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Major Article

Comparison of the effectiveness of automatic and manual plasma-treated hydrogen peroxide mist disinfection in various teaching hospital environments

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Gram-positive bacteria
Colony-forming unit
No-touch disinfection technology

Background: Automatic disinfection technologies have been developed to improve the reliability and thoroughness of hospital disinfection. However, it is not clear whether automated systems can achieve similar disinfection results to those obtained by well-trained professionals using manual methods. We evaluated the disinfection efficacies of automatic and manual plasma-treated hydrogen peroxide mist (PTHPM) systems in various hospital environments.

Methods: Disinfection was performed in 23 rooms in a teaching hospital, covering various hospital wards, outpatient departments, and emergency rooms. Overall, 459 surfaces were swabbed before and after disinfection. Only gram-positive bacteria were analyzed statistically owing to the low prevalence of gram-negative bacteria and molds.

Results: Before disinfection, the viability of gram-positive bacteria, based on colony-forming units, was highest in outpatient departments, followed by emergency rooms and hospital wards using both automatic and manual disinfection. Automatic PTHPM disinfection reduced the colony-forming units of gram-positive bacteria significantly in various environments. There were no significant differences in the effectiveness of automated and manual PTHPM disinfection.

Conclusions: Automated PTHPM disinfection can be as effective as manual PTHPM disinfection in eliminating microbial contamination in teaching hospital environments.

BACKGROUND

Maintaining a contamination-free environment in health care settings is essential for preventing health care-associated infections, a major cause of morbidity and mortality worldwide. The persistence of pathogens, such as *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), and carbapenem-resistant Enterobacteriaceae, on hospital surfaces presents a major risk for infection transmission, particularly in high-risk areas, such as operating rooms and intensive care units (ICUs).[1] Accordingly, effective disinfection protocols play crucial role in infection control.[2]

Surface disinfection involves the use of chemical disinfectants, including hydrogen peroxide, sodium hypochlorite, and quaternary ammonium compounds. Among them, hydrogen peroxide is less harmful to patients because its decomposition results in harmless

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byproducts—water and oxygen. Further, hydrogen peroxide is widely utilized as a disinfectant, and several studies have reported its effectiveness in inactivating pathogens.[3-6] Disinfection methods utilizing hydrogen peroxide can be broadly categorized based on its physical form into fumigation and aerosolized mist applications.[7,8] Among aerosol-based techniques, plasma-treated hydrogen peroxide mist (PTHPM) disinfection represents a notable advancement. PTHPM technology combines the established antimicrobial properties of hydrogen peroxide with plasma activation to generate reactive oxygen species, which amplify biocidal effects against a wide spectrum of pathogens, including bacteria, viruses, fungi, and spores.[9] The fine aerosolized mist produced by PTHPM systems can penetrate difficult-to-access surfaces and objects effectively, providing uniform disinfection coverage in complex hospital environments.[10]

Manual surface disinfection is widely used to reduce environmental contamination in hospitals. However, there is a risk of residual contamination on surfaces, particularly in high-touch and hard-to-reach areas[11,12] and in high-turnover environments such as emergency departments, outpatient clinics, and multibed hospital wards, where rapid patient flow and limited time between cases reduce opportunities for thorough manual cleaning.[13,14] Therefore, complying with standardized infection control guidelines, such as the Centers for Disease Control and Prevention's (CDC's) recommendation that all frequently touched surfaces in patient rooms should be cleaned and disinfected at least once daily using US Environmental Protection Agency (EPA)-registered hospital-grade disinfectants, remains challenging.[15]

Automated disinfection technologies have been developed to address these limitations and enhance the reliability and thoroughness of environmental cleaning methods. Among various no-touch disinfection technologies, hydrogen peroxide-based systems have attracted increasing attention owing to their broad microbicidal spectrum, including sporicidal activity, and applicability across diverse environmental conditions.[16,17]

