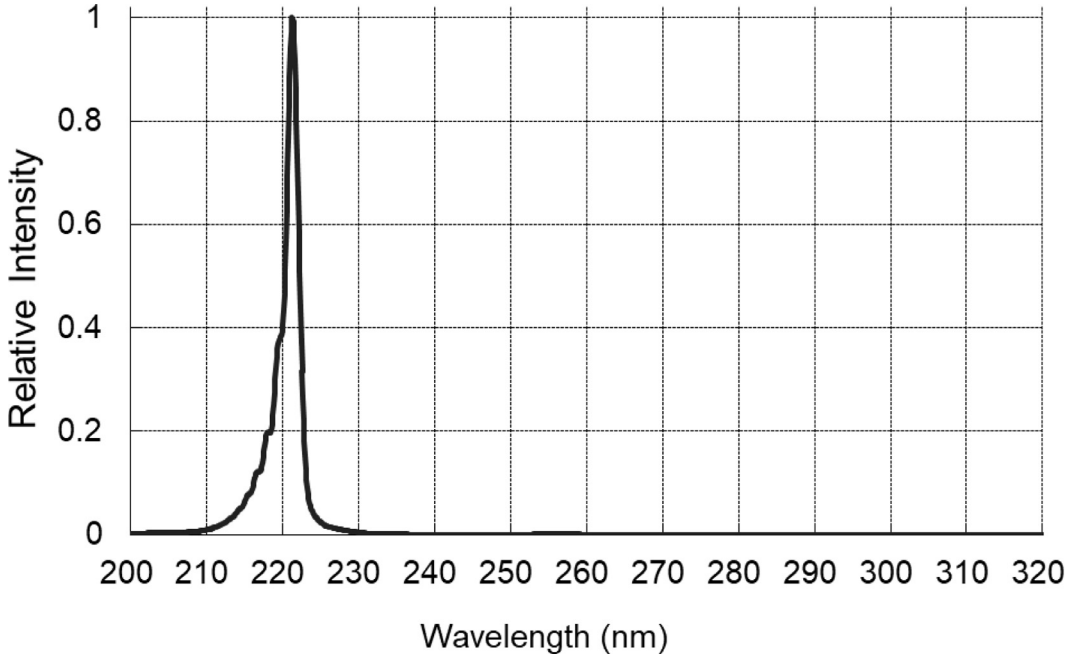

Fig 1. Spectrum emitted by the Kr-Cl excimer lamp equipped with an optical filter.

plates were incubated aerobically for 48 hours at 37°C. The number of AB CFUs on each plate was counted next.

Statistical analysis

Owing to the non-normal distribution of microbiological data, Wilcoxon matched-pairs signed-rank tests were used to determine the differences in AB counts before and after 222-nm UV disinfection. Data were analyzed using JMP version 14.0 (SAS Institute Inc., Cary, NC), and $P < .05$ was considered to indicate statistical significance.

RESULTS

Of the 50 mobile phones, 5 (10%) were contaminated with MRSA. The median AB CFU was 17 (range: 3-122) and mean AB CFU ± standard deviation (SD) was 25.2 ± 24.5. For MRSA-positive samples, the median MRSA CFU was 3.5 (range: 0-6) and mean MRSA CFU was 3.4 ± 1.7. The mean $\log_{10}$ MRSA CFU reductions on plastic plates are listed in Table 1. The mean MRSA CFU ± SD of control plates was $(9.43 \pm 0.98) \times 10^6$. Exposure to 222-nm UVC radiation for 1.5 and 2.5 minutes (9 and 15 mJ/cm^2) achieved mean $\log_{10}$ MRSA CFU reductions of 2.91 and 3.95, respectively. Log_{10} MRSA CFU reductions increased with irradiation time.

