Assessment of the role of healthcare environmental hygiene in patient safety and development of a facility-level self-assessment tool

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Assessment of the role of healthcare environmental hygiene in patient safety and development of a facility-level self-assessment tool

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In memory of the three Wild Women who taught me most of what matters:
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1. Publications and presentations

Book Chapter

Peters, A Guitart C, Pittet D "Addressing the global challenge of access to supplies during COVID-19: Mask reuse and local production of alcohol-based handrub" *Environmental and Health Management of Novel Coronavirus Disease (COVID-19).* Elsevier. Dehghani et al. Ed. 2021.

Original research

Peters A, Schmid MN, Kraker MEA, Parneix P, Pittet D. Results of an international pilot survey on healthcare environmental hygiene at the facility level. *Am J Infect Control*. 2022 Mar 6:S0196-6553(22)00133-X.

Peters A, Schmid M, Parneix P et al. Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review. *Antimicrob Resist Infect Control 11:38 (2022).*

Peters A, Carry, J, Cave, C et al. Acceptability of an alcohol-based handrub gel with superfatting agents among healthcare workers: a randomized crossover controlled study. *Antimicrob Resist Infect Control (In press).*

Peters, A, Cave, C, Carry, J et al. Tolerability and acceptability of three alcohol-based handrub gel formulations: a randomized crossover study. *J Hosp Infect.* 2022 Feb 3:S0195-6701(22)00034-2.

Peters A, Lotfinejad N, Palomo R et al. Decontaminating N95/FFP2 masks for reuse during the COVID-19 epidemic: a systematic review. *Antimicrob Resist Infect Control* May 29;10(1):83.

Peters A, Palomo, R, Ney H, et al. "The COVID-19 pandemic and N95 masks: reusability and decontamination methods". *Antimicrob Resist Infect Control* 10, 83 (2021).

Pires D, Gayet-Ageron A, Guitart C, et al. "Effect of Wearing a Novel Electronic Wearable Device on Hand Hygiene Compliance Among Health Care Workers: A Stepped-Wedge Cluster Randomized Clinical Trial." *JAMA Netw Open*. 2021 Feb 1;4(2):e2035331.

Tartari E, Fankhauser C, Peters A, et al. "Scenario-based simulation training for the WHO hand hygiene self-assessment framework."*Antimicrob Resist Infect Control*. 2019 Mar 28; 8:58.

Peters A. "The global proliferation of high-containment biological laboratories: understanding the phenomenon and its implications." OIE. *Rev Sci Tech.* 2018 Dec; 37(3):857-883.

Reviews, editorials and letters

Tušl, M., Thelen, A., Marcus, K. et al. Opportunities and challenges of using social media big data to assess mental health consequences of the COVID-19 crisis and future major events. Discov Ment Health 2, 14 (2022).

Lotfinejad N, Peters A, Tartari E, et al. "Hand hygiene in health care: 20 years of ongoing advances and perspectives". *Lancet Infect Dis*. 2021 Aug;21(8):e209-e221.

Ghasemi S, Peters A, Pittet D. "Vérités et rumeurs à propos des masques". Hygiènes 2021;29(2):121-126.

Guitart C, Peters A, Lotfinejad N, et al. Neonates, Sepsis, and Antimicrobial Resistance—Steps to Tackle Difficult Issues in Our Most Vulnerable Population. *Journal of Obstetrics and Gynaecology Canada*. May 11, 2020. https://doi.org/10.1016/j.jogc.2020.04.011

Peters A, Palao VC, Lotfinejad N, et al. "WHO Year of the Nurse and Midwife: More clean and educated hands for all". *J Infect Prev*. 2020 Sep;21(5):166-169.

Lotfinejad N, Peters A, Pittet D. Hand hygiene and the novel coronavirus pandemic: the role of healthcare workers. *J Hosp Infect*. 2020;105(4):776-777.

Peters A, Vetter P, Guitart C, et al. Understanding the emerging coronavirus: what it means for health security and infection prevention. *J Hosp Infect*. 2020;104(4):440-448.

Arredondo-Provecho A, Horcajo-Díaz E, Fankauser-Rodríguez C, et al. (2020). Día Mundial de la Higiene de Manos. Campaña para mejorar la higiene de manos en la asistencia sanitaria. Revista Española de Salud Pública, 94, 202005045.

Thampi N, Longtin Y, Peters A, et al. It's in our hands: a rapid, international initiative to translate a hand hygiene song during the COVID-19 pandemic. *J Hosp Infect*. 2020;105(3):574-576. doi:10.1016/j.jhin.2020.05.003

Peters A, Parneix P, Otter J, et al. Putting some context to the aerosolization debate around SARS-CoV-2. *J Hosp Infect*. 2020;105(2):381-382.

Peters A, Ghasemi S, Pittet D. The Crucial Role of Midwives in Preventing Maternal Sepsis: It All Started in a Maternity Ward. *J Epidemiol Glob Health*. 2020;10(2):113-114.

Martischang R, Peters A, Guitart C, et al. (2020), Promises and limitations of a digitalized infection control program. *J Adv Nurs*, 76: 1876-1878.

Lotfinejad N, Tuor C, Peters A, et al. The duality of nurses' work: How can the profession that saves the most lives in the world avoid spreading disease? *Int J Nurs Stud*. 2020 Jul;107:103616.

Martischang R, Peters A, Reart AN, et al. The voice of nurses in hospital epidemiology and infection control: An example from the 19th century. *Int J Infect Dis.* 2020 Jul;96:119-120.

Peters A, Buetti N, Pittet D. Der schädliche Effekt von Falschinformationen – ein Beispiel aus der VRE-Kontrolle. Bulletin. *Swissnoso*. 01/2020.

Peters A, Frat E, Iten A, et al. “Alcohol-based hand rub and influenza A: the danger of publishing a flawed study with no clinical relevance”. *Journal of Hospital Infection.* 104: 1, P120-122, Jan 01, 2020

Peters A, Palomo R, Pittet D. The great nursing brain drain and its effects on patient safety. *Antimicrob Resist Infect Control*. 2020 Apr 30;9(1):57.

Peters A, Lotfinejad N, Guitart C, et al. "Nurses and midwives: clean care is in your hands": the 5th May 2020 World Health Organization SAVE LIVES: Clean Your Hands campaign. *Antimicrob Resist Infect* Control. 2020 Apr 19;9(1):54.

Peters A, Dubas CM, Lotfinejad N, et al. Home deliveries in limited resource environments. *Am J Infect Control*. 2020 Aug;48(8): 859-861.

Peters A, Pittet D. 2019. Influenza and alcohol-based handrub: the danger of ignoring clinical relevance. *mSphere.* 4:6. Nov/Dec 2019.

Tartari E, Muthukumaran P, Peters A, et al. "Monitoring your institution: the WHO hand hygiene self-assessment framework-is it worth it?" *Clin Microbiol Infect*. 2019 Aug; 25(8):925-928.

Guitart C, Bleeker C, Peters A, et al. "Why should my hospital use the Hand Hygiene Self-Assessment Framework proposed by the World Health Organization?" *HosCom International.* 16:1. Jul 2019.

Peters A, Pittet D. "Excellence in hand hygiene begins where strategy, leadership, and culture come together". *HosCom* 16:1 Jun, 2019.

Kilpatrick C, Bourqui L, Peters A, et al. "Hand hygiene: Sounds easy, but not when it comes to implementation". *J Infect Public Health*. 2019 May - Jun;12(3):301-303.

Peters A, Pham M, Guitart C, et al. "Why should we as a developed country care about Universal Health Coverage?". *International Journal of Infection Control.* May 2019

Peters A, Tartari E, Mai SHC, et al. "2019 WHO hand hygiene campaign and global survey: clean care for all-it's in your hands." *Lancet Infect Dis.* 2019 May; 19(5):463-464.

Peters A, Borzykowski T, Tartari E, et al. "Clean Care for All - It's in Your Hands": The 5th of May 2019 World Health Organization SAVE LIVES: Clean Your Hands Campaign. *J Infect Dis*. 2019 Apr 22.

Vermeil T, Peters A, Kilpatrick C, et al. Hand hygiene in hospitals: anatomy of a revolution. *J Hosp Infect*. 2019 Apr; 101 (4): 383-392.

Peters A, Tartari E, Lotfinejad N, et al. "Fighting the good fight: the fallout of fake news in infection prevention and why context matters." *J Hosp Infect*. 2018 Dec;100(4):365-370.