PTHPM can be categorized into manual and automated spraying systems. Automated systems are capable of consistently applying disinfectants across surfaces, minimizing the variation observed in manual methods and reducing the potential for human error.[18] These systems facilitate the disinfection of areas that are difficult to reach manually (eg, behind medical equipment or within ventilation ducts).[19] The increased consistency and coverage make automated disinfection systems valuable in settings where a high standard of cleanliness is critical for patient safety and infection prevention.[20,21]

Manual PTHPM application is relatively cost-effective and operationally flexible. However, it imposes a high physical burden on workers, requires extensive personal protective equipment and shows variability in effectiveness depending on operator performance.[13] Automated PTHPM systems benefit from standardized applications and reduced labor demands but are often cost-prohibitive and may be less effective in environments with complex spatial configurations due to limited accessibility.[21,22] Although each approach offers distinct advantages and limitations, comparative studies evaluating their disinfection efficacy remain limited.[10]

Given that health care facilities encompass diverse architectural layouts, functional purposes, and disinfection requirements, we aimed to compare the disinfection efficacy of manual and automated PTHPM applications under real-world hospital conditions to inform the selection of optimal strategies tailored to specific health care settings.

METHODS

Experimental procedure

The experimental conditions were identical to those used in a previous study of PTHPM disinfection,[23] wherein disinfection conditions were standardized, including the hospital setting, rooms, and objects sampled for microbial culture.[23] The study was conducted at an 855-bed university hospital in Seoul, Korea, which handles approximately 2,500 outpatients daily. The disinfection practices at this facility followed established guidelines that recommend the use of chlorine-based disinfectants for routine cleaning and increased concentrations in areas with elevated infection risks. The study was conducted according to the hospital's standard disinfection protocols. In total, 23 rooms in the hospital were included in this study, spanning 7 hospital wards, 12 outpatient departments (OPDs), and 4 emergency rooms. The inpatient wards included single-patient rooms, 4-patient rooms, general isolation units, VRE isolation rooms, ICU isolation rooms, dialysis isolation rooms, and peritoneal dialysis rooms. The OPDs examined in this study included a computed tomography (CT) room, X-ray room, tuberculosis consultation room, infectious disease clinic, pediatric examination room, ear, nose, and throat clinic, ophthalmology examination room, dental clinic, chest medicine endoscopy room, gastroenterology endoscopy room; general surgery treatment room, and obstetrics and gynecology (OBGY) delivery room. The emergency care spaces included a resuscitation room, pediatric care area, critical care unit (10 beds), and triage room. Between 15 and 24 surfaces per room were selected, for a total of 459 surfaces from 23 rooms across various hospital settings. The objects sampled for microbial culture included beds, telephones, desks, chairs, cabinets, door handles, electronic devices, and medical equipment (Fig. 1). Swab samples were collected before and after disinfection to evaluate microbial presence and disinfection efficacy.

Following previously described methods,[23] disinfection was performed by closing the doors and windows of each room (without sealing), followed by automatic spraying of the disinfectant in 4 directions based on room volume. We used the PlaClin-Auto automatic PTHPM surface disinfector (CODESTERI Inc) and PlaClinSol disinfectant (CODESTERI Inc) containing 5.9% w/w hydrogen peroxide and additional undisclosed substances (Fig. 2). Real-time monitoring of hydrogen peroxide levels was conducted inside and outside the 23 rooms using Polytron 7000 hydrogen peroxide detectors (Draeger), ensuring safety throughout the study. Surface samples were collected before and after disinfection using sterile swabs to evaluate the presence of bacteria. The collected samples were cultured on 5% sheep blood agar plates and incubated at 37 °C for 24 hours. Gram staining of the bacterial colonies was performed to assist with identification. The bacterial species were then determined using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS) using a MALDI Biotyper and MALDI Biotyper software (version 2.3, Bruker Daltonics). A trained medical laboratory specialist identified the bacterial species.

Statistical analysis

The Wilcoxon rank-sum test was used to compare cultured bacteria on surfaces and materials before disinfection. The Wilcoxon signed-rank test was used to compare bacterial counts before and after disinfection; it was also used to compare the data before and after disinfection to evaluate differences between the manual and automatic disinfection methods. Manual disinfection data were based on the results of a previous study.[23] Bacterial viability, measured in colony-forming units (CFUs), was used for statistical analyses. All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc).

