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Major Article

Disinfecting noncritical medical equipment—Effectiveness of hydrogen peroxide dry mist as an adjunctive method

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Infection prevention
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Background: Manual disinfection of medical devices is prone to failure. Disinfection by aerosolized hydrogen peroxide might be a promising adjunctive method. We aimed to assess effectiveness of dry mist of hydrogen peroxide (HPDM) on noncritical medical equipment.

Methods: One cycle of HPDM was applied on a convenience sample of 16 different types of "ready to use" noncritical medical devices in a closed, but nonsealed room. Of every object, 2 adjacent areas with assumed similar bacterial burden were swabbed before and after HPDM deployment, respectively. After culturing, colony forming units (CFU) were counted, and bacterial burden per cm^2 calculated.

Results: Of 160 objects included in the study, 36 (23%) showed a CFU-count of zero both before and after HPDM use. A decrease from a median of 0.14 CFU/cm^2 (range: 0.00-125.00/cm^2) to a median of 0.00 CFU/cm^2 (range: 0.00-4.00/cm^2) ($P < .001$) was observed. The bacterial burden was reduced by more than 90% in 45% (95% CI: 37-53) of objects. No pathogenic bacteria were identified.

Discussion: HPDM reduced bacterial burden on noncritical medical items. Since cleanliness of the included "ready to use" objects was high and no pathogens were found before nebulization, the HPDM device did not increase patient safety in this setting.

Conclusion: HPDM nebulization can be a useful nonmanual adjunctive disinfection method in high-risk settings.

BACKGROUND

Hospitalized patients are at constant risk of acquiring multidrug resistant organisms (MDRO) or developing healthcare-associated infections. Many studies have demonstrated that environmental surfaces (eg, bedrails) and equipment (eg, stethoscopes) are a reservoir for pathogenic bacteria including MDRO.[1-6] In a comprehensive review, Otter et al. summarize evidence that contaminated surfaces contribute to the transmission of hospital pathogens.[7] It was also shown that patients who are admitted to a room previously occupied by a patient colonized or infected with vancomycin-resistant enterococci (VRE), methicillin-resistant *Staphylococcus aureus* (MRSA) or other pathogenic bacteria, are at increased risk of acquiring this specific pathogen from the previous patient.[8-11] To reduce bacterial burden of surfaces and equipment, effective cleaning and disinfection is required.

Disinfection describes a process that eliminates many or all pathogenic microorganisms, except bacterial spores, on inanimate objects.[12] Noncritical items—items that come in contact with intact

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Conflicts of interest: Christian Garzoni served as external scientific advisor to 99Technologies on Healthcare Acquired Infections from 2013 to 2017. The other authors declare no conflict of interest.

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Authors' contributions: AW, EA, CG, AZ and HS designed the study. EA acquired the data. AW, EA and SPK performed statistical analyses. AW, EA, SPK, and HS analyzed and interpreted the data. EA and AW drafted the manuscript, and SPK, CG, AZ, and HS provided critical review of the manuscript for important intellectual content. All authors agree with the content and conclusions of this manuscript.

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skin but not mucous membranes—such as medical equipment (eg, bedpans, blood pressure cuffs, crutches) and environmental surfaces (eg, bedside tables) are disinfected with a low-level disinfectant.[12] However, disinfection procedures are highly operator-dependent and prone to failure when executed manually.[13] Therefore, nonmanual automatized disinfection techniques, such as aerosolized hydrogen peroxide (HP) or ultraviolet light, are an interesting alternative or adjunctive infection control measure.

