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Impact of Environmental Hygiene Interventions on Healthcare-Associated Infections and Patient Colonization: A Systematic Review

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Abstract

Background: Healthcare-associated infections (HAIs) are an important concern in medical settings, as they can increase patient morbidity and mortality, prolong hospital stays, and escalate healthcare costs. Environmental hygiene and cleaning play a crucial role in controlling these infections, particularly in avoiding the spread of multidrug-resistant organisms (MDROs).Aim: To investigate the effect of environmental hygiene interventions on HAIs & case colonization. Patients and methods: This systematic review followed PRISMA guidelines, searching PubMed, Embase, Cochrane Library, Web of Science, & Scopus without date or language restrictions. Inclusion criteria encompassed RCTs, prospective cohorts, and before-after studies evaluating hygiene interventions in healthcare settings, focusing on HAIs, colonization, and microbial burden. Risk of bias has been evaluated utilizing the Cochrane RoB tool. Results: From 635 records, 8 studies (3 RCTs, 5 before-after) were included, involving mechanical (e.g., pulsed-xenon UV, filters), chemical (e.g., copper surfaces, hydrogen peroxide), and human factors interventions. Over half demonstrated significant reductions in HAIs or colonization (e.g., MRSA, VRE, C. difficile), with many reducing environmental bioburden. Heterogeneity in designs, microorganisms, and controls limited meta-analysis; most studies were high quality but lacked true controls. Conclusion: Environmental hygiene interventions effectively reduce HAIs and colonization, particularly for environmentally persistent pathogens like VRE. However, study variability underscores the need for standardized, multicenter RCTs to strengthen evidence and guide infection control policies.

Keywords: *Patient Colonization, Environmental Hygiene, Healthcare-Associated Infections, Systematic Review.*

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Introduction

HAIs are a significant concern in medical settings, as they can increase cases death and morbidity, prolong hospital stays, and escalate healthcare costs **(1)**.

Environmental cleaning and hygiene have a critical role in controlling these infections, particularly in avoiding the transmission of multidrug-resistant organisms (MDROs) (Al-Taie & Khattak, 2024). **(2)**.

Hospitals serve as reservoirs for pathogens, and frequently touched surfaces can harbor infectious agents, contributing to HAIs **(1,3)**.

There are various strategies deployed to enhance hygiene and reduce infection rates, including routine cleaning and disinfection of surfaces, which are vital in both intensive and non-intensive care units **(4)**.

The efficacy of these interventions has been demonstrated, for instance, through the increased microbiological cleanliness achieved in Tanzanian hospitals following a targeted educational intervention **(5)**.

Such initiatives not only improve cleanliness but can also sustain long-term infection control by implementing proper training, monitoring, and feedback mechanisms **(6)**.

Furthermore, innovative approaches like probiotic-based sanitation (PBS) offer promising alternatives to traditional disinfectants by using probiotics to outcompete harmful pathogens, thereby reducing HAIs without exacerbating antimicrobial resistance or environmental pollution **(3)**.

Therefore, integrating these and other advanced strategies like artificial intelligence for monitoring and optimizing hygiene practices has the potential to significantly enhance infection control and case safety in healthcare settings **(7)**.

The goal of this systematic review to examine the influence of environmental hygiene interventions on HAIs & case colonization.

Methods

This systematic review has been performed in accordance with the Preferred Reporting Items for Systematic Reviews & Meta-Analyses (PRISMA) guidelines.

Search Strategy

Electronic searches have been carried out in multiple databases, involving PubMed/MEDLINE, Embase, Cochrane Library, Web of Science, & Scopus. Gray literature was not systematically searched, but reference lists of involved research & relevant reviews were hand-searched for additional eligible articles.

The strategy of the investigation applied a combination of Medical Subject Headings (MeSH) terms & free-text keywords associated with the PICO framework (Population: healthcare patients; Intervention: environmental hygiene/cleaning/disinfection; Comparator: standard care or no intervention; Outcome: HAIs, colonization, microbial burden). Key search terms included "healthcare-associated infections," "hospital-acquired infections," "patient colonization," "environmental hygiene," "disinfection," "cleaning intervention," "ultraviolet disinfection," "copper surfaces," "hydrogen peroxide," "probiotic cleaning," "multidrug-resistant organisms,"

"Clostridium difficile," "MRSA," and "VRE," combined with Boolean operators (AND/OR). No language or date filters were applied during the initial search. An example PubMed search string was: ("environmental hygiene" OR "surface disinfection" OR "hospital cleaning") AND ("healthcare-associated infections" OR "HAI" OR "patient colonization") AND ("intervention" OR "trial" OR "study").