RESULTS

Cultured surfaces positive for microorganisms

Microorganisms cultured from 459 surfaces were classified as gram-positive or -negative bacteria and molds (Table 1).

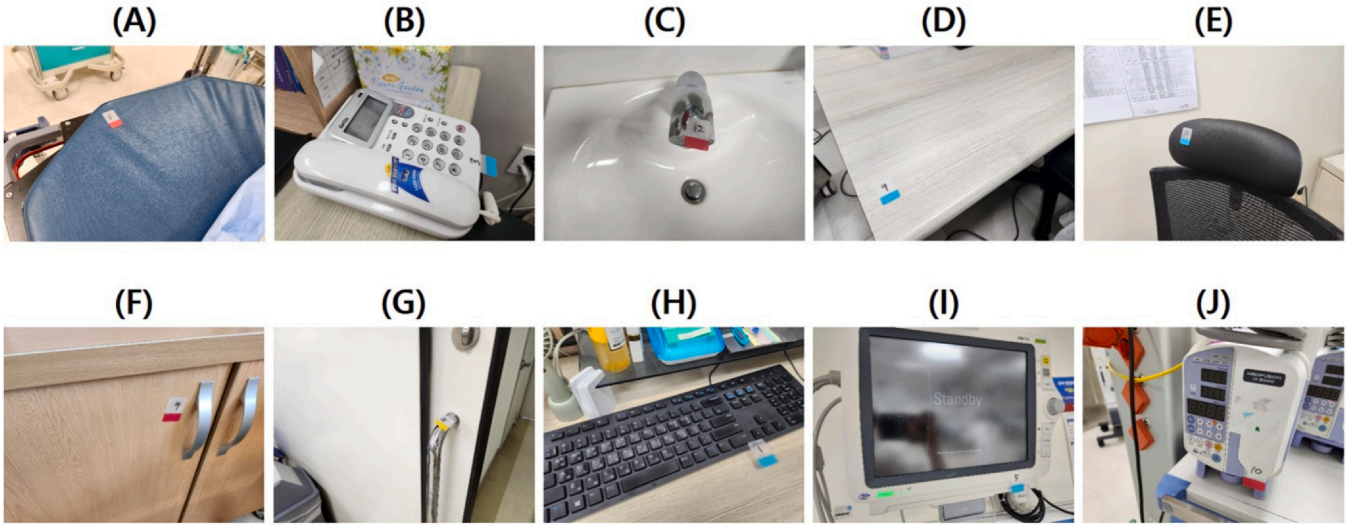

Fig. 1. Examples of objects sampled for microbial culture: (A) patient bed, (B) telephone, (C) water tap, (D) desk, (E) chairs, (F) cabinet, (G) door handle, (H) keyboard, (I) patient monitor, and (J) infusion pump.

Gram-positive bacteria were further categorized into *Bacillus* spp and cocci. Gram-positive bacilli and cocci were detected on 242 and 204 surfaces, respectively, before disinfection. After automatic PTHPM disinfection, they remained on 80 and 30 surfaces, respectively. The total number of surfaces that were culture-positive for gram-positive bacteria was 316, as surfaces positive for both *Bacillus* and cocci were counted as a single instance. Gram-negative bacteria were classified as rods, bacilli, or cocci. A total of 12 surfaces were positive for gram-negative bacilli before disinfection, whereas none were positive for gram-negative rods and cocci. After disinfection, no surfaces were culture-positive for gram-negative bacteria. Molds were detected on 25 surfaces before disinfection, and only 1 surface remained culture-positive for mold afterward. Subsequent analyses focused on gram-positive bacteria owing to the low prevalence of gram-negative bacteria and molds. Some bacterial species were identified through MALDI-TOF MS. Representative gram-positive bacilli were identified in the genus *Bacillus*, including *B cereus*, *B infantis*, *B megaterium*, *B simplex*, and *B circulans*, as well as *Paenibacillus glucanolyticus* and *Streptomyces* spp. Representative gram-positive cocci were identified as coagulase-negative *Staphylococcus*, species such as *S hominis*, *S capitis*, and *S aureus*, as well as *Micrococcus luteus* and *Kocuria rhizophila*. The gram-negative bacilli identified included *Acinetobacter* spp and *Pantoea* spp.

