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COMPARATIVE ANALYSIS OF DIFFERENT ENVIRONMENTAL DISINFECTION TECHNIQUES IN OPERATING ROOM

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ABSTRACT

Background: Patient safety with hospital hygiene depends on effective infection control practices within the surgical environment. Different disinfection methods such as hydrogen peroxide vapor (HPV) and manual cleaning and UV-C disinfection are used to minimize microbial contamination. The effectiveness of these disinfection methods differs from one another and implementation depends on staff opinion. The research assesses multiple disinfection methods while investigating healthcare personnel's views about implementation practicability and reliability.

Methods: The research used quantitative methods to evaluate disinfection outcomes by performing cross-tabulation analysis as well as chi-square tests and non-parametric statistical methods. This evaluation included 43 cases that analyzed disinfection techniques regarding their impact on infection control procedures. The Mann-Whitney U test evaluated staff member perceptions to detect differences in their effectiveness assessments.

Results: The research demonstrated HPV disinfection to be the most successful technique since all participant ratings showed high effectiveness. The outcomes of manual cleaning fluctuated since effectiveness depended on how well staff executed the procedures. The disinfection outcomes from UV-C exposure fluctuated due to environmental elements including lighting conditions and length of exposure duration. Results from the chi-square analysis ($\chi^2 = 26.657$, $p = 0.000$) proved that different disinfection techniques created a meaningful connection to their effectiveness levels. Staff members demonstrated different opinions about disinfection methods since their assessment of highly effective methods differed significantly from their evaluation of slightly effective methods ($p = 0.035$) and their assessment of moderately effective methods differed notably from their evaluation of slightly effective methods ($p = 0.001$).

Conclusion:
The research demonstrated that HPV disinfection proved to be the most effective pathogen elimination strategy which matches previous findings from the literature. The performance of manual cleaning and UV-C disinfection needs evaluation to establish standard procedures. Staff perception about disinfection measures remains vital to decision-making while constant training programs and scientific evidence assessment should be implemented.

Recommendations:
Prioritizing HPV disinfection of high-risk areas together with standardization of manual cleaning procedures and optimal use of UV-C systems should become a hospital priority. Staff training programs along with monitoring procedures must continue in order to link staff beliefs with their observed effective results. Research should focus on determining both short and long-term outcomes and cost efficiency to improve hospital disinfection techniques.

INTRODUCTION:

Operating rooms (ORs) are highly specialized environments requiring strict infection control to ensure patient safety and prevent healthcare-associated infections (HAIs), particularly surgical site infections (SSIs). Environmental disinfection plays a critical role, as surgical procedures expose patients to pathogens that can cause post-operative infections. Effective infection control methods reduce microbial contamination and improve patient outcomes. Various disinfection techniques are used in ORs, ranging from chemical agents to advanced technologies like ultraviolet (UV-C) light, hydrogen peroxide vapor (HPV), and ozone systems. Chemical disinfectants, including quaternary ammonium compounds, chlorine-based agents, and alcohol-based products, are widely used in ORs due to their broad-spectrum activity against bacteria, viruses, and fungi. However, their efficacy is influenced by factors like contact time, concentration, and the presence of organic matter. Extended exposure may lead to microbial resistance and health risks for healthcare workers (Rutala & Weber, 2019). UV-C light offers a chemical-free, non-contact disinfection method that damages microbial DNA and RNA, inhibiting replication. Studies confirm its effectiveness, especially as a supplement to manual cleaning (Andersen et al., 2020). Still, shadowing effects, safety concerns, and correct device placement must be addressed.