Inclusion criteria: Types of studies: Randomized controlled trials (RCTs), prospective cohort research, before-and-after studies, or quasi-experimental designs evaluating environmental hygiene interventions, **participants:** Patients in healthcare settings, involving hospitals, intensive care units (ICUs), burn units, hematology units, or nursing homes, where healthcare-associated infections (HAIs) or patient colonization with pathogens were assessed, **interventions:** Any environmental hygiene intervention aimed at reducing microbial burden, HAIs, or patient colonization. Interventions were categorized as mechanical, chemical, or human factors. Studies must have reported pre- and post-intervention outcomes or compared intervention groups to controls **and comparators:** Studies with or without control groups were included. Controls could include standard cleaning practices, no intervention, or baseline periods before intervention implementation and **outcomes:** Primary outcomes were rates of HAIs and/or case colonization with microorganisms like vancomycin-resistant enterococci (VRE), Clostridium difficile (C. difficile), multidrug-resistant organisms (e.g., Pseudomonas aeruginosa, methicillin-resistant Staphylococcus aureus (MRSA), Acinetobacter baumannii, extended-spectrum beta-lactamase [ESBL] Enterobacteriaceae), or invasive fungal infections. Secondary outcomes included reductions in environmental bioburden and any reported statistical significance.

Exclusion criteria: researches have been excluded if they were case reports, reviews, editorials, animal studies, or focused solely on hand hygiene without an environmental component. Non-English language publications, studies without full-text availability, or those lacking quantifiable outcomes on HAIs or colonization were also excluded.

Study Selection: Two independent reviewers evaluated titles and abstracts for relevance according to established eligibility criteria. Full-text articles of possibly suitable research have been obtained and evaluated for inclusion. Disagreements have been resolved via discussion or by consulting a 3rd evaluator. The process of research choice is demonstrted in the PRISMA flowchart (Figure 1).

Data Extraction: Information from the involved research was independently extracted by 2 reviewers utilizing a standardized form. Extracted items involved study ID, design, title, intervention type, control (if any), microorganisms studied, baseline characteristics (e.g., setting, sample size), results (e.g., rates of HAIs/colonization pre- and post-intervention, total reduction, statistical significance), and any confounding factors adjusted for (e.g., hand hygiene compliance, antimicrobial use, seasonality). Differences in information extraction have been resolved via consensus.

Risk of Bias Assessment

The potential for bias in the researches that were involved has been assessed utilizing the Cochrane Risk of Bias Tool (RoB 1.0) for RCTs, examining domains including allocation concealment, random sequence generation, outcome assessment blinding, personnel and participant blinding, selective reporting, incomplete result information, and additional biases. For non-randomized researches (e.g., before-and-after designs), a modified version of the RoB

tool was employed, concentrating on performance bias, selection bias, attrition bias, detection bias, & reporting bias. Each domain has been assessed as low, high, or unclear risk. The total quality of the research has been classified as high if the majority of domains exhibited a low risk. The outcomes of the risk of bias are displayed in a summary table (Table 2) and a graph (Figure 2).

Results

Search Results:

A total of 635 investigations has been discovered during the initial database exploration. After eliminating duplicate research, 167 unique articles are subject to further assessment. This evaluation process involved abstracts and titles, resulting in the recognition of 25 researches for comprehensive full-text assessment. Ultimately, eight researchers agreed to the established inclusion criteria. The PRISMA flowchart in **Figure 1** illustrates the choice process visually.