Table 1
Surfaces positive for bacteria and molds before and after disinfection using the automatic plasma-treated hydrogen peroxide mist disinfectant

		Number of culture-positive surfaces [Total: 459]	
		Before disinfection	After disinfection
Bacteria	Gram (+)	**316 [459]***	**110 [459]***
	Bacilli (+)	242	80
	Cocci (+)	204	30
	Gram (-)	**12 [459]**	**0 [459]**
	Rods (-)	0	0
	Bacilli (-)	12	0
	Cocci (-)	10	0
Mold	Mold	**25 [459]**	**1 [459]**
Total		**353 [459]**	**111 [459]**

Bold text indicates a higher-level category that includes the subordinate items listed below it.
*In the gram-positive bacterial count, bacilli (+) and cocci (+) were cultured together and counted as one surface when dual positivity was observed.

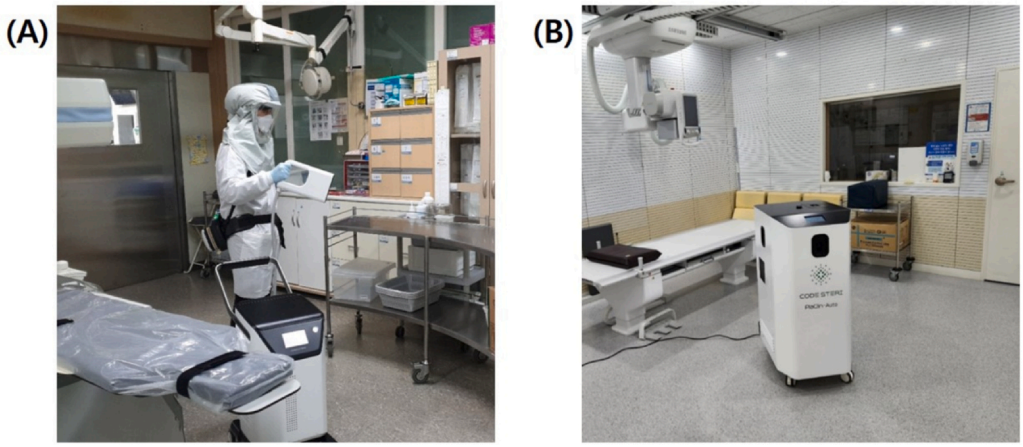

Fig. 2. Manual and automatic plasma-treated hydrogen peroxide (PTHPM) mist disinfection in a hospital environment using a PlaClin-Auto disinfector and disinfectant containing 5.9% w/w hydrogen peroxide: (A) Manual and (B) Automatic PTHPM disinfection.

Table 2
CFU values of gram-positive bacteria on surfaces in 23 rooms (3 types) before and after disinfection using an automatic plasma-treated hydrogen peroxide mist disinfectant