Peters A, Otter J, Moldovan A, et al. "Keeping hospitals clean and safe without breaking the bank; summary of the Healthcare Cleaning Forum 2018". *Antimicrobial Resistance & Infection Control* 7:132, Nov. 2018.

Abbas M, Pires D, Peters A, et al. "Conflicts of interest in infection prevention and control research: no smoke without fire. A narrative review". *Intensive Care Med*. 2018 Oct;44(10):1679-1690.

Pittet D, Peters A, Tartari E. "Enterococcus faecium tolerance to isopropanol: from good science to misinformation". Lancet Infect Dis. 2018 Oct;18(10):1065-1066.

Peters A, Saito H, Borzykowski T, et al. "Let's prevent sepsis in health care - The 5 May 2018 World Health Organization (WHO) Save Lives: Clean Your Hands campaign". *J Infect.* 2018 Jun;76(6):563-569.

Peters A, Masson-Roy S, Pittet D. "Healthcare-associated sepsis and the role of clean hands: When we do not see the trees for the forest" *International Journal of Infectious Diseases.* May 2018 Volume 70, Pages 101–103.

Other Publications (industry journals, newspapers, press releases, interviews given)

Lanez E. "Covid : la liste de nos ennemis" *Paris Match.* Nov 29, 2020. (interview)

Peters A, Pittet, D. "COVID-19 and health care environmental hygiene". *MJA Insight*. 27 July 2020.

Peters, A. "Iran's struggle to contain COVID-19". *International Policy Digest.* World News, May 28, 2020.

Peters A, Otter J, Parneix P, et al. "Clean Hospitals - transforming patient safety. A White Paper." *European Cleaning Journal.* 17 Sept, 2019.

Peters, A. "It's in Your Hands": Making hand hygiene infectious *Healthcare Infection Society. blog.* 22 May 2019. https://www.his.org.uk/blog/2019/21052019-clean-your-hands/

Lectures at international events

Interclean Healthcare Cleaning Forum, Amsterdam, 2022
French society for Hospital Hygiene Strasbourg, France (remotely), 2021
Paul Webber Teleclasses, 2021
International Conference on Prevention & Infection Control, Geneva, Switzerland 2021
iClean Australia, 2020 (remotely)
International Solid Waste Association World Congress, Bilbao, Spain 2019
International Conference on Prevention & Infection Control, Geneva, Switzerland 2019
Interclean Healthcare Cleaning Forum Istanbul, Turkey 2019

2. Abstract in English

Background:

Healthcare-associated infections (HAI) are present in every healthcare setting around the world, and are a global issue that causes a high degree of mortality, morbidity, and cost.(1–3) Healthcare environmental hygiene (HEH) is an often overlooked and understudied field in infection prevention. Although hand hygiene is still recognized as the primary vector for HAI, HEH is a far more important aspect than is previously accepted; for a variety of reasons. As a field it is far more vast and heterogenous than hand hygiene; it comprises any areas associated with the healthcare environment including surfaces, sterilization and device reprocessing, air control, water control, waste management, laundry. All of these elements and environments have a range of products and practices used to clean and disinfect when and where needed. Issues affecting the quality of the cleaning and disinfection can stem from or be found in both the technical and human aspects of HEH, as well as the systemic and logistical context of healthcare facilities and the larger environment. Such issues may include efficacy of the chosen interventions, difficulty in quantifying the value HEH brings to a healthcare facility, and the training and management of human resources.

The literature in the field of environmental hygiene is still in its nascent stages. Similarly to the field of hand hygiene 30 years ago, it's importance needs to be quantified and analyzed, both in terms of its contributions to the global burden of mortality and morbidity as well as in its financial burden on health systems.

Objective:

The objective of this work was to begin to assess the role of the healthcare environment in HAIs, analyze how to best assess the level and raise the quality of HEH globally, and to begin developing a "transposable model" of key components in environmental hygiene that can be implemented on a global scale.

Methods:

We first began building up a public-private partnership focused on HEH in 2018. The main mission of the "Clean Hospitals" project is to improve patient safety through improved HEH. It does this by raising awareness of the importance of HEH, working to improve standards and practice on a global level, and conduct academic research needed to address gaps in the field. In the context of this project, the first objective was to conduct a systematic review to see whether there was enough evidence to be able to claim that improvements in HEH could improve patient outcomes. The next element was to work on developing the Healthcare Environmental Hygiene Self- assessment Framework (HEHSAF) for healthcare facilities in order to analyze their environmental hygiene practices in the context of the World Health Organization (WHO)

Multimodal Hand Hygiene Improvement Strategy, and assess which elements in their HEH system and practices need improvement. A pilot survey of this tool was conducted in 35 countries in 2021.

Results:

The building up of the Clean Hospitals project resulted in a partnership with 15 companies active in different aspects of HEH. The academic arm of the project is made up of a governing Board and an Academic Taskforce, a group of experts from academia in charge of research. We have given numerous lectures at international events on HEH and published extensively in the field. We have developed a range of workshops and educational activities for our industry partners as well.

The systematic review showed that interventions in HEH often reduce HAI among a number of microorganisms of interest. It also showed that these interventions are very effective in reducing environmental bioburden, and that more and larger high-quality studies are needed in order to study the effects of different types of interventions in the healthcare environment.

The HEH international pilot survey reached its goal of having at least four facilities participate from each of the World Bank income level countries. Its results demonstrated that almost all healthcare facilities across all resource levels have major issues with their HEH programs, and that there is a dire need for resources and tools to be developed. The data gathered was then used to improve the HEHSAF tool.

Conclusions:

The PhD project is only the beginning of what we are trying to accomplish. We plan to update the systematic review every five years to keep up with a rapidly evolving field. the HEHSAF tool will be ready for in-depth testing in reference hospitals this year, and hopefully ready for global dissemination in 2023. Subsequently, our aim is to develop educational resources around the HEHSAF in order to address the need for facility-level guidance to improve HEH worldwide.

3. Abstract in French

Contexte :

Les infections liées aux soins de santé (ILS) sont présentes dans tous les établissements de santé du monde et constituent un problème mondial qui entraîne un degré élevé de mortalité, de morbidité et de coûts. L'hygiène de l'environnement des soins de santé (HEH) est un domaine souvent négligé et peu étudié de la prévention des infections. Bien que l'hygiène des mains soit toujours reconnue comme le principal vecteur des infections nosocomiales, l'hygiène de l'environnement des soins de santé est un domaine bien plus important qu'on ne le pense, et ce pour plusieurs raisons. C'est en effet un domaine beaucoup plus vaste et hétérogène que l'hygiène des mains ; il comprend tout ce qui est associé à l'environnement des soins de santé, y compris les surfaces, la stérilisation et le retraitement des dispositifs, le contrôle de l'air, le contrôle de l'eau, la gestion des déchets, le linge. L'ensemble de ces éléments et différents environnements sont associés à une large diversité de produits, pratiques et techniques à adapter en fonction du besoin et recommandations. Les problèmes affectant la qualité du nettoyage et de la désinfection peuvent provenir ou se rencontrer dans les aspects techniques et humains de l'HEH, ainsi que dans le contexte systémique et logistique des établissements de santé et de l'environnement au sens large. Ces questions peuvent inclure l'efficacité des interventions selectionnées, la conscience de leur coût et de leur valeur pour l'établissement de santé, ainsi que la formation et la gestion des ressources humaines.

La littérature dans le domaine de l'hygiène environnementale est encore à ses débuts. Tout comme le domaine de l'hygiène des mains il y a 30 ans, son importance doit être quantifiée et analysée, à la fois en termes de contribution au fardeau mondial de la mortalité et de la morbidité, et de charge financière pour les systèmes de santé.

Objectif :

L'objectif de ce travail était de commencer à évaluer le rôle de l'environnement de soins dans les IASS, d'analyser la meilleure façon d'évaluer le niveau et d'améliorer la qualité de l'hygiène de l'environnement au niveau mondial, et de commencer à développer un "modèle transposable" des composants clés de l'hygiène de l'environnement qui pourrait être mis en œuvre à l'échelle mondiale.