Airborne HP is active against a wide range of microorganisms, including bacteria, yeasts, fungi, viruses, and spores. It can either be applied in aerosolized (eg, dry mist) or vaporised form. Passaretti et al. showed that the risk of acquiring an MDRO in general, and a VRE specifically, was reduced by 64% and 80%, respectively after room disinfection with HP.[14] Horn et al. demonstrated that the odds ratios of acquiring an extended-spectrum beta-lactamase producing Gram-negative bacterium, an MRSA, a VRE, and *Clostridium difficile* after introducing HP vapour for terminal decontamination of patient rooms were 0.06, 0.53, 0.05, and 0.65, respectively.[15]

Medical equipment, which is commonly removed from the patient room before terminal room disinfection, was shown to be often contaminated by pathogens.[1-5] It comes into direct contact with the patient or is placed in the immediate patient environment. Moreover, some parts of the medical equipment may be difficult to disinfect manually. These items might therefore benefit from an adjunctive, standardized, nonmanual disinfection step to further reduce bacterial burden before being passed to the next patient. With the present study, we aimed to investigate the effectiveness of applying a single cycle of HP aerosolized disinfection of noncritical medical items.

METHODS

Study setting and objects

The study was conducted at the University Hospital Zurich, Switzerland, a 950-bed tertiary-care teaching hospital with 6 intensive care units (ICU).

We included 16 different noncritical object types, 8 from general wards and ICUs each. A convenience sample of noncritical objects "ready to use," that is disinfected according to internal University Hospital Zurich guidelines with aldehyd- (Kohrsolin FF) or alcohol based (Meliseptol) disinfectants, were collected throughout the hospital. Healthcare professionals (HCP) were not aware of the study execution, and the routine disinfecting procedure had not been supervised. Ten items of every object type were analysed.

Dry mist hydrogen peroxide nebulization procedure

A programmable device (HyperDRYMist, Modulator Micro-Nebulizer 99MB by 99Technologies, Switzerland) generating a dry mist of hydrogen peroxide, with a particle size of < 1 μm, was used. The disinfecting solution consists of purified water, 6.6% w/w hydrogen peroxide, 60 mg/l silver cations and a set of undisclosed proprietary co-formulants, which synergistically enhance biocidal action. The bactericidal properties result from the oxidative action of hydroxyl radicals on the lipid membrane, DNA, and other essential cell components of microorganisms, and the effect of silver cations that reverse membrane polarity and inhibit protein synthesis and cytoplasmic enzyme activity. The disinfectant is micro-nebulized as a dry aerosol that accesses all surfaces exposed to air. Disinfection happened in a nonclimatized room of 60 m^3 with closed, but unsealed doors and windows. The HPDM micro-nebulizer was placed in a corner of the room, and the study objects were placed at a distance of >2 m from the machine. One cycle consisted of 10 minutes "dissemination time" (ie, time of active nebulization), 45 minutes "exposure time" (ie, time of ongoing activity and progressive decay of hydrogen peroxide), and 15 minutes "ventilation time" (ie, time of clearing residue levels of hydrogen peroxide by ventilating the room). A total of 3 ml/m^3 of disinfectant solution was nebulized, corresponding to 140 ppm of hydrogen peroxide.

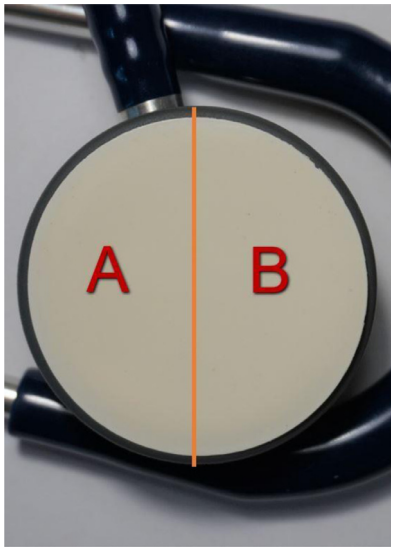

Fig 1. Example of study object. The swabbed area of all study objects was divided in area A and area B of same size and hypothetically same bacterial burden. Areas A and B were swabbed before and after nebulization alternately.