Room	No. of culture-positive surfaces [Total surfaces]	CFU, median (IQR)		CFU after disinfection	Difference in CFU, *P*-value	
		Before disinfection	After disinfection	Marked reduction, %*	Before disinfection†	Before-after disinfection‡
Hospital ward	**90 [151]**	**1.5(0-9)**	**0 (0-0)**	**80**	**.3266**	**< .0001**
1-patient	17 [20]	8.5(0-18.5)	0 (0-1)	88	.0801	.0006
4-patient	17 [22]	7(1-13)	0 (0-1)	71	.2159	.0004
Isolation	16 [23]	2(0-6)	0 (0-0)	75	.9584	.0002
Isolation (VRE)	6 [20]	1(0.5-1.5)	0(0-0)	100	.4747	.4082
Isolation (ICU)	7 [18]	1.5(0-10)	0(0-0)	100	.5475	.0156
Isolation (Dialysis)	11 [24]	0(0-3)	0(0-0)	64	.0166	.0218
Peritoneal dialysis	14 [24]	1(0-5)	0(0-0)	79	.1487	.0039
OPD	**164 [219]**	**2(0-9)**	**0(0-0)**	**86**	**.4915**	**< .0001**
CT	9 [15]	5(0-10)	0(0-0)	100	.5262	.0039
X-Ray	13 [16]	2(1-7)	0(0-0)	92	.8500	.0056
Examining (TB)	11 [14]	1(0-7)	0(0-0)	73	.4165	.0264
Examining (ID)	15 [21]	2(1-5)	0(0-0)	87	.8476	.0009
Examining (PED)	15 [16]	8.5(2-20)	0(0-0)	100	.0204	.0001
Examining (ENT)	17 [24]	2(0-5)	0(0-0)	82	.5935	< .0001
Examining (OT)	14 [24]	3.5(0-11.5)	0(0-0)	93	.7304	.0001
Examining (DENT)	15 [18]	4(0-12)	0(0-0)	93	.3709	.0003
Endoscopy (CM)	13 [15]	3(0-9)	0(0-0)	85	.7559	.0004
Endoscopy (GE)	18 [20]	1.5(0-14)	0(0-0)	89	.9757	< .0001
Treatment (GS)	11 [16]	1(0-3)	0(0-1)	73	.4037	.1250
Delivery (OBGY)	13 [20]	1.5(0-5)	0(0-1)	62	.6055	.0960
Emergency room	**62 [89]**	**2(0-10)**	**0(0-0)**	**85**	**.7921**	**< .0001**
Resuscitation	15 [23]	2(0-6)	0(0-0)	80	.4923	.0039
Pediatric	11 [24]	2(0-16)	0(0-0)	100	.8782	.0010
Critical care	18 [24]	4.5(0-17.5)	0(0-0)	89	.3697	< .0001
Triage	18 [18]	2.5(0-9.5)	0(0-0)	78	.9329	.0009
Total	**316 [459]**	**2(0-10)**	**0(0-0)**	**85**		**< .0001**

CFU, colony-forming unit; *CM*, chest medicine; *DENT*, dental; *ENT*, ear, nose, and throat; *GE*, gastroenterology; *GS*, general surgery; *ICU*, intensive care unit; *ID*, infectious disease; *IQR*, interquartile range; *OBGY*, obstetrics and gynecology; *OT*, ophthalmology; *PED*, pediatrics; *TB*, tuberculosis; *VRE*, vancomycin-resistant *Enterococcus*.
Bold text indicates a higher-level category that includes the subordinate items listed.
*When CFU = 0 before disinfection, values were excluded from the analysis if marked reduction in CFU was observed.
†The *P*-value is the difference in CFU before disinfection between the corresponding and other rooms (Wilcoxon rank-sum test).
‡The *P*-value is the difference in CFU before and after disinfection in each room (Wilcoxon signed-rank test).

Automatic PTHPM disinfection efficacy in 23 hospital rooms

The median CFU values (interquartile range [IQR]) of gram-positive bacteria in hospital wards, OPDs, and emergency rooms before disinfection were 1.5(0-9), 2(0-9), and 2(0-10), respectively (Table 2). After disinfection, the mean CFU values were 0(0-0) across all areas. The proportions of surfaces with a marked reduction in CFU were 80% in hospital wards, 86% in OPDs, and 85% in emergency rooms. Surfaces with 0 CFU before disinfection were excluded from analyses.

No significant differences were observed in CFU values before disinfection among the hospital wards ($P = .3266$), OPDs ($P = .4915$), and emergency rooms ($P = .7921$). Before disinfection, OPDs had the highest CFU values, followed by emergency rooms and hospital wards. However, the differences in CFU values before and after disinfection in each of the 23 rooms were highly significant ($P < .0001$), indicating effective disinfection.