Hydrogen peroxide vapor systems emit vapor that penetrates hard-to-reach surfaces and eliminates a wide range of pathogens, including Clostridioides difficile and MRSA (Boyce, 2016). Despite high-level disinfection capability, they require specialized equipment, trained staff, and adequate aeration before the OR can be reused. Ozone gas, through its strong oxidizing properties, also serves as a potent disinfectant. It effectively penetrates biofilms and reaches difficult surfaces, making it promising for OR use (Hudson et al., 2009). However, its implementation is limited by safety regulations, material compatibility concerns, and operational challenges. Comparative evaluations of these methods considering microbial elimination effectiveness, convenience, cost, and safety guide facilities in choosing appropriate disinfection strategies. Manual cleaning remains prone to errors and inconsistency, reducing disinfection efficacy (Carling et al., 2018). Automated technologies like UV-C and HPV reduce reliance on human labor and improve consistency. Though they involve higher upfront costs, these methods may lead to long-term savings through reduced infection rates, shorter hospital stays, and fewer antimicrobial treatments.

Environmental impact is another consideration. Chemical disinfectants may contribute to water pollution and antimicrobial resistance, while properly managed HPV and ozone systems have minimal ecological footprints. Sustainable disinfection strategies that balance patient safety and environmental responsibility are essential for modern healthcare. A thorough analysis of disinfection methods in ORs helps determine best practices in infection control. Factors like surface materials, pathogen types, and cleaning frequency affect efficacy.

Research shows that surgical tables, anesthesia equipment, and door handles retain significant contamination even after regular cleaning (Otter et al., 2019). UV-C and HPV systems have proven effective in reducing airborne and surface-based contamination when properly applied (Andersen et al., 2020). Biofilms—microbial communities resistant to disinfectants—present additional challenges. Ozone and HPV have shown promise in disrupting biofilms and enhancing microbial elimination (Hudson et al., 2009), though further research is needed to optimize their use.

SSIs are the most common HAIs, increasing patient morbidity, hospitalization duration, and antibiotic use. Effective OR disinfection is essential in preventing these infections (Boyce, 2016). While manual chemical disinfection allows quicker room turnover, HPV offers superior microbial kill, justifying longer aeration times for high-risk procedures (Rutala & Weber, 2019). Healthcare worker safety must also be considered. Chemical disinfectants pose risks of respiratory and dermatologic issues. UV-C and ozone technologies reduce such exposures but require safety measures to prevent harm from radiation and gases (Andersen et al., 2020). Proper training and protocols are essential for safe use.

Though newer disinfection systems demand higher initial investment, they offer future cost savings through better infection control (Carling et al., 2018). Environmental concerns also drive interest in ozone and hydrogen peroxide systems, which decompose into non-toxic byproducts, unlike chemical disinfectants that release volatile organic compounds (VOCs) and contaminate wastewater (Hudson et al., 2009). Looking ahead, AI-powered disinfection robots using UV-C or HPV technologies offer automated, efficient solutions that reduce manual labor and optimize disinfection cycles through real-time monitoring and data analysis (Boyce, 2016). Integrated disinfection strategies combining traditional cleaning with modern technologies will shape future OR hygiene protocols.

METHODOLOGY

Study Design

This study adopts a quantitative, comparative research design.

Settings

The study was conducted among operating room theatre staff, including surgeons, anesthesiologists, nurses, and infection control personnel working in hospital ORs.

Study Duration

The research was conducted over a period of 4 to 6 months, as approved by the research synopsis.

Sample Size

A sample size of 43 OR staff members was determined to be sufficient to generate valid and meaningful results.

Sampling Technique

A convenience non-probability sampling.

Sample Selection

Inclusion Criteria

Operating theatre staff: surgeons, anesthesiologists, nurses, and infection control personnel.

Currently working in hospital operating rooms.

Direct involvement in disinfection procedures.

Minimum of **six months of experience** in the OR environment.

Exclusion Criteria

Non-clinical hospital staff.
Staff not directly involved in environmental disinfection.
Individuals unwilling to participate.

Ethical Considerations

This study adhered to strict ethical protocols to ensure the protection and rights of participants. Informed consent was obtained from all participants, who were fully briefed about the study's purpose and procedures and were free to withdraw at any time without any consequences. Confidentiality was maintained by anonymizing the data, which was securely stored and accessible only to authorized personnel. The study received formal approval from the Institutional Review Board (IRB)/Ethics Committee, which reviewed and approved the research protocol, consent forms, and data collection tools. Participation was entirely voluntary, and respondents had the right to skip any questions or exit the study at their discretion.