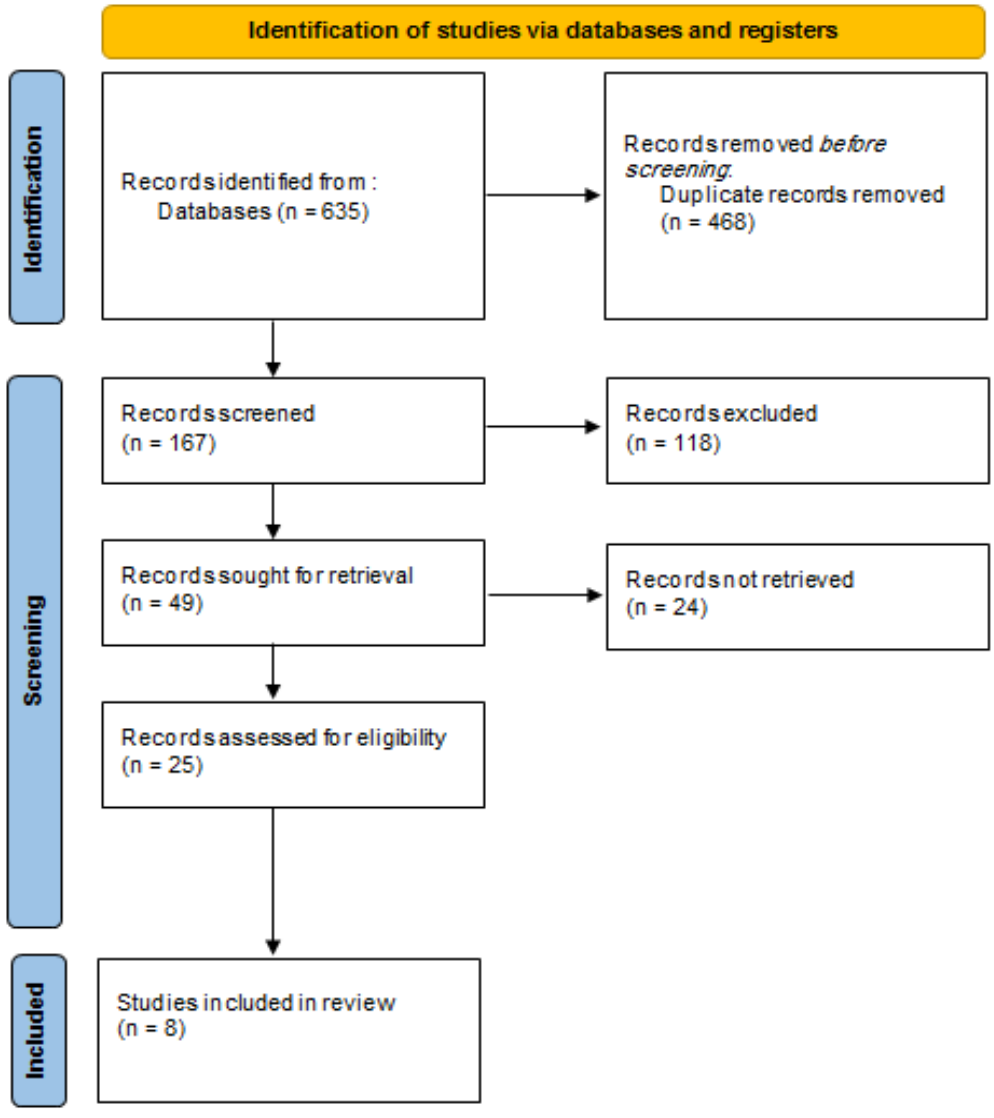

Figure 1: PRISMA Flow Chart for the Process of Research Choice.

Baseline characteristics of our involved research: Eight studies, including three prospective studies, only three randomized controlled trials, and the remaining were prospective before-and-after studies. Most of our included studies had no control group. More details about our involved research were represented in Table 1.

Study ID	Study design	Study title	Intervention	control	Micro-organisms studied for colonization
Vianna et al 2016	Prospective prior to and following	Effect of pulsed xenon UV light on the	Mechanical	No	MRSA, *C. difficile*, VRE

	research	frequency of infections acquired in a community hospital			
Özen et al 2016	Retrospective prior to and following research	A quasi-experimental investigation evaluating the efficacy of portable high-efficiency particulate absorption filters in avoiding infections among hematology cases throughout construction.	Mechanical	No	Invasive fungal infections
Green et al 2017	Prospective prior to and following research	Pulsed-xenon UV light disinfection in a burn unit: Effects on environmental bioburden, gaining of MDROs, & healthcare-related illnesses	Mechanical	No	ESBL Enterobacteriaceae, *C. difficile*, MDR[b] *P. aeruginosa*, MRSA[c], *S. maltophilia*
Kovach et al 2017	Prospective prior to and following research	Assessment of an ultraviolet room cleaning technique to reduce infection, microbial burden, & hospitalization rates in nursing homes	Mechanical	No	N/A
Kim et al	Before & following	Prospective cohort research	Chemical	No	*C. difficile*, *A. baumannii*, VRE,