Sampling and microbiology

Swab samples of 160 objects were collected before and after nebulization. Shape and dimension of swabbed area was individualized according to object (Fig 1, and Appendix A). The largest possible area making a rectangle or round shape was swabbed. Hypothesising that swabbing removes bacteria, 2 adjacent areas with assumed equal bacterial burdens (area A and B) were swabbed before and after nebulization.

Sampling was performed with moistened eSwabs comprising 1 millilitre of Liquid Amies medium. Specimens were stored at 4°C and processed within 24 hours after sampling. After vortexing the swabs in Amies medium for 15 seconds, an aliquot of 500 μl Liquid Amies medium per sampled object was plated on a 5% sheep blood agar plate. The agar plates were incubated 72 hours at 36°C, and colony forming units (CFU) of aerobic bacterial growth per agar plate were counted manually.

Identification of both opportunistic and pathogenic bacteria (eg, *S. aureus, Enterobacteriaceae* ssp., *Pseudomonas aeruginosa,* and *Enterococci* ssp.), as well as environmental flora was performed by experienced laboratory technicians in the on-site laboratory. After culturing aerobic bacteria on sheep blood agar, subculturing was performed on sheep blood and MacConkey agar. For species identification catalase and oxidase test, followed by latex agglutination test for *S. aureus* identification and multicolor system Enterotubes for identification of *Enterobacteriaceae* ssp. were used.

Bacterial burden

For samples with CFU too numerous to count, CFU count was set to 500 per sampled area. Bacterial burden was calculated in CFU/cm^2. According to Dancer et al. we defined a “clean object” as an object with <5 CFU/cm^2.[16]

Table 1
Bacterial burden of all objects before nebulization

Objects	No. of included objects	Swabbed area in cm^2	Ward type	Material	"Easy to clean" vs "Difficult to clean"	CFU/ cm^2 before nebulization, median (range)	*P* value (Wilcoxon rank-sum test)*
Blood pressure cuff	10	285	GW	P	E	0.22 (0.01-0.73)	.614
ECG electrodes	10	35	GW	M	D	1.23 (0.00-14.29)	.001
Infusion pump (inside)	10	108	ICU	M	D	0.01 (0.00-0.11)	.004
Infusion pump (outside)	10	54	ICU	P	E	0.13 (0.00-0.67)	.631
Infusion stand	10	145	GW	M	E	0.04 (0.00-0.40)	.079
Monitor	10	127	ICU	P	E	0.01 (0.00-0.13)	.003
Oxygen regulator	10	20	ICU	P	E	0.20 (0.00-0.70)	.865
Patient's phone	10	8	GW	P	E	1.50 (0.00-8.50)	.001
Pulse oximeter	10	4	ICU	P	D	1.00 (0.00-125.00)	.014
Remote control	10	50	GW	P	E	1.68 (0.04-10.00)	.003
Stethoscope diaphragm	10	8	GW	P	E	0.00 (0.00-4.00)	.021
Suction pump	10	22	ICU	P	E	0.27 (0.09-3.82)	.076
Syringe pump	10	93	ICU	P	D	0.03 (0.00-0.47)	.107
Thermometer	10	8	ICU	P	D	0.25 (0.00-0.50)	.382
Tourniquet	10	52	GW	F	D	0.42 (0.00-1.88)	.126
Wheelchair	10	108	GW	M	E	0.00 (0.00-1.13)	.001
All objects	160					0.14 (0.00-125.00)	

NOTE. Baseline bacterial burden (CFU/cm^2) of all 160 objects before HPDM nebulization. CFU counts of samples with CFU too numerous to count were set to 500 CFU per sampled area. CFU too numerous to count were present on 2 ECG electrodes, 2 pulse oximeters and 2 remote controls. * Wilcoxon rank-sum test was used to compare bacterial burden between objects.
cm^2, square centimetres; *HPDM*, hydrogen peroxide dry mist; *D*, "difficult to clean" object; *E*, "easy to clean" object; *F*, fabric; *ICU*, intensive care unit; *GW*, general ward; *M*, metal; *No.*, number; *P*, plastic

The "percentage decrease" of CFU after nebulization was calculated as follows:

$$\text{Percentage decrease} = 100 - \left(\frac{\textit{CFU after nebulization}}{\textit{CFU before nebulization}} \times 100\right)$$

If bacterial burden before nebulization was zero any increase of bacterial burden after nebulization was set as "percentage decrease" = −100%.