The efficacy of 222-nm UV disinfection in reducing AB contamination on doctors' hospital-use-only mobile phones is summarized in Table 2. Before disinfection, the number of CFUs on the front keypads and back sides were not significantly different in each group ($P = .7$). However, 9 mJ/cm^2 of 222-nm UVC irradiation (0.1 mW/cm^2 for 1.5 minutes) significantly reduced AB contamination on mobile phones in both the groups. Exposure to 222-nm UVC radiation was associated with 93.4% and 94.7% decrease in AB contamination, respectively, with reference to baseline.

DISCUSSION

In this study, 10% of doctors' hospital-use-only mobile phones were contaminated with MRSA. There are only few reports investigating the MRSA contamination of hospital-use-only mobile phones in Japanese hospitals. Kanayama et al had reported that 2.3% of 221 hospital-use-only mobile phones, used by nurses in a Japanese university hospital, were colonized with MRSA.[14] Furthermore, pulsed-field gel electrophoresis revealed MRSA strains on these mobile phones to be genetically similar to those found on the hands of nurses. Although our sample size was small, the rate of MRSA contamination on mobile phones was found to be higher than that reported previously.[14] The high contamination rate may be attributed to the mobile phones being used by doctors, rather than nurses. Several studies have shown hand hygiene compliance rates to be commonly lower among doctors than among nurses.[15,16] Poor hand hygiene compliance may have led to the higher contamination rates on doctors' mobile phones.

In addition, cleaning habits may have affected the contamination rates. Mobile phones are some of the most frequently used devices in hospitals. In Japan, almost every medical staff has access to a mobile phone during his or her shift in the hospital. Surface contamination of mobile phones may occur when they are handled after contact with patients or hospital environments contaminated with multidrug-resistant organisms, including MRSA. In our hospital, shared computer keyboards and nurses' mobile phones are cleaned daily with benzalkonium chloride containing wipes in each ward. However, doctor's mobile phones are personal, and their cleanliness depends on personal habits. Several studies have reported that only few medical staff voluntarily disinfect their mobile phones.[17,18] These results strongly recommend routine daily cleaning of mobile phones for effective reduction of device contamination; moreover, medical staff should perform hand hygiene before and after using mobile phones.

In our in vitro study, 9 and 15 mJ/cm^2 222-nm UVC irradiation resulted in mean $\log_{10}$ MRSA CFU reductions of 2.91 and 3.95, respectively. These results were consistent with a previous report.[6] Moreover, 9 mJ/cm^2 222-nm UVC irradiation significantly reduced AB contamination on mobile phones; in previous studies, the use of chemical agents for the disinfection of mobile phones resulted in similar levels of CFU reduction (87%-95%).[19,20] Although the irradiation area becomes smaller, the time required for a similar disinfection effect is shortened as the irradiation distance is smaller.

Our current results suggested that the 222-nm UVC disinfection device is quite effective in reducing AB and MRSA contamination, and provide a useful no-touch option for rapid and effective disinfection

Table 1
Efficacy of 222-nm ultraviolet C (UVC) light (0.1 mW/cm^2) in reducing methicillin-resistant *Staphylococcus aureus* (MRSA) contamination

	UVC irradiation time			
	1.5 min (9 mJ/cm^2)	2.5 min (15 mJ/cm^2)	5 min (30 mJ/cm^2)	10 min (60 mJ/cm^2)
Mean log reduction ± SD	2.91 ± 0.11	3.95 ± 0.05	4.86 ± 0.03	5.41 ± 0.12

SD, standard deviation.
The mean MRSA CFU ± SD of control plates was $(9.43 \pm 0.98) \times 10^6$.