Méthodes :

Nous avons tout d'abord mis en place un partenariat public-privé axé sur l'HEH en 2018. La mission principale du projet "Clean Hospitals" est d'améliorer la sécurité des patients grâce à une meilleure HEH. Pour ce faire, il sensibilise à l'importance des HEH, s'efforce d'améliorer les normes et les pratiques au niveau mondial et mène les recherches universitaires nécessaires pour combler les lacunes dans ce domaine. Dans le contexte de ce projet, le premier objectif était de

conduire une revue systématique pour documenter l'existence possible de preuves pour pouvoir affirmer que l'amélioration de l'HEH pouvait améliorer la qualité des soins aux patients. L'étape suivant à été de travailler sur le développement du Healthcare Environmental Hygiene Self-assessment Framework (HEHSAF) pour les établissements de santé afin d'analyser leurs pratiques d'hygiène environnementale dans le contexte de la stratégie multimodale de promotion de l'hygiène des mains de l'Organisation mondiale de la santé (OMS), et d'évaluer les éléments de leur système et de leurs pratiques d'hygiène environnementale qui doivent être améliorés. Une enquête pilote de test de cet outil a été menée dans 35 pays en 2021.

Résultats :

La construction du projet Clean Hospitals a donné lieu à un partenariat avec 15 entreprises actives dans différents aspects de l'HEH. Le volet académique du projet est constitué d'un conseil d'administration et de la Taskforce académique en charge de la recherche. Nous avons donné de nombreuses conférences lors d'événements internationaux sur les HEH et publié de nombreux articles dans ce domaine. Nous avons également développé une série d'ateliers et d'activités éducatives pour nos partenaires industriels.

L'examen systématique a montré que les interventions en matière d'HEH réduisent souvent les IAH pour un certain nombre de micro-organismes d'intérêt. Elle a également montré que ces interventions sont très efficaces pour réduire la charge biologique environnementale, et que des études de qualité plus nombreuses et plus importantes sont nécessaires pour étudier les effets des différents types d'interventions dans l'environnement de soins.

L'enquête pilote internationale HEH a atteint son objectif d'obtenir la participation d'au moins quatre établissements dans chacun des pays de la Banque mondiale. Ses résultats ont démontré que presque tous les établissements de santé, quel que soit leur niveau de ressources, ont des problèmes majeurs avec leurs programmes HEH, et qu'il y a un besoin urgent de développer des ressources et des outils pour les améliorer. Les données recueillies ont ensuite été utilisées pour optimaliser l'outil HEHSAF.

Conclusions :

Le projet de doctorat n'est que le début de ce que nous essayons d'accomplir. Nous prévoyons de mettre à jour la revue systématique tous les cinq ans afin de suivre l'évolution du domaine. L'outil HEHSAF sera prêt à être testé en profondeur dans des hôpitaux de référence en 2022, et nous espérons qu'il sera prêt à être diffusé dans le monde entier en 2023. Par la suite, notre objectif est de développer des ressources éducatives autour de l'outil HEHSAF afin de répondre au besoin de conseils au niveau des établissements pour améliorer l'HEH dans le monde entier.

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5. General introduction

In order to understand the importance of healthcare environmental hygiene (HEH) for patient safety, one must first understand the global burden of healthcare-associated infections (HAIs), and the role that the healthcare environment plays in their transmission. The first of these two subjects is a bit easier to describe, as there has been a great deal of research in the field in the last 25 years.

HAIs are present in every healthcare setting around the world, and are a global issue that causes a high degree of mortality, morbidity, and cost.(1–3) Patients are a population that are at higher risk, either because their health is already compromised, or because they are undergoing invasive procedures. Furthermore, the flora of pathogenic microorganisms in healthcare facilities (HCFs) is inherently different than in the community. Because HCFs house a highly concentrated population of both infectious and vulnerable patients which are often cared for by the same group of people, some pathogens spread differently in such environments.

HAIs acquired during HCF stays(4) cause more deaths than malaria, tuberculosis, and AIDS combined, and the burden of six common types of HAI is higher than the total burden of 32 of the most common major communicable diseases worldwide.(3,5) Beyond mortality, HAIs also increase morbidity, prolong hospital stay, and burden healthcare systems financially.(6,7) The total annual global cost for five common types of HAI is estimated at $8.3- $11.5 billion.(8) Despite their ubiquity, still much is unknown about how to prevent these infections; no single HCF in the world can claim to be unaffected by them. Because HAIs are caused by a number of different pathogens and can be transmitted to patients in different ways, it can sometimes be difficult for HCFs to view them as a single major challenge instead of a number of more minor ones.

The role of HEH is an often-overlooked and understudied field in infection prevention, and much of the literature in the field of environmental hygiene is still in its nascent stages. Similarly to the field of hand hygiene 30 years ago, its importance needs to be quantified and analyzed, both in terms of its contributions to the global burden of mortality and morbidity as well as in its financial burden on health systems. Although contaminated hands are still recognized as the primary vector for HAI, HEH is a far more important aspect than was previously thought; for a variety of reasons. As a domain, it is far more vast and heterogenous than hand hygiene, and comprises any area associated with the healthcare environment, including those within the patient environment. HEH includes cleaning and disinfecting surfaces, sterilization and device reprocessing, air control, water control, waste management and laundry. All of these elements and environments have a range of products and practices used to clean and disinfect them when and where needed. Issues affecting the quality of the cleaning and disinfection can stem from or be found in both the technical and human aspects of HEH, as well as the systemic and logistical context of the healthcare facilities and the larger environment. Such issues may include efficacy

of the chosen interventions, awareness of their cost and value to HCFs, and the training and management of human resources. Because of the complexity of HEH, and the inherent differences in nosocomial pathogens, understanding how it affects disease transmission presents additional challenges.

5a. A brief history:

The perceived role of the healthcare environment in patient safety, has varied both historically and geographically. In the absence of scientific evidence for the importance of HEH, guidelines were rather varied or nonexistent, and institutions were, in many respects, left mostly to their own devices. International guidelines such as the 2004 WHO guidelines for infection prevention and control provided only very rudimentary guidance for environmental management, with only a few paragraphs devoted to cleaning and disinfection of surfaces in healthcare facilities.(9)

Practices ranged from cleaning patient areas for mostly aesthetic purposes, to continually disinfecting environments that were not common vectors of transmission, such as floors in common areas of HCFs. In the US in the 1970s and '80s, it was generally considered that disease transmission to patients from the healthcare environment was insignificant.(10) Around the late1990s to mid-2000s, scientists and academics began exploring the role of the hospital environment on HAIs, specifically for known environmental pathogens such as *Clostridioides difficile*, vancomycin-resistant enterococci (VRE), norovirus, *Pseudomonas aeruginosa*, *Acinetobacter* spp. and methicillin-resistant *Staphylococcus aureus* (MRSA).(11–18) Experts began calling for the need for standards for cleaning healthcare facilities and exploring standardization and the creation of guidelines for HEH.(19–24) Germany's Rudolf Schuelke Foundation issued a HEH consensus paper in 2013.(25) The CDC began investing actively in research in 2015 after the Ebola crisis, focusing on areas such as understanding transmission events related to patient room surfaces, measuring cleanliness, improving HEH through looking at the process of how it was performed and evaluating emerging technologies.(10)

The COVID-19 pandemic has had an undeniable impact on the awareness of HEH worldwide. Although the virus itself is enveloped and quite easy to kill, there was a significant quantity of research performed around various aspects of environmental transmission and remanence on environmental surfaces.(26–28) Although there are still no universal global guidelines for routine environmental cleaning and disinfection in healthcare, a large amount of research has been performed in the last few years, as evidenced through the proliferation of reviews on the subject.(29–46) As an indicator, a search in PubMed for "environmental cleaning systematic review" in early April 2022 resulted in 0 articles before 2001, 11 articles between 2001-2010 (avg. 1.1 per year), 82 articles between 2011-2019 (avg. 9.1 per year), and 72 since 2020 (avg. 32.0 per year). National and regional guidelines have also been updated; though the CDC issued the new guidelines for low-resource settings in 2019,(47) the bulk of new guidelines including

their new core components for HEH,(48) as well as the German(49) and UK guidelines(50) for environmental hygiene which were published during the pandemic.

5b. Clean Hospitals

In order to address the urgent need for attention to HEH on both the facility and the global level, Prof. Pittet began to design and develop the Clean Hospitals project.(51) Clean Hospitals is a public-private partnership that was officially launched at the Healthcare Cleaning Forum at Interclean Amsterdam in 2018,(52) and currently includes over 14 industry stakeholders and a panel of academic experts. The main mission of the "Clean Hospitals" project is to work across disciplines and interest groups in order to improve patient safety through improved HEH. By harnessing the collective strengths of academia, industry, HCF, governmental bodies and other key stakeholders, the project aims to have a direct impact on HCF staff, the community, and the larger natural environment.