Categorization of objects

For subgroup analysis we grouped the objects according to: (1) ward type, that is objects collected on general wards vs objects collected on ICUs; (2) material, that is plastic, metal and fabric; (3) Flat, "easy to clean" objects vs angled, nonflat "difficult to clean" objects (Table 1).

Statistical analysis

Wilcoxon rank sum test was used to compare bacterial burdens between objects. Wilcoxon signed ranks test was used for paired comparison of bacterial burden before and after nebulization. After dichotomizing results of percentage of decrease in ≥90% and <90% ("90% decrease"), Fisher's exact test was used to test for differences between object types, materials, and bacterial burden before nebulization. Significance was set as $P < .05$. All statistical analyses were performed with STATA version 15 (Stata Corp., College Station, TX).

RESULTS

Object type and bacterial burden before nebulization is shown in Table 1. We found high median colonization on ECG electrodes, patients' phones, pulse oximeters and on remote controls, and low median colonization on the inside of infusion pumps, monitors, stethoscope diaphragms, and wheelchairs. Before nebulization, no bacterial growth was detected in 25.6% of objects. Eight (5%) objects were "not clean," that is ≥5 CFU/cm^2, according to Dancer et al.'s "microbiological standards for surface hygiene in hospitals" (2 ECG electrodes, 2 patients' phones, 2 pulse oximeters, 2 remote controls).[16] In all 124 objects with detectable colonization, only skin or environmental flora was identified and no pathogenic bacterium was found. For raw data of all sampled items see Appendix B.

Of all 160 objects, 23% (n = 36) did not show bacterial contamination before and after nebulization. Table 2 shows median bacterial burden before and after nebulization, and median "percentage decrease" due to nebulization. Fig 2 shows median CFU before and after nebulization per object type, Appendix C shows results for every single object. Across all objects, we found decrease from a median of 0.14 CFU/cm^2 (range: 0.00-125.00) to a median of 0.00 CFU/cm^2 (range: 0.00-125.00, $P < .001$). All but 6 objects (insides of infusion pump, stethoscope diaphragms, syringe pump, thermometer, tourniquet, and wheelchairs) showed a statistically significant CFU decrease. After nebulization, 99% (n = 159) of objects were "clean," according to Dancer's "microbiological standards for surface hygiene in hospitals" [16] and 63% (n = 100) showed no bacterial growth. In 45% of objects (95% confidence interval (CI): 37-53) the decrease of CFU was more than 90%.

Before nebulization, objects from general wards had higher CFU counts compared to objects from ICUs (median 0.10 CFU/cm^2 [range: 0.00-4.00] vs 0.29 CFU/cm^2 [0.00-14.2; $P = .033$]). Nebulization of objects from general wards and ICUs lead to a "90% decrease" in 35% (CI: 25-46) and 55% (CI: 43-66; $P = .033$), respectively. We did not find differences in nebulization effectiveness when comparing objects of different materials, nor when comparing "difficult to clean" and "easy to clean" objects (data not shown). In "nonclean" objects with a bacterial burden > 5 CFU/cm^2 (n = 8), the HPDM nebulization resulted in a median decrease of 89% CFU (data not shown)

DISCUSSION

Our study, investigating a nonmanual disinfection method of noncritical medical equipment, demonstrated that 23% of the objects "ready to use" did not show any bacterial contamination and 95% were "clean" (ie, <5 CFU/cm^2) before HPDM nebulization. Furthermore, including all objects into analysis, HPDM led to a median CFU decrease of 79% (IQR: 0-100) and reduced more than 90% of CFU in 45% (72/160) of objects.