2018	prospective	was conducted in a high-incidence setting to investigate the effectiveness of environmental disinfection using photocatalysts as a further measure to limit the spread of methicillin-resistant Staphylococcus aureus.			MRSA
Salgado et al 2013	RCTs	In the ICU, the prevalence of healthcare-acquired infections is decreased by the presence of copper surfaces.	Chemical	Rooms without copper	VRE, MRSA
Ray et al 2017	Randomized controlled trial	to determine the impact of an environmental disinfection intervention on the prevalence of Clostridium difficile infection associated with healthcare-, a randomized controlled trial was conducted across multiple treatment centers.	Human factors	Disposable bleach wipes for terminal & daily disinfection, bleach, frequent following up	*C. difficile*
Boyce	RCTs	For the	Chemical	Quaternary	MRSA, *C.*

et al 2017		purpose of comparing the effects of an enhanced H2O2 disinfectant with a quaternary ammonium-based disinfectant on surface pollution & health care results, a prospective cluster-controlled crossover experiment is being conducted.		ammonium compounds (bleach for *C. difficile* rooms)	*difficile*, VRE

Table 1: Baseline Characteristics of Our Involved Researchers

MRSA multidrug-resistant S.aures; MDR multidrug resistant, VRE vancomycin-resistant enterococci

Risk of Bias of Our Involved Studies:

Regarding our eight involved researches, Most of our included studies had high quality according to the ROB1 tool. Our RCTs were low risk regarding all ROB1 domains. A risk of bias summary and graph are provided in Table 2 & Figure 2.

Table 2: Risk of bias summary.

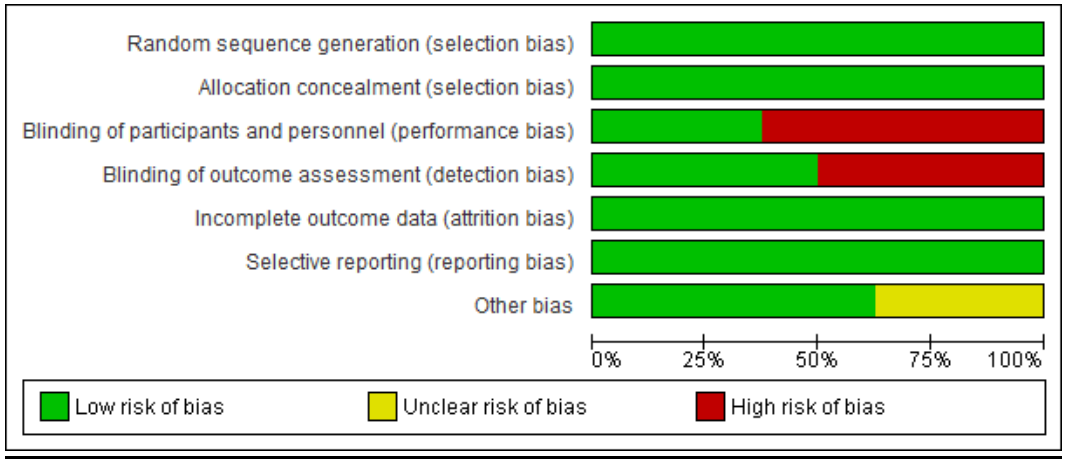

Figure 2: Risk of bias graph.

Outcomes: The results of this systematic review indicated that improvements in environmental hygiene were frequently related to a decrease in healthcare-associated infections in a seemingly causal way. More than fifty percent of the research indicated a significant reduction in colonization or healthcare-associated infections for all microorganisms examined. These findings underscore the significance of environmental cleanliness in ensuring the safety of cases. Several investigations that didn't illustrate a statistically significant decrease in healthcare-associated infections or case colonization still advocated for their interventions due to their substantial reduction of ambient bioburden. Although eight investigations included controls, several utilized before-and-after designs and hence lacked adequate controls. Two utilized comparable institutions as "proxy" controls. Frequently, research utilized the baseline rate of colonization or healthcare-associated infections prior to the intervention's implementation while attempting to control for confounding variables like hand hygiene, antimicrobial utilization, and the seasonality of the relevant illnesses. The efficacy of the therapies was dependent upon the microorganisms examined and the extent to which particular infections spread inside the healthcare environment. For example, VRE, recognized for its environmental transmission, was occasionally mitigated more effectively than diseases that are commonly transmitted via hand contact between patients. The chosen investigations showed significant heterogeneity regarding the kinds of therapies & their quality. The review tries to mitigate specific restrictions by carrying out subset analysis. On the other hand, the findings are reflective of the conditions that exist in this field; there is a significant amount of work that remains to be performed.