Table 2
Overall colony-forming unit (CFU) counts and proportion of samples with CFUs at baseline and after 9 mJ/cm^2 222-nm UV disinfection (0.1 mW/cm^2 for 1.5 min) for aerobic bacteria

	Before disinfection back side	After 222-nm UV disinfection front keypad
Mean CFU ± SD	27.7 ± 26.5	1.95 ± 1.93
Median CFU (range)	17.5 (5-102)	1 (0-5)*
Proportion of samples with CFU present (%)	20/20 (100%)	14/20 (70%)
Total number of CFUs	554	39
	Before disinfection front keypad	**After 222-nm UV disinfection back side**
Mean CFU ± SD	29.4 ± 25.2	1.65 ± 1.53
Median CFU	22.5 (4-100)	2 (0-5)†
Proportion of samples with CFU present (%)	20/20 (100%)	13/20 (65%)
Total number of CFUs	587	33

CFU, colony-forming units; SD, standard deviation; UV, ultraviolet.
*$P < .001$ (before disinfection vs after 222-nm UV disinfection).
†$P < .001$ (before disinfection vs after 222-nm UV disinfection).

of mobile devices. Although the most common UVC disinfection system, currently in use, is a germicidal lamp emitting 254-nm UVC,[5] it can only be used in unoccupied spaces since the wavelength is harmful to both skin and eyes. In contrast, recent studies have shown that 222-nm UVC light, which is part of the far-UVC light (207-222 nm) spectrum, shares similar germicidal properties, but is less harmful to the skin and eyes than 254-nm UVC light.[6-12] The studies together suggested that a 222-nm UVC disinfection device may be easier to use for routine device cleaning than a 254-nm UVC disinfection device in environments where patients and medical staff exist, such as nurse stations and patient rooms. However, further studies investigating the safety of 222-nm UVC disinfection in occupied spaces would be required in future.

The efficacy of 222-nm UVC disinfection in mobile phones was less than that recorded in our in vitro MRSA study. This may be related to the nonflat surface and organic load of mobile phones. Far-UVC light (207-222 nm) is very strongly absorbed by proteins,[21] and is safer for the skin and eyes than conventional 254-nm UVC light. We have investigated the in vitro efficacy of 222-nm UVC disinfection on MRSA in the absence of organic load on flat surfaces. However, in reality, the surfaces of mobile phones and other medical equipment have significant organic loads.

Our study has several limitations. We only investigated the efficacy of 222-nm UVC disinfection on MRSA contamination of hospital-use-only mobile phones. We did not test the other equipment used in the hospital, such as computer keyboards. We also did not investigate whether the doctors cleaned their mobile phones routinely, on a daily basis, and complied with regular hand hygiene guidelines; we did not identify multidrug-resistant organisms other than MRSA. Finally, we did not investigate whether the MRSA contamination was brought on by doctors using the mobile phones. Therefore, we cannot ascertain whether the MRSA isolated from mobile phones originated from doctors, patients under their treatment, or from the wider hospital environment.

In conclusion, we investigated the contamination rate of MRSA on doctors' hospital-use-only mobile phones and demonstrated 222-nm UVC disinfection to be effective in the reduction of MRSA in vitro, along with significant reduction of AB contamination on mobile phone surfaces. These findings provided important evidence for the effectiveness of 222-nm UVC disinfection and supported the application of this no-touch disinfection technology in various clinical settings and devices.

Acknowledgments

We would like to thank Ushio Inc. for providing the Care222 device for use during this study. We would like to thank Editage (www.editage.com) for English language editing. This study was supported by a research grant from Ushio Inc.