The objects of noncritical medical equipment included in our study were "ready to use" and showed a low bacterial burden. Compared to other studies assessing contamination after standard

Table 2
Bacterial burden of included objects before and after nebulization

Objects	No. of included objects	CFU/cm^2 before nebulization, median (range)	CFU/cm^2 after nebulization, median (range)	Percentage decrease, median (range)	> 90% decrease, %	*P* value (Wilcoxon signed ranks test)*
Blood pressure cuff	10	0.22 (0.01-0.73)	0.06 (0.01-0.15)	69.88 (-55.56-94.23)	30	.014
ECG electrodes	10	1.23 (0.00-14.29)	0.14 (0.00-5.71)	85.79 (0.00-100.00)	30	.006
Infusion pump (inside)	10	0.01 (0.00-0.11)	0.00 (0.00-0.06)	0.00 (-100.00-100.00)	30	.499
Infusion pump (outside)	10	0.13 (0.00-0.67)	0.00 (0.00-0.15)	100.00 (0.00-100.00)	70	.008
Infusion stand	10	0.04 (0.00-0.40)	0.00 (0.00-0.03)	100.00 (0.00-100.00)	70	.008
Monitor	10	0.01 (0.00-0.13)	0.00 (0.00-0.02)	0.00 (0.00-100.00)	40	.047
Oxygen regulator	10	0.20 (0.00-0.70)	0.00 (0.00-0.20)	100.00 (0.00-100.00)	80	.007
Patient's phone	10	1.50 (0.00-8.50)	0.25 (0.00-3.75)	82.64 (0.00-100.00)	40	.006
Pulse oximeter	10	1.00 (0.00-125.00)	0.00 (0.00-4.00)	100.00 (0.00-100.00)	80	.008
Remote control	10	1.68 (0.04-10.00)	0.46 (0-00-3.20)	64.58 (0.00-100.00)	20	.006
Stethoscope diaphragm	10	0.00 (0.00-4.00)	0.00 (0.00-0.00)	0.00 (0.00-100.00)	30	.084
Suction pump	10	0.27 (0.09-3.82)	0.09 (0.00-0.64)	81.67 (0.00-100.00)	40	.006
Syringe pump	10	0.03 (0.00-0.47)	0.01 (0.00-1.31)	34.09 (-1933.33-100.00)	40	.299
Thermometer	10	0.25 (0.00-0.50)	0.00 (0.00-0.25)	100.00 (-100.00-100.00)	60	.051
Tourniquet	10	0.42 (0.00-1.88)	0.08 (0.00-2.81)	28.79 (-563.64-100.00)	40	.575
Wheelchair	10	0.00 (0.00-1.13)	0.00 (0.00-0.00)	0.00 (0.00-100.00)	20	.158

NOTE. Bacterial burden before and after HPDM nebulization of objects * Wilcoxon signed ranks test compares bacterial burden (in CFU/ cm^2) from objects before nebulization with bacterial burden (in CFU/cm^2) after nebulization.
CFU, colony forming unit; *CI*, confidence interval; *cm^2*, square centimetres; *ECG*, electrocardiogram; *No.*, number.

disinfection procedures we found a 10-100 fold lower median bacterial burden of only 0.14 CFU/cm^2.[17-19] Moreover, no pathogenic bacteria were identified on the included medical devices. Still, 8 out of 160 objects (5%) were "not clean" (ie, ≥5 CFU/cm^2) according to established criteria,[16] even though all objects should have undergone a disinfection procedure according to our hospitals' guidelines. Heavy contamination is a surrogate marker of an insufficient cleaning and disinfection process and points out the critical role of the human factor in the cleaning procedure,[20]