Study ID	**Micro-organism**	**Intervention**	**Total decrease**	**Significant decrease**	**Effect of the healthcare-associated infections intervention**
Green et al 2017	Pulsed Xenon ultraviolet	Culture of (coagulase negative staphylococci, Bacillus spp., Micrococcus spp.,	No	No	ESBL *Enterobacteriacae*, *C. difficile*, multidrug-resistant microorganism P. MRSA, aeruginosa, *S. maltophilia*
Kovach et al 2017	Pulsed Xenon ultraviolet	ATP; culture of gram (+) rod or cocci, gram-(+) bacilli	No	NA	NA
Kim et al 2018	Photocatalyst antimicrobial coating (TiO2)	Culture of Bacillus spp, Staphylococcus spp.,	MRSA	No	*C. difficile*, MRSA, *A. baumannii*, VRE
Salgado et al 2013	Copper alloy-coating	Culture of *A. baumanni,* vancomycin-resistant enterococci, MR	Composite (VRE, MRSA)	Composite (VRE, MRSA)	MRSA, VRE

		SA, *E. Coli, P. aeruginosa*,			
Boyce et al 2017	*C. difficile*	Liquid H2O2	Yes	No	Colonization rate & HAI rate (combined): 1.0–0.56 Measurement unit: cases per 1000 cases days RR: NA CI: NA P value: Not Applicable The composite result (colonization plus HAI rate of all microorganisms) yielded an incidence rate ratio of 0.77, with a range of 10.3–8.0; P = 0.068; ninety-five percent confidence interval 0.579–1.029.
Ray et al 2017	*C. difficile*	Training, following up & feedback	No	No	Information is unavailable for the intervention interval. colonization rate: NA rate of HAI for the pre-intervention interval exclusively (intervention versus control hospitals): 5.6–5.8. Unit of measurement: 10,000 cases days. RR: NA CI: NA P value: 0.8

Table 3: Effects of Healthcare Environmental Hygiene Interventions on Hais & Case Colonization.*:*

VRE vancomycin-resistant enterococci, *MRSA* multidrug-resistant *S. aureus*, *N/A* not available.

Discussion

This systematic review included eight studies **(8–15).**

The findings of our study indicated that interventions in environmental hygiene were frequently related to a decrease in healthcare-associated infections in a manner that appeared to be causal. A significant drop in colonization or healthcare-associated infections was observed for all of the microorganisms that were examined in more than half of the investigations. These findings provide evidence that environmental hygiene has a significant role in ensuring the safety of cases. Even though the majority of the investigations didn't demonstrate a statistically significant lessening in case colonization or HAI, they nonetheless suggested their strategies for utilization

since they did significantly lower the amount of environmental bioburden found in the environment.

The efficacy of the therapies was based upon the microorganisms examined and the extent to which specific pathogens disseminated inside the healthcare environment. VRE, for example, which has been demonstrated to disseminate through the environment, was occasionally more successfully decreased compared to pathogens that are recognized to regularly spread via hands from one case to another.

The studies selected have shown significant heterogeneity regarding the kinds of interventions & their quality. The review tries to mitigate certain limitations by the execution of subset analysis. Nonetheless, the outcomes illustrate the current state of this domain; a significant amount of work needs to be performed.

According to the systematic review by **Peters et al., (16)** the majority of research indicated a decrease in cases colonization or healthcare-associated infections, and all research that assessed bioburden showed a decrease after the HEH intervention. Furthermore, 75% (9/12) of the involved research supported the intervention. Fifty-eight percent of trials (7 out of 12) exhibited a substantial reduction in HAI/colonization. Research indicated that VRE colonization decreased despite intervention compliance being below the threshold required to significantly diminish other pathogens.