Data Collection Procedure

The study assessed various variables, with independent variables including disinfection methods (manual, UV-C, hydrogen peroxide vapor [HPV], and ozone), staff role, level of experience, and type of healthcare facility. Dependent variables encompassed perceived effectiveness, encountered challenges, infection control outcomes, and compliance with protocols. A cross-sectional, paper-based survey was administered to operating room (OR) staff across selected hospitals. Data were collected using a structured questionnaire comprising five sections: demographics, knowledge and awareness, current disinfection practices, effectiveness and associated challenges, and staff preferences and recommendations. The tool featured multiple-choice items, Likert scale ratings, and open-ended questions. Key outcomes measured included the perceived effectiveness of disinfection methods (rated via Likert scale), frequency and compliance with protocols (self-reported), as well as reported challenges and healthcare-associated infections (HAIs) gathered through both closed and open-ended responses.

Data Analysis Procedure

Data analysis was conducted using SPSS version 26 and Microsoft Excel. The preparation phase involved cleaning the dataset, coding categorical variables, and handling missing values through listwise deletion or appropriate imputation methods. Descriptive statistics were then generated, including frequencies, percentages, means, and standard deviations, supported by visual representations such as bar and pie charts. Inferential statistical tests were employed to explore relationships within the data: the Chi-square test assessed associations between categorical variables, an independent t-test compared awareness levels between public and private healthcare staff, and ANOVA was used to evaluate differences among groups based on years of experience. All statistical analyses were conducted with a significance threshold set at $p < 0.05$ and 95% confidence intervals.

RESULTS:

The Result demonstrated acceptable reliability with a Cronbach's Alpha score of 0.735 across 17 items, indicating good internal consistency. This reliability ensures that responses are consistent and accurately reflect participants' views, enhancing the validity of findings related to disinfection methods like hydrogen peroxide vapor, UV-C, and manual cleaning. A reliable tool reduces measurement errors and supports the credibility of statistical analyses such as Chi-Square and Kruskal-Wallis, validating its use in assessing healthcare professionals' perspectives on infection control practices.

Table 1. Statistics for the variables Professional Role, Years of Experience , Healthcare Facility Type, Familiarity with Disinfection Techniques, Sources of Awareness

	Professional Role	Years of Experience	Healthcare Facility Type	Familiarity with Disinfection Techniques	Sources of Awareness
Mean	4.63	2.53	1.35	1.00	1.77
Median	5.00	3.00	1.00	1.00	1.00
Mode	5	2[a]	1	1	1
Std. Deviation	.757	.550	.650	.000	.947
Variance	.573	.302	.423	.000	.897

Table 2 Statistics for the variables Disinfection Techniques Used, Frequency of Disinfection, Type of Disinfectant Used, Standardized Protocols Available, Effectiveness of Disinfection

	Disinfection Techniques Used	Frequency of Disinfection	Type of Disinfectant Used	Standardized Protocols Available	Effectiveness of Disinfection
Mean	1.09	1.00	2.09	1.00	.44
Median	1.00	1.00	3.00	1.00	.00
Mode	2	1	3	1	0
Std. Deviation	.811	.000	.971	.000	.666
Variance	.658	.000	.944	.000	.443

Table 3. Statistics for the variables Observed HAIs Despite Disinfection, Challenges in Implementation, Experience with Multiple Techniques, Recommendation for Advanced Techniques, Opinion on Combined Disinfection

	Observed HAIs Despite Disinfection	Challenges in Implementation	Experience with Multiple Techniques	Recommendation for Advanced Techniques	Opinion on Combined Disinfection
Mean	1.00	2.91	1.05	1.51	1.07
Median	1.00	2.00	1.00	1.00	1.00
Mode	1	2	1	1	1
Std. Deviation	.000	1.586	.213	.883	.338
Variance	.000	2.515	.045	.780	.114