In practice, Clean Hospitals both conducts and facilitates research that is still missing in the field, using this work to raise industry standards and increase the visibility of HEH globally. Academic members also lecture and teach, work to improve standards and practice, and collaborate with scientists and industry partners to organize a global day for HEH awareness.

5c. Objectives

The overall objective of the research in this PhD is to improve both the academic understanding of the role of HEH in patient safety, and to give hospitals tools to improve their programs and practices on the facility level. Ultimately, improvements in HEH will benefit public health by lowering rates of healthcare-associated infections, reducing antimicrobial resistance, and protecting hospital staff as well as the larger environment.

5d. Study setting

The systematic review was conducted at the University of Geneva Hospitals and Faculty of Medicine. The pilot survey was conducted during COVID-19 and was thus virtual, although it included data from hospitals in 35 different countries. Before the pandemic, a number of on-site visits were conducted to gather HCF ethnographic data on HEH programs. These visits were conducted in HCFs in Switzerland, Malaysia, the Netherlands, and Turkey. These visits served to gather data for constructing the pilot survey, and subsequently, the HEHSAF tool.

5e. Background of the systematic review

In addition to learning more about the challenges faced by industry, gathering stakeholders into working groups, and beginning to study optimal models for HEH, one of the first major projects was to compile proof of the role of the healthcare environment in patient safety. If this link was

not evident, increasing the support, and ultimately the budget, for HEH would prove difficult. The most thorough way to study this was to conduct a systematic review to measure the role of interventions in HEH on HAIs and patient colonization.

Until recently, evidence for the role of contaminated surfaces on HAI was virtually nonexistent; it is essentially only over the last few years that there are beginning to be major studies and even some randomized clinical trials published in major journals.(53–56) A 2004 systematic review only found four studies that could be included; most were on floor disinfection, and there was insufficient evidence to draw any conclusions.(57) It was imperative to conduct another one, especially because a proliferation of other studies and reviews(58–60) being performed in HEH indicated that there may be enough evidence to draw different conclusions.

Our systematic review's eligibility assessment, article inclusion and full analysis was completed in 2021. Although this meant that some time elapsed between the search and the publication of the article, most new studies that were being conducted were being conducted in an outbreak setting due to COVID-19, and would have been excluded from the review.

5f. Research during COVID-19

During the first few waves of the pandemic, the academic research agenda of Clean Hospitals, like so many other institutions, was centered around SARS-CoV-2. In the context of the global shortage of PPE, our research group's focus was mainly on the reprocessing of single use N95/FFP2 filtering facepiece respirators, with some involvement concerning the health security implications of the virus and the importance of aerosol transmission versus other routes of transmission.(61–65) Though coincidental, the increased attention that the pandemic generated in IPC in general, and in HEH in particular, was timely both for the review and the other research project that were planned for the PhD.

5g. The need for standards

From speaking with other colleagues in the field and from my own experience it was clear that HEH practices and programs around the world were totally heterogeneous and often severely lacking. While visiting hospitals around the world through both Clean Hospitals activities and "Train-the-Trainers" activities in hand hygiene,(66) I was often privileged to be able to have in-depth visits of a number of HCFs' environmental hygiene programs. Not a single hospital had elements that could not be improved, and many had rather suboptimal or dysfunctional programs in place. Still, there were positive and surprising elements in every place visited, which reinforced my belief that improving HEH worldwide must be a collaborative effort; institutions have so much that they can learn from each other, regardless of geographic location or resource level. This simultaneous need for standards and collaboration generated the idea of the "Transposable Model" for HEH. The model would be generated through extensively studying a

number of reference hospitals and visiting a number of others, in order to create a tool for implementation that could be used to improve HEH globally, even in the absence of official international guidelines and standards. The first part of developing the Transposable Model was to develop a tool for HCFs to analyze their HEH programs.

Prof. Pittet's team had already created a similar tool for hand hygiene implementation. The Hand Hygiene Self-Assessment Framework (HHSAF) is based on the WHO multimodal hand hygiene promotion strategy,(67) has already been implemented in three global surveys and includes over 3,200 HCFs.(68–70) We decided to create a similar tool for HEH, also in the context of the WHO multimodal strategy and with a focus on a holistic approach to implementation. Like the HHSAF, the HEHSAF would be a facility level tool aiming to provide the situational analysis on a global scale, regardless of resource level and geographic location. This tool can give HCFs a baseline snapshot of their current environment, as well as show progress over time if reused at a later date.

5h. Background of the pilot study

In order to further develop the tool and test the applicability and appropriateness of the HEHSAF to different geographic, cultural and resource contexts we used a preliminary and unscored version of the tool in an international pilot study.(71) Before the pilot survey, there was very little data comparing different HEH systems internationally. This online survey was designed to provide valuable feedback concerning the content and wording of the pilot study itself. Additionally, it aimed to provide qualitative data about practices in and attitudes towards HEH around the world.

5i. Background of the HEHSAF

The feedback from the pilot survey was incorporated into the tool, and further developed by the Clean Hospitals Academic Taskforce and working group. A preliminary scoring system has been developed, and the survey is ready for the next round of in depth testing in partner institutions. Though this document is still under development, I have included it after the two published articles, as it illustrates the direction in which the project will continue to develop over the coming years.

6. Methodological contributions

6a. Methods: Systematic Review(72)

This review analyzed the evidence for the ability of interventions in HEH to prevent HAIs and to reduce patient colonization with multidrug-resistant microorganisms (MDROs) and other epidemiologically relevant pathogens. Original studies measuring the effect of an HEH intervention on HAI or patient colonization published before December 31, 2019 were eligible

for inclusion. All types of interventions in HEH were included, unless they were conducted in outbreak settings, included hand hygiene interventions, or involved a complete rebuild/ renovation of a HCF's built environment. The primary outcomes were either HAI and/or patient colonization, and the secondary outcome was a reduction in environmental bioburden. Studies with an English abstract were eligible for inclusion if published in English, German, French, or Spanish.

The review was performed according to the Prisma Checklist. Development of the search strategy and the literature search was performed in PubMed and Web of Science. Data extraction was performed by two authors and a third was consulted if there were any uncertainties. A descriptive analysis with a narrative synthesis was performed, as well as additional sub-group analyses by type of intervention, type of microorganism and study quality. A quality scoring system was developed in order to score studies on their sample size, study design, presence of a control, adjustment for confounding factors, as well as issues with reporting and conflicts of interest. For the secondary outcome, studies were included if they measured environmental bioburden either through cultured environmental samples or adenosine tri-phosphate (ATP) sampling.

6b.Candidate's role in the systematic review

I conceptualized the review together with support from Prof. Pittet. The MeSH terms (medical subheadings) and search strategy was developed together with one of my colleagues. I drafted the protocol for Prospero,(73) uploaded all the results into the Ryyan review manager and performed all deduplication of the results. I screened the titles and abstracts of all retrieved articles and read the papers selected for full-text analysis in order to select the studies included in the review. A second colleague also screened the abstracts individually and any discretions between our results was resolved either through discussion or with the help of a third colleague.

I developed the standardized extraction form and then extracted the relevant data from the articles. These data included: study title, authors, year of publication, study design, type of intervention, specific intervention, sample size, presence of a control, types of microorganisms studied, outcome, whether the intervention method was recommended by the study authors, quality score and grade, reduction in bioburden, and any additional comments. Another colleague also performed duplicate data extraction with the same standardized extraction form, in order to verify that information was not misinterpreted or overlooked. I then synthesized and analyzed the results, performed the sub group analyses and wrote the review for publication.

6c. Methods: Pilot Survey(71)

The pilot survey was conducted online and was sent to 743 HCFs from a database of 18,443 HCFs around the world that had participated in at least one of the HHSAF surveys.(69,74,75) It

remained open from April 16th - June 30th, 2021. A self-selecting survey approach was used, and all types of HCFs were included. We sent several rounds of invitations to ensure that we had participation from at least four HCFs from each of the four income levels as defined by the World Bank.(76)

The content of the 39 question survey was hosted on the SurveyHero® platform and constructed around the five elements of the WHO multimodal hand hygiene promotion strategy, including: system change, training and education, monitoring and feedback, workplace reminders and institutional safety climate.(67) In addition to this data, the survey also included a number of questions about respondent characteristics, facility characteristics, and appropriateness of the survey including hospital name, location, and number of beds. The survey was only in English, and Google Translate was used for any translation necessary in the free text responses. Only the smallest and largest HCFs from Croatia's participants were included in the subset analysis by income level, because of the disproportionately high number of participants from that country.