We found that in 45% of objects HPDM nebulization led to a more than 90% decrease in CFU. In heavily contaminated objects, the HPDM nebulization resulted in a median decrease of 89% CFU. Other studies also reported good effectiveness of HP systems. Weber et al. reviewed the effectiveness of HP systems for terminal room decontamination and found several studies (predominantly using vaporized HP) demonstrating reduction of multidrug-resistant organisms by a percentage between 86% and 100%.[21] A systematic review by Falagas et al. found that disinfection with terminal cleaning vs HP reduced the percentage of contaminated environmental sites from 39% to 28.3% vs 2.2%, respectively.[22] The studies included in these 2 reviews might not be entirely comparable to our study, as all but 1 study targeted pathogenic bacteria only (eg, MRSA, *Serratia* sp.)—in

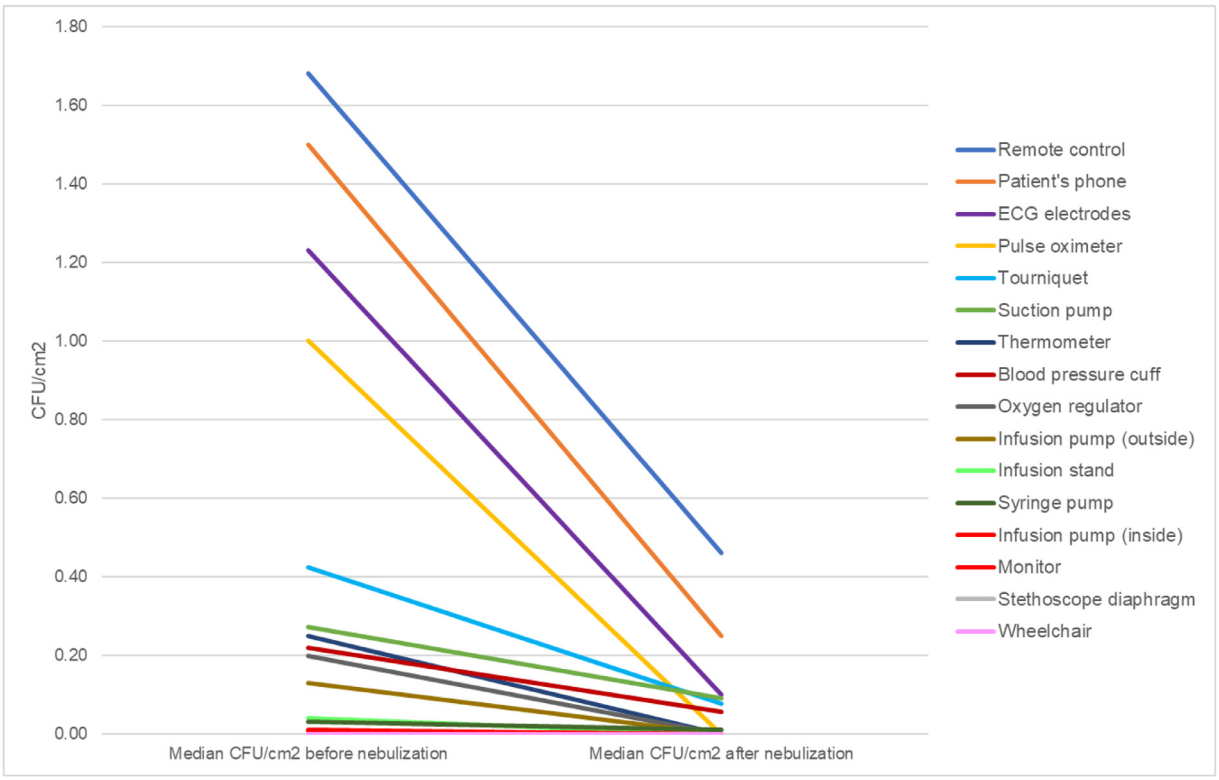

Fig 2. Median bacterial burden before and after nebulization. Median bacterial burden (CFU/cm^2) before and after HPDM nebulization of objects. (*CFU*, colony forming unit; *cm*, centimetre; *ECG*, electrocardiogram).