Comparison of disinfection efficacy between automatic and manual PTHPM disinfection

The median CFU values (IQR) of gram-positive bacteria in hospital wards, OPDs, and emergency rooms before disinfection were 1.5(0-9), 2(0-9), and 2(0-10) for automatic disinfection and 1(0-7), 7 (2-26), and 5 (1-28) for manual disinfection, respectively (Table 3). After disinfection, the median CFU values were 0(0-0) for both automatic and manual disinfection.

After manual and automatic disinfection, 6 of the 23 rooms exhibited statistically significant differences in CFU values. The 6 rooms ($P < .05$) included a 4-patient room ($P = .0006$), VRE isolation rooms ($P = .0357$), CT rooms ($P = .0347$), OBGY delivery rooms ($P = .0011$), critical care units (10 beds, $P = .0367$), and triage rooms ($P = .0140$).

DISCUSSION

Various disinfection strategies have been developed to address the microbial contamination of environmental surfaces in health care settings. These strategies can be broadly categorized into manual cleaning performed by trained personnel and automated no-touch disinfection technologies that operate independently of human intervention.[7,24] To address the limitations of manual surface disinfection—such as variability in techniques, incomplete coverage, and inconsistent compliance with infection control guidelines—the adoption of automated disinfection systems, including those that utilize dry-mist technologies with chemical disinfectants, such as hydrogen peroxide, has increased; this has sparked discussion and scrutiny in both practical and academic contexts, in part owing to the limited availability of real-world randomized controlled trials and robust cost-effectiveness data.[22] Nevertheless, hydrogen peroxide vapor and dry mist systems reduce environmental contamination and health care-associated infection rates significantly in various settings and are increasingly being adopted in hospital environments as part of routine infection prevention strategies.[7,16,17]

Automated hydrogen peroxide vapor and aerosol mist systems have demonstrated high efficacy in eliminating pathogens from environmental surfaces, particularly when used for terminal disinfection following patient discharge. These no-touch technologies are increasingly employed to control outbreaks of resilient health care-associated pathogens, including *C difficile*, MRSA, and VRE.[25] In support of this, a 2009 hospital study showed that a dry-mist

Table 3
CFU values of gram-positive bacteria from surfaces in 23 rooms (3 types) between automatic and manual plasma-treated hydrogen peroxide mist disinfection