Surveys in which individual responses were omitted were included for analysis, and if a HCF completed the survey more than once, only the most recent version was retained. All quantitative data gathered from completed survey questionnaires were both included in the analysis and stratified by income level. The analysis was performed using OpenEpi.

6d. Candidate's role in the pilot survey

I conceptualized the project with support from Prof. Pittet. I developed the study design for the survey, and did the background research to decide what to include and how to include it. Content development was primarily my work, with some feedback from the Clean Hospitals working group and other colleagues. Data collection was automated by SurveyHero®, but data cleaning and analysis was primarily my work with help from a junior colleague. I wrote the paper.

8.Publications

8a.Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review (See pages 20-42)

8b.Results of an international pilot survey on healthcare environmental hygiene at the facility level (See pages 43-59)

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Antimicrobial Resistance and Infection Control

REVIEW Open Access

Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review

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Abstract

Background: Healthcare-associated infections (HAI) are one of the gravest threats to patient safety worldwide. The importance of the hospital environment has recently been revalued in infection prevention and control. Though the literature is evolving rapidly, many institutions still do not consider healthcare environmental hygiene (HEH) very important for patient safety. The evidence for interventions in the healthcare environment on patient colonization and HAI with multidrug-resistant microorganisms (MDROs) or other epidemiologically relevant pathogens was reviewed.

Methods: We performed a systematic review according to the PRISMA guidelines using the PubMed and Web of Science databases. All original studies were eligible if published before December 31, 2019, and if the effect of an HEH intervention on HAI or patient colonization was measured. Studies were not eligible if they were conducted in vitro, did not include patient colonization or HAI as an outcome, were bundled with hand hygiene interventions, included a complete structural rebuild of the healthcare facility or were implemented during an outbreak. The primary outcome was the comparison of the intervention on patient colonization or HAI compared to baseline or control. Interventions were categorized by mechanical, chemical, human factors, or bundles. Study quality was assessed using a specifically-designed tool that considered study design, sample size, control, confounders, and issues with reporting. The effect of HEH interventions on environmental bioburden was studied as a secondary outcome.

Findings: After deduplication, 952 records were scrutinized, of which 44 were included for full text assessment. A total of 26 articles were included in the review and analyzed. Most studies demonstrated a reduction of patient colonization or HAI, and all that analyzed bioburden demonstrated a reduction following the HEH intervention. Studies tested mechanical interventions (n = 8), chemical interventions (n = 7), human factors interventions (n = 3), and bundled interventions (n = 8). The majority of studies (21/26, 81%) analyzed either *S. aureus*, *C. difficile*, and/or vancomycin-resistant enterococci. Most studies (23/26, 88%) reported a decrease of MDRO-colonization or HAI for at least one of the tested organisms, while 58% reported a significant decrease of MDRO-colonization or HAI for all tested microorganisms. Forty-two percent were of good quality according to the scoring system. The majority (21/26, 81%) of study interventions were recommended for application by the authors. Studies were often not powered adequately to measure statistically significant reductions.

Interpretation: Improving HEH helps keep patients safe. Most studies demonstrated that interventions in the hospital environment were related with lower HAI and/or patient colonization. Most of the studies were not of high quality; additional adequately-powered, high-quality studies are needed.

Systematic registration number: CRD42020204909

Keywords: Cleaning, Disinfection, Infection prevention, Healthcare-associated infection, Healthcare environmental hygiene, Infection control, Environmental services, Intervention

Background

Clean healthcare facilities look appealing, offer a sense of security and increase patient satisfaction.[1] Although visually clean facilities have become the standard of healthcare settings in high-income countries, cleanliness not only plays a role in quality of care, but in its safety. The microbiological aspect of cleanliness, healthcare environmental hygiene (HEH), has remained a neglected field, with little investment beyond what is considered the norm. Few high-quality studies link interventions in HEH to a reduction in either patient colonization with epidemiologically relevant pathogens or healthcare-associated infections (HAI). Tough there are many reasons for this, one is the lack of literature critically evaluating the role of HEH in patient safety.

HAI are acquired during hospital stay[2] and cause more deaths worldwide than malaria, tuberculosis, and AIDS combined, and the burden of the six main types of HAI is higher than the total burden of the 32 major communicable diseases.[3,4] These infections also increase morbidity, prolong hospital stay, and are a major financial burden to healthcare systems.[5,6] The total annual global cost for five of the most common types of HAI is estimated at $8.3–$11.5 billion.[7] Despite their ubiquity, still much is unknown about how to prevent HAI, and no single hospital or healthcare facility in the world can claim to be unaffected.

While HAIs are usually the result of an infection with the patient's own fora, this fora can change due to colonization with hospital pathogens through HCWs' hands or from the hospital environment. Definitively knowing whether an HAI came from the patient's environment or from another source is difficult. Tough it is known that some bacteria are more often transmitted through the patient environment than others, it is comparatively rare that extensive investigations are performed at the time of diagnosis. Usually such investigations are reserved for unusual infections or outbreak situations, in hospitals with sufficient resources to undertake them.

Over the past 25 years, best practice interventions such as hand hygiene in patient care have reduced the number of HAIs.[8,9] Poor hand hygiene has been recognized as being one of the main drivers of HAIs among patients.[9] Even if such practices can reduce HAIs by up to 50%, there is still a remaining proportion that needs to be addressed and where HEH may play a role.[10] A prerequisite for addressing some of these challenges is to review the literature to evaluate whether HEH interventions have a direct effect on HAI and thus, on patient safety.

HEH is essential for all types of healthcare facilities, from hospitals and long-term care facilities to home care environments. Environmental hygiene builds on both technical and human components, and it includes all aspects of the healthcare environment that are not the patient or the HCWs themselves. The technical component includes cleaning and disinfection of surfaces, water management, air control, waste management, laundry, and sterilization and device reprocessing. The human component includes best practice implementation, staff management, and environmental services departments' structural organization.[11] This component includes the evaluation of the cost and value of HEH interventions and programs, the training and monitoring of staff, their career

development and workflow organization. Both of these components carry major implications for the wellbeing of patients, HCWs, the community and the larger natural environment.

Beyond the biological plausibility that the healthcare environment has a direct effect on patient safety, a number of reports over the last decades increasingly highlighted the potential impact of environmental hygiene on health.[12,13] Most common healthcare-associated pathogens are known to survive on surfaces for hours or days, some for weeks and a few for over a year.[14,15] It has been shown that hygiene failures correlate strongly with HAI in an ICU setting.[16] There is an increase of 150–500% in the chance of acquiring a pathogen if the prior room occupant was colonized with it.[17]

This paper reviews the evidence-base for the ability of interventions in the hospital environment to reduce patient colonization with multidrug-resistant microorganisms (MDROs) and other epidemiologically relevant pathogens, and to prevent HAI. This exercise is difficult for a number of reasons. First, high-quality randomized controlled trials in HEH are sparse. Secondly, the bulk of studies are retrospective or prospective before-and after studies with limited methodological quality. Third, there is heterogeneity of the field about "clean environment" and how environmental hygiene is defined. Finally, HEH interventions are often combined with other infection prevention and control (IPC) interventions such as hand hygiene or a reorganization of patient care. These confounding factors can cause difficulty when determining whether outcomes are a direct effect of an HEH intervention.

Methods

We performed the systematic review protocol according to the PRISMA checklist,[18] in both the PubMed and Web of Science databases. The full search strategies are available in the supplementary files. The primary outcome is a comparison of the measure of patient colonization or HAI compared to baseline/control. HAI was defined according to the WHO definition.[2]

The secondary outcome was environmental bioburden as defined as either cultured environmental samples or adenosine tri-phosphate (ATP) sampling. Although ATP sampling is technically a proxy measure of bioburden, it correlates closely with microbiological sampling in the literature.[19] Other proxy measures for bioburden such as the use of florescent dye were not included. Though the use of fluorescent techniques can show a measurable improvement in cleaning procedures, they do not necessarily demonstrated an impact on bioburden, depending on what is being used to remove the fluorescent dye. Therefore, studies that used improved cleaning practices or fluorescent marking as a proxy measure of bioburden were marked as "NA".

All original studies were eligible if they were published before December 31, 2019, and if they measured the effect of an HEH intervention on HAI or patient colonization. Studies with an English abstract were eligible when published in English, French, German, or Spanish and only included if they were original research.