The research conducted by **Salgado et al., (10)** aimed to determine whether the introduction of copper alloy-surfaced objects in an intensive care unit diminished the incidence of healthcare-associated infections. The outcomes illustrated that the rate of HAI and/or colonization by VRE or methicillin-resistant Staphylococcus aureus in intensive care units' rooms featuring copper alloy surfaces was significantly reduced in comparison with standard intensive care unit rooms (0.071 versus 0.123). The rate for HAI was decreased from 0.081 to 0.034.

Mitchell et al. (17) aimed to assess the efficacy of an environmental cleaning bundle in diminishing healthcare-associated infections within hospitals. Their findings indicated that post-intervention, infections with VRE diminished from 0.35 to 0.22 per 10,000 occupied bed-days (relative risk 0.63, ninety-five percent CI 0.41–0.97, p-value equal to 0.0340).

Furthermore, **Marra et al. (18)** carried out a systematic literature review & meta-analysis on the efficacy of no-touch disinfection techniques in reducing healthcare-associated infections. They indicated a statistically significant decline in infection rates with VRE (RR, 0.42; ninety-five percent CI, 0.28–0.65); nevertheless, no distinctions have been observed in the rates of methicillin-resistant Staphylococcus aureus or gram (-) multidrug-resistant pathogens.

Leistner et al. (4) assessed the impact of 3 distinct surface-cleaning approaches on the occurrence of healthcare-associated infections and detected a declining trend in MRSA infections related to environmental disinfection and probiotic cleaning, in addition to a reduction in VRE infections throughout probiotic cleaning.

Conversely, **Wong et al. (19)** evaluated whether the implementation of distinct environmental cleaning management strategies in the MICU diminished the incidence of HAIs, revealing that the HAI densities were 14.32‰ & 14.90‰ throughout the baseline & intervention intervals, correspondingly. The healthcare-associated infections density didn't diminish following the intervention interval; rather, it declined to 9.07‰ throughout the subsequent phase. This may be attributed to the challenges in attaining high levels of hand-hygiene compliance. Enhancing

environmental sanitation is an essential adjunctive measure for decreasing the occurrence of HAIs.

Additionally, it was disagreed with by **Allen et al. (20),** who aimed to assess the efficacy of an environmental hygiene bundle regarding alterations in healthcare-associated infection rates, cleaning performance, & the attitudes & knowledge of environmental services workers (ESW). They noted a statistically insignificant alteration in HAI rates during the control & research intervals (rates per 10,000 occupied bed days: methicillin-resistant Staphylococcus aureus —pre-0.22, post-0.0; vancomycin-resistant enterococci —pre-0.11, post-0.0).

Conclusion

This systematic review illustrated that healthcare environmental hygiene interventions can have an essential role in dropping healthcare-associated infections and case colonization, particularly for microorganisms with high environmental persistence such as VRE. However, the heterogeneity of study designs, variability in intervention types, and frequent lack of appropriate control groups limit the strength of the overall evidence. Future research must focus on well-designed, multicenter randomized controlled trials that standardize intervention protocols, control for confounding factors, and assess long-term sustainability of outcomes. Strengthening the evidence base in this manner will better inform policy and optimize infection prevention practices in healthcare settings.

Limitations: Though eight studies had controls, many had before-and-after study designs and consequently didn't implement suitable controls. Only a minority used true controls (two used proxy institutions). Many studies utilized the baseline rate of colonization or healthcare-associated infections prior to the intervention's implementation while attempting to control for confounding variables like hand hygiene, antibacterial usage, and the seasonality of the relevant illnesses.

References

Assadian O, Harbarth S, Vos M, Knobloch JK, Asensio A, Widmer AF. Practical recommendations for routine cleaning and disinfection procedures in healthcare institutions: a narrative review. J Hosp Infect. 2021;113:104–14.

Al-Taie, M., & Khattak, M. N. (2024). The impact of perceived organizational support and human resources practices on innovative work behavior: does gender matter?. Frontiers in Psychology, 15, 1401916.

Kanamori H, Rutala WA, Sickbert-Bennett EE, Weber DJ. Role of the contaminated environment in transmission of multidrug-resistant organisms in nursing homes and infection prevention. Am J Infect Control. 2023;51(11S):A151-A157.

Muthoni MS. Hospitals surfaces and sites as a reservoir for pathogenic bacteria that play a role in transmission of infectious diseases. J Health Environ Res. 2021;7(3):139-44.