References

1. Kanamori H, Rutala WA, Weber DJ. The role of patient care items as a fomite in healthcare-associated outbreaks and infection prevention. *Clin Infect Dis*. 2017; 65:1412–1419
2. Donskey CJ. Beyond high-touch surfaces: portable equipment and floors as potential sources of transmission of health care-associated pathogens. *Am J Infect Control*. 2019;47:90–95
3. Brady RRW, Verran J, Damani NN, Gibb AP. Review of mobile communication devices as potential reservoirs of nosocomial pathogens. *J Hosp Infect*. 2009;71:295–300
4. Haun N, Hooper-Lane C, Safdar N. Healthcare personnel attire and devices as fomites: a systematic review. *Infect Control Hosp Epidemiol*. 2016;37:1367–1373
5. Marra AR, Schweizer ML, Edmond MB. No-touch disinfection methods to decrease multidrug-resistant organism infections: a systematic review and meta-analysis. *Infect Control Hosp Epidemiol*. 2018;39:20–31
6. Buonanno M, Ponnaiya B, Welch D, et al. Germicidal efficacy and mammalian skin safety of 222-nm UV light. *Radiat Res*. 2017;187:493–501
7. Ponnaiya B, Buonanno M, Welch D, Shuryak I, Randers-Pehrson G, Brenner DJ. Far-UVC light prevents MRSA infection of superficial wounds in vivo. *PLoS One*. 2018;13: e0192053
8. Narita K, Asano K, Morimoto Y, et al. Disinfection and healing effects of 222-nm UVC light on methicillin-resistant *Staphylococcus aureus* infection in mouse wounds. *J Photochem Photobiol B*. 2018;178:10–18
9. Narita K, Asano K, Morimoto Y, Igarashi T, Nakane A. Chronic irradiation with 222-nm UVC light induces neither DNA damage nor epidermal lesions in mouse skin, even at high doses. *PLoS One*. 2018;1: e0201259
10. Kaidzu S, Sugihara K, Sasaki M, Nishiaki A, Igarashi T, Tanito M. Evaluation of acute corneal damage induced by 222-nm and 254-nm ultraviolet light in Sprague-Dawley rats. *Free Radic Res*. 2019;53:611–617
11. Yamano N, Kunisada M, Kaidzu S, et al. Long-term effects of 222-nm ultraviolet radiation C sterilizing lamps on mice susceptible to ultraviolet radiation. *Photochem Photobiol*. 2020;96:853–862
12. Fukui T, Niikura T, Oda T, et al. Exploratory clinical trial on the safety and bactericidal effect of 222-nm ultraviolet C irradiation in healthy humans. *PLoS One*. 2020;15: e0235948
13. CLSI. *Performance Standards for Antimicrobial Susceptibility Testing*. 28th ed. Wayne, PA: Clinical Laboratory Standards Institute; 2018. CLSI supplement M100
14. Katsuse Kanayama A, Takahashi H, Yoshizawa S, Tateda K, Kaneko A, Kobayashi I. *Staphylococcus aureus* surface contamination of mobile phones and presence of genetically identical strains on the hands of nursing personnel. *Am J Infect Control*. 2017;45:929–931
15. Erasmus V, Daha TJ, Brug H, et al. Systematic review of studies on compliance with hand hygiene guidelines in hospital care. *Infect Control Hosp Epidemiol*. 2010; 31:283–294
16. Ibrahim MAB, Chow C, Poh BF, Ang B, Chow A. Differences in psychosocial determinants of hand hygiene between health care professional groups: insights from a mixed-methods analysis. *Am J Infect Control*. 2018;46:253–260
17. Sadat-Ali M, Al-Omran AK, Azam Q, et al. Bacterial flora on cell phones of health care providers in a teaching institution. *Am J Infect Control*. 2010;38:404–405
18. Simmonds R, Lee D, Hayhurst E. Mobile phones as fomites for potential pathogens in hospitals: microbiome analysis reveals hidden contaminants. *J Hosp Infect*. 2020;104:207–213
19. Singh S, Acharya S, Bhat M, Rao SK, Pentapati KC. Mobile phone hygiene: potential risks posed by use in the clinics of an Indian dental school. *J Dent Educ*. 2010; 74:1153–1158
20. Egert M, Spath K, Weik K, et al. Bacteria on smartphone touchscreens in a German university setting and evaluation of two popular cleaning methods using commercially available cleaning products. *Folia Microbiol (Praha)*. 2015; 60:159–164
21. Goldfarb AR, Saidel LJ. Ultraviolet absorption spectra of proteins. *Science*. 1951; 114:156–157