Studies were not eligible if they were conducted in vitro, did not include patient colonization or HAI as an outcome, were bundled with hand hygiene interventions, or were implemented during an outbreak. Outbreaks were excluded because outbreak management broadens the intervention, and it would not be possible to adjust for that effect. Complete structural rebuilds were excluded, because interventions such as renovating a building or replacing a plumbing system are not feasible HEH interventions in most contexts. There is also evidence that such interventions result in reduction of the studied pathogen for a limited time, after which the environment can become recolonized.[20]

Interventions of interest were either mechanical, chemical, or they applied a human factors design. The standardized extraction forms included type of intervention, study title, authors, year of publication, study design, type of intervention(s), intervention(s), sample size or sample size proxy, control, microorganisms studied, outcome, whether the method is recommended for application by the authors, quality score and grade, reduction in bioburden, and comments.

Interventions were stratified into chemical, mechanical, human factors, and bundles of combining two or more of the aforementioned categories. Titles, abstracts and the full text of all potentially eligible studies were screened independently by at least two reviewers. Inclusions and exclusions were recorded following the PRISMA guidelines, and reasons for exclusion were detailed. Data were extracted by two authors. Any disagreement was resolved through discussion with a third author. Any missing data was requested from original study authors by email. Ethical approval was not required for this review.

As a wide variety of procedures and methodologies were identified, a descriptive analysis with a narrative synthesis was performed. Due to this heterogeneity, additional sub-group analyses by type of intervention, type of microorganism, and study quality were performed.

The study designs were divided into the following categories: randomized controlled trials (RCTs), quasi-experimental studies (prospective and retrospective), and before-and-after studies (prospective and retrospective). Sample sizes were categorized by ranges from less than 10 to more than 100'000 patients/ patient-days/ room cleanings. Presence of a study control was adjusted to include proxies for a control. The main confounding factors that were analyzed included hand hygiene compliance, antibiotic use, and the seasonality of certain HAI.

Available tools for analyzing study quality were assessed, and selected using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist for conducting observational studies which had been previously used for such a review.[21,22] The STROBE checklist was, however, difficult to apply to some HEH interventions, in particular when a study had no control, its primary outcome was laboratory-based or based on bioburden measurements. We therefore also constructed a specifically-designed quality scoring system which included what the reviewers deemed the most important elements in the studies. Obviously, this scoring system is only meant to compare this specific list of studies and is not applicable in other contexts. After discussion in a working group, the following five elements were included in the quality assessment: study design, sample size, control, confounders, and issues with reporting. Among issues with reporting, conflict of interest (COI) was defined as minor if less than half of the authors disclosed a COI, such as having worked for industry as a consultant in the same field, and major if more than half of authors were funded by industry for the study.

Table 1 summarizes the quality scoring scale used in the review. Studies were graded from 0-20 points. "High quality" studies referred to studies that received an A or B grade according to the quality scale (Table 1). Some studies that ranked lower on the quality scale were well-performed, but simply not designed or powered to determine significant changes in patient colonization or HAI.

Findings

Of the 952 retrieved and deduplicated studies, 44 were included for full-text review. A total of 26 studies were included in the final analysis (Figure 1 and Table 2). Studies reported mechanical (n=8),[23–30] chemical (n=7),[31–37] human factors (n=3),[38–40] and bundled interventions (n=8).[41–48] All of the studies that examined HAI only examined HAI in patients, not HCWs. Two studies were published before the year 1990,[25,28] while the others (24/26) were published between 2013 and 2020. Of all of the 26 interventions, only five (19%) were not recommended for application by the study authors.[23,25,30,39,42]

Table 1 Healthcare environmental hygiene intervention studies; quality scoring scale; systematic review

From: Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review

Scale	0	1	2	3	4
Study design	Before and after (retrospective, no control)	Before and after (prospective, no control)	Quasi experimental (retrospective, control)	Quasi experimental (prospective, control, not randomized)	Randomized controlled trial (prospective)
Sample size	Less than the above numbers/N/A	Over 10 patients/over 100 patient-days/over 100 room cleanings	Over 100 patients/over 1000 patient-days/over 1000 room cleanings	Over 1000 patients/over 10,000 patient-days/over 10,000 room cleanings	Over 10,000 patients/100,000 patient-days/100,000 room cleans
Control	No	N/A [1]	Proxy control/not well-executed	N/A	Yes
Adjusted for confounding factors	Not at all	N/A	Somewhat	N/A	Yes
Issues with reporting, including conflict of interest	Major COI[a] and clear issues with data reporting	No/minor COI but clear issues with data reporting or major COI and minor issues with data reporting	No/minor COI but minor issues with data reporting or major COI and seemingly transparent data reporting	Minor COI and seemingly transparent data reporting	No COI and seemingly transparent data reporting

Studies were scored from a possible total of 20 points. Grade A was given for 16–20 points, B for 11–15 points, C for 6–10 points, and D for 0–5 points

N/A not available, *COI* conflict of interest

[a]Major COI referred to if over half of the study authors were funded by industry to conduct the study

Among them, three were mechanical interventions,[23,25,30] one was a human factors intervention,[39] and one was a bundled intervention.[42] All of the chemical interventions were recommended for application by the study authors.[31–37]

Five studies were RCTs.[32,37,39,47,48] The remaining studies had prospective quasi-experimental designs (n=3),[25,33,44] retrospective quasi-experimental design (n=1),[38] prospective before-and-after designs (n=11),[23,24,27,28,30,31,34,41–43,45] and retrospective before-and-after designs (n=6).[26,29,35,36,40,46] In total, only 31% (8/26) studies had a true control.[25,32,37,39,42,44,47,48]

Over half (15/26, 58%) of the studies demonstrated a significant decrease in patient colonization or HAI following the chosen intervention for all microorganisms tested.[24,26,29,31,33,35–38,40,41,43–46] In one study, the reduction was not significant for all patient groups.[26] If additional interventions that demonstrated a reduction in all microorganisms tested were included, whether significant or not, this increased to 69%.[23,28,32] If the additional interventions that demonstrated a reduction in at least one of the microorganisms tested (significant or not) were included, this increased to 88%.[25,27,34,47,48]

Analysis by type of intervention (Table 2)

Of the eight studies that implemented mechanical interventions,[23–30] 63% (5/8) reported statistically significant reductions in HAI or colonization for at least one tested microorganism.[24–27,29]