Leistner R, Kohlmorgen B, Brodzinski A, Schwab F, Lemke E, Zakonsky G, et al. Environmental cleaning to prevent hospital-acquired infections on non-intensive care units: a pragmatic, single-centre, cluster randomized controlled, crossover trial comparing soap-based, disinfection and probiotic cleaning. EClinicalMedicine. 2023;59.

Gon G, Kabanywanyi AM, Blinkhoff P, Cousens S, Dancer SJ, Graham WJ, et al. The Clean pilot study: evaluation of an environmental hygiene intervention bundle in three Tanzanian hospitals. Antimicrob Resist Infect Control. 2021;10(1):8.

Parry MF, Sestovic M, Renz C, Pangan A, Grant B, Shah AK. Environmental cleaning and disinfection:

sustaining changed practice and improving quality in the community hospital. Antimicrob Steward Healthc Epidemiol. 2022;2(1):e113.

Alahi MEE, Sukkuea A, Tina FW, et al. Integration of IoT-Enabled Technologies and Artificial Intelligence (AI) for Smart City Scenario: Recent Advancements and Future Trends. Sensors (Basel). 2023;23(11):5206.

Kim MH, Lee SG, Kim KS, Heo YJ, Oh JE, Jeong SJ. Environmental disinfection with photocatalyst as an adjunctive measure to control transmission of methicillin-resistant Staphylococcus aureus: a prospective cohort study in a high-incidence setting. BMC Infect Dis. 2018;18(1):610.

Boyce JM, Guercia KA, Sullivan L, Havill NL, Fekieta R, Kozakiewicz J, et al. Prospective cluster controlled crossover trial to compare the impact of an improved hydrogen peroxide disinfectant and a quaternary ammonium-based disinfectant on surface contamination and health care outcomes. Am J Infect Control. 2017;45(9):1006–10.

Salgado CD, Sepkowitz KA, John JF, Cantey JR, Attaway HH, Freeman KD, et al. Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit. Infect Control Hosp Epidemiol. 2013;34(5):479–86.

Ray AJ, Deshpande A, Fertelli D, Sitzlar BM, Thota P, Sankar T, et al. A multicenter randomized trial to determine the effect of an environmental disinfection intervention on the incidence of healthcare-associated Clostridium difficile infection. Infect Control Hosp Epidemiol. 2017;38(7):777–83.

Vianna PG, Dale Jr CR, Simmons S, Stibich M, Licitra CM. Impact of pulsed xenon ultraviolet light on hospital-acquired infection rates in a community hospital. Am J Infect Control. 2016;44(3):299–303.

Özen M, Yılmaz G, Coşkun B, Topçuoğlu P, Öztürk B, Gündüz M, et al. A quasi-experimental study analyzing the effectiveness of portable high-efficiency particulate absorption filters in preventing infections in hematology patients during construction. Turkish J Hematol. 2016;33(1):41.

Green C, Pamplin JC, Chafin KN, Murray CK, Yun HC. Pulsed-xenon ultraviolet light disinfection in a burn unit: impact on environmental bioburden, multidrug-resistant organism acquisition and healthcare associated infections. Burns. 2017;43(2):388–96.

Kovach CR, Taneli Y, Neiman T, Dyer EM, Arzaga AJA, Kelber ST. Evaluation of an ultraviolet room disinfection protocol to decrease nursing home microbial burden, infection and hospitalization rates. BMC Infect Dis. 2017;17(1):186.

Peters A, Schmid MN, Parneix P, Lebowitz D, de Kraker M, Sauser J, et al. Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review. Antimicrob Resist Infect Control. 2022;11(1):38.

Mitchell BG, Hall L, White N, Barnett AG, Halton K, Paterson DL, et al. An environmental cleaning bundle and health-care-associated infections in hospitals (REACH): a multicentre, randomised trial. lancet Infect Dis. 2019;19(4):410–8.

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(1):20–31.

Wong SS, Huang CH, Yang CC, Hsieh YP, Kuo CN, Chen YR, et al. Reducing health care-associated infections by implementing separated environmental cleaning management measures by using disposable wipes of four colors. Antimicrob Resist Infect Control. 2018;7(1):34.

Allen M, Hall L, Halton K, Graves N. Improving hospital environmental hygiene with the use of a targeted multi-modal bundle strategy. Infect Dis Heal. 2018;23(2):107–13.