our study, on the other hand, we did not find pathogenic bacteria on any of our objects before the study procedure. Additionally, most of the included studies in the aforementioned reviews used vaporisation systems, which were reported to be more effective than aerosolized HP.[23,24]

The vast majority of previous studies evaluating HP effectiveness investigated noncritical environmental surfaces and not medical devices. We identified only a single study testing effectiveness of HP disinfection on medical devices using *Bacillus* spores as indicators.[25] This study especially assessed decontamination of the inner part of medical equipment (ie, ventilators or suction pumps) and found that 3 diffusion cycles of HP dry aerosol had a sporicidal effect in 62% of tested items, with an increase to 100% effectiveness when devices were ventilated.

Compared to environmental surfaces, noncritical medical devices might be more difficult to clean. In our study, many of the included objects, eg. pulse oximeters, were angled and not flat. CFU decrease did not differ between these probably "difficult to clean" objects compared to "easy to clean" objects. One particular advantage of HP disinfection is that all surfaces exposed to the HP-containing air are disinfected irrespective of their shape. After expiration of the dissemination time, the concentration of HP is evenly distributed in the whole room and distance between object and HP device is negligible. “Difficult to clean” objects might therefore benefit the most from this nontouch disinfection technique.

Our study has limitations. First, we included “ready to use” medical devices and assumed prior disinfection according to our hospitals’ guidelines, but the execution of the disinfection procedure could not be verified. This, however, better represents a real-life situation. Second, we included 36 objects into the analysis of this real life study that did neither show contamination before nor after nebulization. That, in turn, has led to an underestimation of HPDM nebulization efficacy. By performing a sensitivity analysis excluding these 36 objects, we found that the median percentage decrease was 100% and the 90%-decrease was 58% (data not shown). Third, we did not use neutralizers to inactivate residual disinfectants potentially inhibiting bacterial growth, thus potentially leading to an underestimation of bacterial contamination before nebulization. Still, the relative reduction of CFU count is unchanged, as aerosolized hydrogen peroxide does not require the use of neutralizers, as it breaks down into water and oxygen relatively rapidly (within 30 minutes on a surface).[26]

CONCLUSIONS

In conclusion, our study testing an easy-to-use HPDM device on noncritical medical items in a “real life setting,” shows relevant reduction of bacterial burden after HP disinfection. Of interest, bacterial burden before nebulization was very low in our hospital and we did only identify nonpathogenic bacteria on the included objects. Thus, effectiveness of the HPDM system to reduce pathogenic bacteria could not be proven. Nevertheless, noncritical medical equipment has been shown to be contaminated with pathogens in many other settings. The effectiveness of HP systems to reduce contamination with MRSA, *C. difficile* and other pathogens was demonstrated by other authors and there is no rationale to assume a different efficacy between pathogenic and nonpathogenic bacteria.[27-29] In view of the fact that medical devices can act as fomites, HPDM nebulization might act as “safety-net” in disinfection processes on high-risk wards like ICUs or during outbreaks. It could for example be used to routinely disinfect noncritical medical equipment after patient discharge or during the patient’s absence from the room due to a medical procedure. Alternatively, noncritical medical equipment could be pooled in a small room allowing an even shorter disinfection cycle time due to the low room volume. Use of the present HPDM device exhibits less logistic issues compared to vapour HP techniques as no room sealing is needed and room occupation dead-time is usually less than 1 hour. Compatibility of HP disinfectants with medical equipment has to be assessed before application. Further research is warranted to investigate if HPDM disinfection of noncritical medical devices reduces MDRO transmission in routine use within real-world settings.

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SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.ajic.2020.05.016.

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