Room	No. of culture-positive surfaces, Manual*/Automatic [Total surfaces]	CFU manual disinfection, median (IQR)*		CFU automatic disinfection, median (IQR)		Difference in CFU after manual versus automatic disinfection, *P*-value†
		Before disinfection	After disinfection	Before disinfection	After disinfection	
Hospital ward	88/90 [151]	1(0-7)	0(0-0)	1.5(0-9)	0(0-0)	-
1-patient	17/17 [20]	10.5(3-31.5)	0(0-0)	8.5(0-18.5)	0(0-1)	.0617
4-patient	18/17 [22]	9.5(2-34)	0(0-0)	7(1-13)	0(0-1)	.0006
Isolation	8/16 [23]	0(0-2)	0(0-0)	2(0-6)	0(0-0)	.0676
Isolation (VRE)	11/6 [20]	0(0-3)	0(0-0)	1(0.5-1.5)	0(0-0)	.0357
Isolation (ICU)	12/7 [18]	2(0-4)	0(0-0)	1.5(0-10)	0(0-0)	1
Isolation (Dialysis)	10/11 [24]	0(0-3)	0(0-0)	0(0-3)	0(0-0)	.0621
Peritoneal dialysis	12/14 [24]	0.5(0-2.5)	0(0-0)	1(0-5)	0(0-0)	.0556
OPD	191/164 [219]	7(2-26)	0(0-0)	2(0-9)	0(0-0)	-
CT	13/9 [15]	4(1-83)	0(0-1)	5(0-10)	0(0-0)	.0347
X-Ray	16/13 [16]	7(2.5-65)	0(0-1)	2 (1-7)	0(0-0)	.3526
Examining (TB)	14/11 [14]	13.5(7-25)	0(0-0)	1(0-7)	0(0-0)	.5473
Examining (ID)	14/15 [21]	2(0-10)	0(0-0)	2 (1-5)	0(0-0)	.2283
Examining (PED)	22/15 [16]	10.5(2.5-19)	0(0-1)	8.5 (2-20)	0(0-0)	.3316
Examining (ENT)	16/17 [24]	3(1-8.5)	0(0-0)	2(0-5)	0(0-0)	.8775
Examining (OT)	15/14 [24]	7(1.5-38)	0(0-1)	3.5(0-11.5)	0(0-0)	.2239
Examining (DENT)	13/15 [18]	16.5(5-34)	0(0-0)	4(0-12)	0(0-0)	.3724
Endoscopy (CM)	15/13 [15]	100(32-103)	0(0-0)	3(0-9)	0(0-0)	.6497
Endoscopy (GE)	20/18 [20]	7(3-16)	0(0-1)	1.5(0-14)	0(0-0)	.6038
Treatment (GS)	18/11 [16]	5(1-16.5)	0(0-2)	1(0-3)	0(0-1)	.8784
Delivery (OBGY)	15/13 [20]	3(1-9)	0(0-0)	1.5(0-5)	0(0-1)	.0011
Emergency room	74/62 [89]	5(1-28)	0(0-0)	2(0-10)	0(0-0)	-
Resuscitation	16/15 [23]	1(0-5)	0(0-0)	2(0-6)	0(0-0)	.0702
Pediatric	22/11 [24]	24(5.5-38.5)	0(0-0)	2(0-16)	0(0-0)	1
Critical care	18/18 [24]	3.5(0.5-55.5)	0(0-0)	4.5(0-17.5)	0(0-0)	.0367
Triage	18/18 [18]	3.5(3-13)	0(0-0)	2.5(0-9.5)	0(0-0)	.0140

CFU, colony-forming unit; *CM*, chest medicine; *DENT*, dental; *ENT*, ear, nose, and throat; *GE*, gastroenterology; *GS*, general surgery; *ICU*, intensive care unit; *ID*, infectious disease; *IQR*, interquartile range; *OBGY*, obstetrics and gynecology; *OT*, ophthalmology; *PED*, pediatrics; *TB*, tuberculosis; *VRE*, vancomycin-resistant *Enterococcus*.
*Supplementary Table S1 data from previous manual plasma-treated hydrogen peroxide mist disinfection studies.
†The *P*-value corresponds to the difference in CFU after manual and automatic disinfection in each room (Wilcoxon signed-rank test).

hydrogen peroxide system achieves a 91% reduction in surface contamination compared with the 50% reduction observed with standard bleach cleaning, highlighting its potential as an effective alternative for *C difficile* decontamination.[10] Similarly, Shapey et al[3] reported that H_2O_2 mist significantly reduces environmental contamination in elderly care wards, surpassing the efficacy of routine manual cleaning. A more recent study in burn units has demonstrated reductions in MRSA contamination from 8.3% after manual cleaning to 2.8% following hydrogen peroxide fogging, along with complete elimination of VRE.[25] Reductions of approximately 98% in total bioburden and 6-log sporicidal activity using automated H_2O_2 systems have been reported, noting that the addition of ultraviolet disinfection provided no measurable benefit.[26] Collectively, these findings underscore the robust and broad-spectrum antimicrobial efficacy of automated hydrogen peroxide disinfection systems and support their integration into infection prevention protocols, particularly in high-risk environments, such as ICUs, isolation rooms, and outbreak settings.

Few studies have directly compared the disinfection efficacy of hydrogen peroxide mist when manually applied by trained personnel, allowing for targeted spraying in areas with potentially high bioburden, and automated systems that uniformly disperse disinfectants, regardless of the room layout. Manual misting requires less labor than conventional wipe-based cleaning but still necessitates human involvement and the use of appropriate personal protective equipment. Fully automated misting systems offer advantages in terms of consistency, labor savings, and safety, especially when human access is limited or variability must be minimized.[27] Health care environments are heterogeneous in terms of spatial complexity, functional requirements, and disinfection needs.