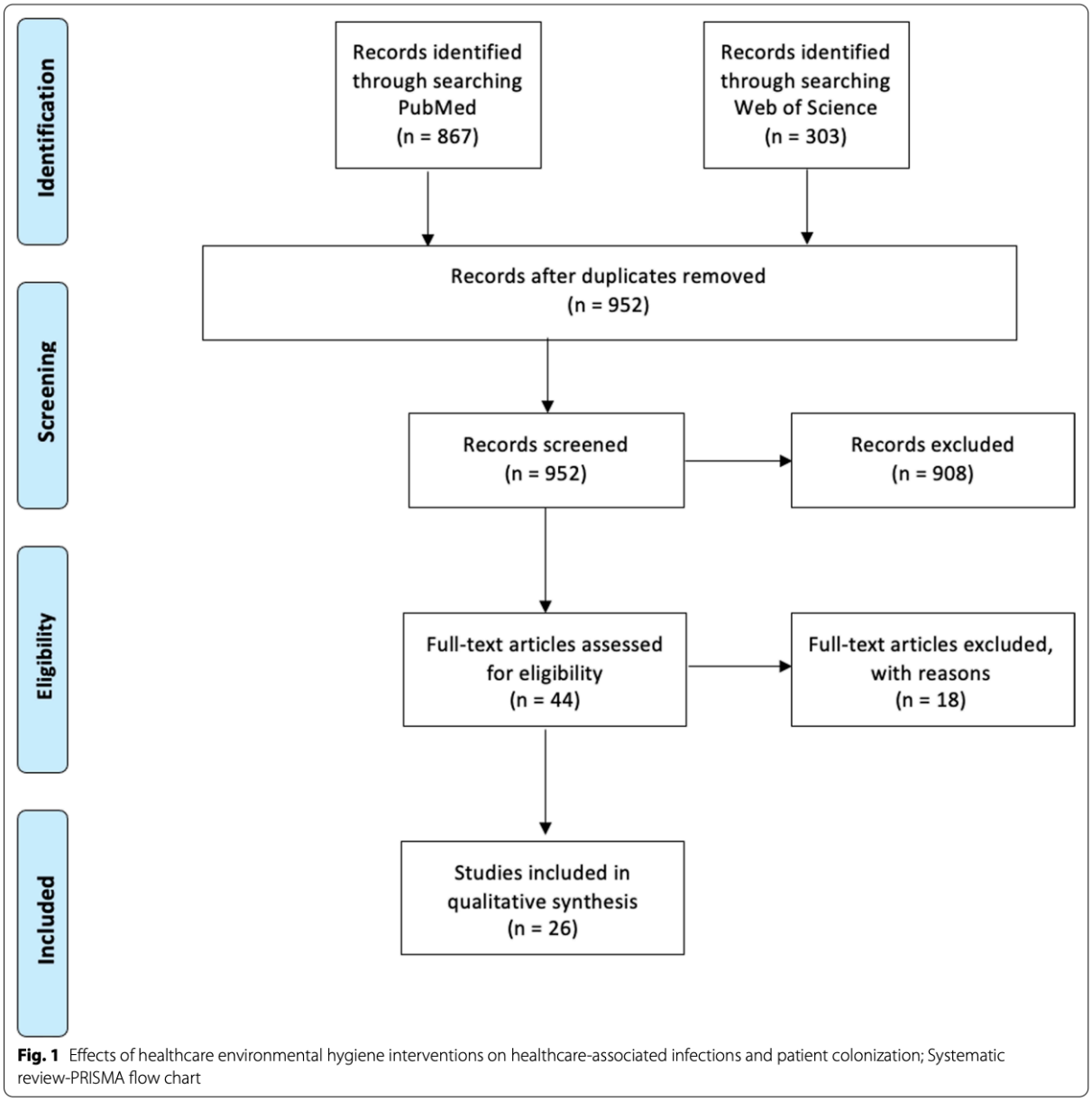

Fig. 1 Effects of healthcare environmental hygiene interventions on healthcare-associated infections and patient colonization; Systematic review-PRISMA flow chart

Table 2 Results of the environmental hygiene studies organized by type of intervention; systematic review; N = 26

From: Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review

Type of intervention	Study title	Year	Authors	Study design	Interventions	Sample size proxy	Sample size (patients)	Control	Microorganisms studied for colonization or HAI (same type)	Outcome: rate/reduction/cases	Method recommended*	Quality	Grade	Reduction in Bioburden	Comments
Mechanical	Protective isolation in a burns unit: the use of plastic isolators and air curtains [25]	1971	Lowbury et al	Prospective quasi experimental study	Isolators for burn patients (plastic, ventilated, air curtains both open and closed topped, with pre-filter and main filter)	NA	84	Open wards	*Coliform bacilli*, *P. aeruginosa*, *Proteus* sp., *S. aureus*	Lower incidence of infection with *P. aeruginosa* with intervention. *Proteus spp.* and miscellaneous *coliform bacilli* appeared on burns at least as often in isolators as in the open ward	No	12	B	Yes	Limited results for *P. aeruginosa*, other IPC[g] measures are more important
Mechanical	Lack of nosocomial spread of Varicella in a pediatric hospital with negative pressure ventilated patient rooms [28]	1985	Anderson et al	Prospective before and after study	Negative pressure ventilation	NA	125	No	*H. zoster*, *V. zoster*	No cases of nosocomial spread in the new facility, with infected patients put in negative pressure rooms	Yes	6	C	NA	In a preceding study in an isolation facility without negative pressure ventilation, nosocomial infections occurred in 7 out of 41 susceptible patients who were on the same ward as two patients with chickenpox
Mechanical	Implementation and impact of ultraviolet environmental disinfection in an acute care setting [29]	2014	Haas et al	Retrospective before and after study	Pulsed Xenon UVC disinfection in the operating rooms (daily), dialysis unit (weekly), and terminal disinfection for all burn unit discharges	11,389 room cleans	NA	No	*C. difficile*, MDR Gram negative, MRSA, VRE[f]	Significant reduction in both incidence rates and HAI for VRE, MRSA, resistant gram-negative bacteria and *C. difficile*	Yes	9	C	NA	–
Mechanical	A Quasi-Experimental Study Analyzing the Effectiveness of Portable High-Efficiency Particulate Absorption Filters in Preventing Infections in Hematology Patients during Construction [26]	2016	Özen et al	Retrospective before and after study	HEPA[h] filters	NA	413	No	Invasive fungal infections	Reduction of the HAI rates and reduction of invasive fungal infections in all of the patients following the installation of the HEPA filters. Intervention was significantly protective against IFI infection for specific groups of patients	Yes	10	C	NA	*Aspergillus* was mentioned in abstract but not specifically analyzed. But initial assessment was on the infection rates of both bacteria and fungi. Economic results should be taken cautiously because patients bills are unclear and significance of results depends on exchange rates

Mechanical	Impact of pulsed xenon ultraviolet light on hospital-acquired infection rates in a community hospital [27]	2016	Vianna et al	Prospective before and after study	Pulsed Xenon UVC terminal disinfection	>4400 rooms	NA	No	*C. difficile*, MRSA, VRE	In non-ICU areas, significant reduction of *C. difficile*, no significant reduction of VRE, and significant increase of MRSA. In the ICU, reduction of all infections, but only a significant reduction for VRE	Yes, (though MRSA increased significantly)	5	D	NA	In non-ICU *only C. difficile* rooms received the intervention, which explains the results for the other pathogens
Mechanical	Pulsed-xenon ultraviolet light disinfection in a burn unit: Impact on environmental bioburden, multidrug-resistant organism acquisition and healthcare associated infections [30]	2017	Green et al	Prospective before and after study	Pulsed Xenon UVC[a] terminal disinfection for *C. difficile* associated disease rooms, and some daily disinfection	653 occupied bed days	NA	No	*C. difficile*, Extended spectrum beta-lactamase Enterobacteriaceae, MDR[b] *P.aeruginosa*, MRSA[c], *S. maltophilia*	No statistically significant impact on HAI[d] or MDR organisms acquisition. After intervention the ICU[e] experienced along interval without HAI-*C. difficile* infection	No	8	C	Yes	Intervention period too short to really measure effect on colonization and HAI, study was not designed for this
Mechanical	Evaluation of an ultraviolet room disinfection protocol to decrease nursing home microbial burden, infection and hospitalization rates [24]	2017	Kovach et al	Prospective before and after study	Pulsed Xenon UVC terminal disinfection and shared living spaces disinfection	247	NA	No	N/A	Significant reductions in nursing home acquired relative to hospital-acquired infection rates for the total infections. Significant reduction of Hospitalizations for infection, with a notable reduction in hospitalization for pneumonia	Yes	6	C	Yes	-
Mechanical	Effectiveness of ultraviolet disinfection in reducing hospital-acquired *Clostridium difficile* and vancomycin-resistant Enterococcus on a bone marrow transplant unit [23]	2018	Brite et al	Prospective before and after study	Pulsed Xenon UVC disinfection and active surveillance	NA	579	No	*C. difficile*, VRE	No significant reduction in the incidence of VRE or *C. difficile* after the intervention	No	11	B	NA	-
Chemical	Impact of hydrogen peroxide vapor room decontamination on *Clostridium difficile* environmental contamination and transmission in a Healthcare setting [31]	2008	Boyce et al	Prospective before and after study	Gaseous hydrogen peroxide terminal disinfection and intensive disinfection in high incidence wards	NA	NA	No	*C. difficile*	Significant reduction of the nosocomial *C. difficile* incidence	Yes	8	C	Yes	Study was after an epidemic, once the strain had become endemic