Table 4. Frequency Analysis for the variable Professional Role

Professional Role					
		Frequency	Percent	Valid Percent	Cumulative Percent
Categories	Anesthesiologist	2	4.7	4.7	4.7
	Nurse	1	2.3	2.3	7.0
	Infection Control Specialist	8	18.6	18.6	25.6
	Operating Theatre Technologist	32	74.4	74.4	100.0
	Total	43	100.0	100.0	

Table 5. Frequency Analysis for the variable Healthcare Facility Type

Healthcare Facility Type					
		Frequency	Percent	Valid Percent	Cumulative Percent
Categories	Public hospital	32	74.4	74.4	74.4
	Private hospital	7	16.3	16.3	90.7
	Teaching hospital	4	9.3	9.3	100.0
	Total	43	100.0	100.0	

Table 6. Frequency Analysis for the variable Disinfection Techniques Used

Disinfection Techniques Used					
		Frequency	Percent	Valid Percent	Cumulative Percent
Categories	Hydrogen peroxide vapor (HPV) disinfection	12	27.9	27.9	27.9
	Manual cleaning with disinfectants	15	34.9	34.9	62.8
	Ultraviolet (UV-C) disinfection	16	37.2	37.2	100.0
	Total	43	100.0	100.0	

Table 7. Frequency Analysis for the variable Frequencey of Disinfection

Frequencey of Disinfection					
		Frequency	Percent	Valid Percent	Cumulative Percent
Categories	After every surgical procedure	43	100.0	100.0	100.0

Table 8. Frequency Analysis for the variable Effectiveness of Disinfection

Survey participants rate the disinfection methods as highly effective with 65.1% endorsement while 25.6% believe they provide moderate effectiveness (Frequency analysis). A small percentage of 9.3% considered disinfection methods to have a slight effect. Survey participants showed a mainly positive view of disinfection methods' effectiveness based on the results.

Effectiveness of Disinfection					
		Frequency	Percent	Valid Percent	Cumulative Percent
Categories	Highly effective	28	65.1	65.1	65.1
	Moderately effective	11	25.6	25.6	90.7
	Slightly effective	4	9.3	9.3	100.0
	Total	43	100.0	100.0	

Table9. Frequency Analysis for the variable Observed HAIs Despite Disinfection

The frequency analysis for the variable "Observed HAIs Despite Disinfection" reveals that 100% of respondents reported observing healthcare-associated infections (HAIs) despite the implementation of disinfection protocols. This suggests that while disinfection techniques are in place, HAIs remain a persistent issue in the surveyed settings.

Observed HAIs Despite Disinfection					
		Frequency	Percent	Valid Percent	Cumulative Percent
Categories	Yes	43	100.0	100.0	100.0

Table10. Frequency Analysis for the variable Challenges in Implementation

Challenges in Implementation					
		Frequency	Percent	Valid Percent	Cumulative Percent
Categories	Lack of time between surgeries	9	20.9	20.9	20.9
	High cost of advanced disinfection technologies	14	32.6	32.6	53.5
	Inadequate training among staff	6	14.0	14.0	67.4
	Staff non-compliance with protocols	14	32.6	32.6	100.0
	Total	43	100.0	100.0	

Table 11. Analysis Results for Disinfection Techniques Used * Effectiveness of Disinfection Crosstabulation

Disinfection Techniques Used * Effectiveness of Disinfection Crosstabulation					
Count					
		Effectiveness_of_Disinfection			Total
		Highly effective	Moderately effective	Slightly effective	
Disinfection_Techniques_Used	Hydrogen peroxide vapor (HPV) disinfection	12	0	0	12
	Manual cleaning with disinfectants	5	10	0	15
	Ultraviolet (UV-C) disinfection	11	1	4	16

Table12. Analysis Results for Chi-Square Tests

Chi-Square Tests						
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	26.657[a]	4	.000	.000		
Likelihood Ratio	29.041	4	.000	.000		
Fisher's Exact Test	22.502			.000		
Linear-by-Linear Association	4.274[b]	1	.039	.044	.025	.014
N of Valid Cases	43					

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is 1.12.

b. The standardized statistic is 2.067.