To determine optimal selection and deployment strategies for infection control in clinical settings, we evaluated the performance of an automated PTHPM method in various clinical settings—including hospital wards, OPDs, and emergency rooms—and compared the results with those from previous experiments involving manual hydrogen peroxide mist application at the same locations. Both methods reduced microbial contamination significantly, achieving complete eradication of gram-positive bacteria (CFU = 0) on high-touch surfaces. Notably, pre-disinfection median CFU values were the highest in OPDs, followed by emergency rooms and hospital wards, consistent with previously reported trends associated with high patient turnover in outpatient environments.[28,29] Importantly, no statistically significant difference in the disinfection efficacy was observed between manual and automated methods under standardized conditions, supporting the hypothesis that automated systems can match the effectiveness of experienced human operators.[30,31]

Overall, equivalence was confirmed at most sites, except for a few specific locations. For example, CFU reductions below 80% were observed in multibed rooms, dialysis and peritoneal units, delivery rooms, and triage areas. Moreover, statistically significant differences in residual contamination between the manual and automated methods were identified in 4-patient wards ($P = .0006$), VRE isolation rooms ($P = .0357$), and ER triage areas ($P = .0140$). These environments are typically characterized by large spatial volumes, complex geometries, and multiple pieces of medical equipment or other obstacles that may hinder uniform mist distribution. Such challenges highlight the importance of tailoring disinfection approaches to the spatial context, which may involve extending the treatment time, deploying multiple devices, enhancing air circulation, or supplementing automated spraying with targeted manual applications.

The interpretation of our results should be viewed in light of few inherent study limitations. The narrow scope of this investigation—restricted to diverse teaching hospital environments—may limit the generalizability of the findings regarding the comparative efficacy of the 2 disinfection methods when applied to other health care settings (eg, smaller clinics, long-term care facilities) or non-medical

spaces. Furthermore, while the study was conducted in a realistic setting to enhance practical relevance, the necessity of working within a dynamic, operating hospital environment introduced complexities. Specifically, the challenges in perfectly controlling or replicating all environmental variables inherent to daily hospital workflow necessitate caution regarding the reproducibility of these exact field measurements. A final critical point concerns the evaluation of the manual disinfection method. Although a standardized operating procedure was employed, the observed efficacy remains intrinsically dependent upon human factors, including the technique, fatigue level, and level of expertise of the administering personnel. Despite our best efforts to control this, the inherent inter-operator variability makes the standardization of manual processes a persistent methodological challenge.

Automated PTHPM systems operate using preprogrammed protocols that ensure consistency, reduce manual workload, and maintain high safety standards through the real-time monitoring of hydrogen peroxide concentrations,[32] making them particularly well-suited for high-risk and labor-intensive environments, such as large operating theater complexes with multiple operating rooms and high-capacity ICUs with multiple isolation rooms.[31] However, their adoption is limited by high costs and logistical constraints, making manual disinfection a viable option in resource-limited settings. In this context, the selection of a disinfection method should not be based solely on efficacy but should also consider operational feasibility, safety, and long-term cost-effectiveness.

Future studies should assess the economic sustainability of automated PTHPM systems, their role in reducing health care-associated infections, and the potential benefits of integrating automated and manual protocols. Health care facilities can develop evidence-based, context-sensitive strategies to optimize outcomes by addressing these considerations.

CONCLUSIONS

Automated hydrogen peroxide mist disinfection demonstrated a similar antimicrobial efficacy to that of manual application by trained personnel under real-world hospital conditions. However, in larger spaces, geometrically complex environments, or areas with physical obstructions that may interfere with the mist distribution, the performance of automated systems may be suboptimal. Further research is warranted to explore strategies for enhancing disinfection efficacy in challenging settings, including adjustments in misting protocols, device positioning, and potential integration with manual methods.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at doi:10.1016/j.ajic.2025.11.012.

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