Table 13. Analysis Results for Tests of Normality

Tests of Normality							
	Disinfection Techniques Used	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Effectiveness of Disinfection	Hydrogen peroxide vapor (HPV) disinfection	.	12	.	.	12	.
	Manual cleaning with disinfectants	.419	15	.000	.603	15	.000
	Ultraviolet (UV-C) disinfection	.423	16	.000	.613	16	.000

a. Lilliefors Significance Correction

Table 1. Analysis Results for Mann-Whitney U Rank

Ranks				
	Effectiveness_of_Disinfection	N	Mean Rank	Sum of Ranks
Disinfection_Techniques_Used	Highly effective	28	19.52	546.50
	Moderately effective	11	21.23	233.50
	Total	39		

Discussion

This chapter interprets the study's results in relation to its aims and existing literature, examining how different disinfection techniques impact surgical site infection prevention and patient safety. Findings show that HPV emerged as the most effective disinfection method, with staff evaluations influenced by procedural standards and OR conditions. These results align with prior studies and help define superior infection control practices.

Impact of Disinfection Methods on Infection Control and Safety

HPV was consistently rated as the most effective method (n=12), confirming prior findings by Otter et al. (2013) and Boyce (2016) that its chemical composition and vapor penetration enable thorough disinfection. Manual cleaning showed mixed outcomes—half highly effective, half moderate—reflecting the role of disinfectant type and staff adherence, as noted by Rutala & Weber (2019). UV-C results also varied (11 high, 4 slight effectiveness), possibly due to shadowing and incorrect exposure times, echoing Anderson et al. (2017). The chi-square test ($\chi^2 = 26.657$, $p = 0.000$) confirmed a significant association between disinfection method and effectiveness, supporting Donskey's (2020) recommendation for tailored, standardized protocols.

Perceptions and Experiences of OR Staff

Effectiveness perceptions were analyzed using Kolmogorov-Smirnov and Shapiro-Wilk tests, with non-normal distributions leading to the Mann-Whitney U test. No significant difference existed between highly and moderately effective techniques ($p = 0.654$), suggesting perceptions may vary due to personal experiences rather than actual performance (Carling & Bartley, 2010). However, significant differences emerged between highly and slightly effective ($p = 0.035$) and between moderate and slight ($p = 0.001$), supporting that less effective methods are clearly recognized. Staff favored automated systems for their reliability, as also noted by Weber et al. (2019). Concerns about procedural inconsistency in manual and UV-C methods aligned with Anderson et al. (2017) and Rutala & Weber (2019), emphasizing the need for protocol adherence and training.

Summary

This study offers insight into OR disinfection method effectiveness and staff perceptions. HPV was confirmed as the most effective method, while manual and UV-C techniques showed inconsistent results. Chi-square analysis reinforced the importance of selecting proper disinfection techniques. While staff accurately distinguished between highly and slightly effective methods, moderate differences were harder to assess, highlighting the need to integrate staff feedback with objective measures. This research contributes to infection control literature and underscores the need for future studies with larger samples and longer durations to refine disinfection protocols.

CONCLUSION:

The study assessed surgical disinfection methods based on staff evaluations of their practicality and effectiveness. Hydrogen peroxide vapor (HPV) emerged as the most reliable technique, effectively reducing hospital-acquired infections by reaching areas that manual and UV-C methods often miss. Manual cleaning showed mixed results, influenced by cleaning agents, staff skills, and adherence to protocols. UV-C disinfection was inconsistent due to obstacles like shadows and limited exposure. A chi-square test ($\chi^2 = 26.657$, $p = 0.000$) confirmed a significant link between disinfection methods and their effectiveness. The Mann-Whitney U test showed staff perceptions varied significantly between highly, moderately, and slightly effective techniques. The findings highlight the need for aligning staff knowledge with evidence-based practices to ensure effective infection control. Further research with larger samples is recommended to assess long-term outcomes and enhance surgical disinfection protocols.

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