Chemical	Implementation of hospital-wide enhanced terminal cleaning of targeted patient rooms and its impact on endemic *Clostridium difficile* infection rates [35]	2013	Manian et al	Retrospective before and after study	Gaseous hydrogen peroxide	196,313 patient-days	NA	No	*C. difficile*	Significant reduction of the nosocomial *C. difficile* associated disease rate between the preintervention period and intervention period	Yes	12	B	NA	-
Chemical	Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit [37]	2013	Salgado et al	Randomized controlled trial	Copper alloy-coated objects	NA	431	Rooms without copper	MRSA, VRE	Significant lower rate of HAI and colonization in ICU rooms with intervention	Yes	10	C	Yes	Over half of intervention group not exposed to all copper surfaces, and over 13% of patients assigned to noncopper rooms were exposed to the intervention
Chemical	Use of a daily disinfectant cleaner instead of a daily cleaner reduced hospital-acquired infection rates [33]	2015	Alfa et al	Prospective quasi experimental study	Hydrogen peroxide disinfectant/detergent in disposable wipes	NA	NA	Similar hospital which only used detergent except for in *C. difficile* isolation rooms	*C. difficile*, MRSA, VRE	Significant reduction of all HAIs when cleaning compliance was high, and for VRE even when compliance was lower	Yes	13	B	NA	-
Chemical	Reduction in *Clostridium difficile* infection associated with the introduction of hydrogen peroxide vapour automated room disinfection [36]	2016	McCord et al	Retrospective before and after study	Gaseous hydrogen peroxide terminal disinfection	>3000 patients room cleanings	NA	No	*C. difficile*	Significant reduction of the *C. difficile* infection rate	Yes	6	C	NA	Intervention is potentially cost saving
Chemical	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 [32]	2017	Boyce et al	Randomized controlled trial	Daily cleaning with liquid hydrogen peroxide, feedback to staff	22,231 patient days	NA	Quaternary ammonium compounds (bleach for *C. difficile* rooms)	*C. difficile*, MRSA, VRE	No significant reduction of the composite colonization and infection outcome. (HAI and acquisition for VRE and MRSA, HAI for *C. difficile*)	Yes	17	A	Yes	Method recommended because surface contamination was also significantly lower
Chemical	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 [34]	2018	Kim et al	Before and after prospective	Photocatalyst antimicrobial coating (TiO2)	NA	621	No	*A. baumannii*, *C. difficile*, MRSA, VRE	Significant reduction in MRSA acquisition rate, and no significant reduction in the MRSA and *C. difficile* incidence rate. Significant reduction in incidence rate of hospital-acquired pneumonia. VRE and *A. baumannii* increased (not significantly)	Yes, for MRSA	11	B	Yes	-

Human factors	*Clostridium difficile* infection incidence: impact of audit and feedback programme to improve room cleaning [40]	2016	Smith et al	Retrospective before and after study	Online training, monitoring, weekly feedback	392,875 patient days	NA	No	*C. difficile*	Reduction of hospital-acquired *C. difficile* infection incidence following the intervention. After implementing the program, the rate of decline accelerated significantly	Yes	10	C	NA	Results may have been affected by confounding factors
Human factors	A Multicenter Randomized Trial to Determine the Effect of an Environmental Disinfection Intervention on the Incidence of Healthcare-Associated *Clostridium difficile* Infection [39]	2017	Ray et al	Randomized controlled trial	Training and monitoring of EVS personnel with feedback	1,683,928 patient days	NA	Disposable bleach wipes for daily and terminal disinfection, bleach, regular monitoring	*C. difficile*	No reduction in the incidence of healthcare-associated *C. difficile* infection during the intervention and postintervention periods	No	15	B	Yes	Environment was cleaner but no effect on *C. difficile* infection. No correlation between bioburden and HAI
Human factors	Environmental services impact on healthcare-associated *Clostridium difficile* reduction [38]	2019	Daniels et al	Retrospective quasi experimental design	Culture of safety with constructive feedback, education, auditing certifications, and accountability	52,290 patients days	NA	Hospitals where this system was already in use	*C. difficile*	Significant reduction in healthcare–associated *C. difficile* infections	Yes	15	B	NA	-
Bundle: chemical, human factors (minor)	Comparison of the effect of detergent versus hypochlorite cleaning on environmental contamination and incidence of *Clostridium difficile* infection [44]	2003	Wilcox et al	Prospective quasi experimental study	Hypochlorite with training	NA	NA	Detergent	*C. difficile*	Significant reduction in *C. difficile* infection associated with the use of hypochlorite in one of the study wards but not the other, where the *C. difficile* infection rate increased	Yes	11	B	Yes	-
Bundle: chemical, human factors	Controlling methicillin-resistant Staphylococcus aureus (MRSA) in a hospital and the role of hydrogen peroxide decontamination: an interrupted time series analysis [46]	2014	Mitchell et al	Retrospective before and after study	Gaseous hydrogen peroxide and liquid hydrogen peroxide disinfection; monitoring and feedback	3600 discharges, 32,600 swabs	NA	No	MRSA	Significant reduction of the incidence of MRSA colonization and infection after the introduction of the disinfectant	Yes	10	C	Yes	Study showed HEH can reduce infections, it does not prove superiority of hydrogen peroxide disinfectant, as it was compared to detergent
Bundle: chemical, human factors	A Successful Vancomycin-Resistant Enterococci Reduction Bundle at a Singapore Hospital [45]	2016	Fisher et al	Prospective before and after study	Training, gaseous hydrogen peroxide, workplace reminders (first part of study, before/during breakpoint), changed bleach cleaning solution, expanded surveillance, and automated alert system (later date, after reduction)	NA	270,000 (at least)	No	VRE	Significant reduction in the VRE rate	Yes	10	C	NA	Active surveillance, automated system and change in manual cleaning solution was only implemented well after the breakpoint in the reduction, so not causal for it.. Minimum sample size calculated form rate and total cases of VRE over 85 months is 270,000 patients)

Bundle: mechanical, chemical	Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and *Clostridium difficile* (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study [48]	2017	Anderson et al	Randomized controlled trial	UVC terminal room disinfection ± Bleach	NA	21 395	Quaternary ammonium compounds(bleach for *C. difficile* rooms)	*C. difficile*, MDR *A. baumannii*, *S. aureus*, VRE	Significant reduction of composite risk of colonization for all organisms except *C. difficile*. For VRE, only bleach and bleach + UVC interventions caused significant reductions in HAI. No statistically significant decrease was seen when using UVC with bleach vs bleach alone (in *C. difficile* rooms)	Yes, when used with quaternary ammonium compounds (so recommended except for *C. difficile*)	19	A	Yes	Composite risk reduction is due to the major significant reduction for VRE
Bundle: chemical, mechanical, workflow	Control of endemic multidrug-resistant Gram-negative bacteria after removal of sinks and implementing a new water-safe policy in an intensive care unit [43]	2018	Shaw et al	Prospective before and after study	Deep cleaning and disinfection of drains and valves; antibacterial water filters in the taps; external cleaning with microfiber cloths and hypochlorite solution	35,909 patients-days	NA	No	*Klebsiella*, *Pseudomonas spp.*	Significant reduction of the incidence rates of MDR-Gram-negative bacteria after the intervention	Yes	10	C	NA	Different IPC interventions implemented during the study period (UVC, sink removal, antibiotic stewardship, environmental cleaning changes). No major changes in hand hygiene compliance
Bundle: human factors, mechanical, workflow	Reducing health care-associated infections by implementing separated environmental cleaning management measures by using disposable wipes of four colors [42]	2018	Wong et al	Prospective before and after study	Training, education and awareness regarding cleaning and 4 color coded reusable wipes	NA	635	Reusable wipes soaked with hypochlorite solution, visual inspection	*C. difficile*, MRSA, VRE	No reduction in HAI density after intervention, but it was during the follow-up period	No	7	C	Yes	Calling the wipes "disposable" is misleading, wipes were disposed after a number of uses depending on the color/environment
Bundle: chemical (minor), human factors, mechanical (minor)	An environmental cleaning bundle and health-care-associated infections in hospitals (REACH): a multicentre, randomised trial [47]	2019	Mitchell et al	Randomized controlled trial	Training, auditing, feedback, implementation of enhanced cleaning practices, and the incorporation of disposable wipes	3,534,439 patient bed-days	NA	Periods where hospitals were not implementing the bundle	*C. difficile*, *S. aureus*, VRE	Significant reduction of VRE infections. No significant changes in the incidence of *S. aureus* bacteremia and of *C. difficile* infections	Yes, for VRE	19	A	NA	Not all hospitals used the wipes, and not all disinfected appropriately for *C. difficile*, which explains the results
Bundle: human factors, workflow	Implementation of human factors engineering approach to improve environmental cleaning and disinfection in a medical center [41]	2020	Hung et al	Prospective before and after study	Education, feedback, redesigned workflow of terminal cleaning and disinfection, a regular method of bleach dilution, and a checklist-form reminder)	NA	NA	No	Carbapenem-resistant *A. baumannii* complex, MRSA, VRE	Significant reduction in total MDRO colonization, but no reduction in HAI	Yes	5	D	Yes	Very few results on HAI, results are technically correlation. No information on specific pathogens for HAI, no adjustment for confounding factors. Authors recommend measures although HAI rates did not improve

*Recommended by the study authors, [a]UVC ultraviolet-C light, [b]MDR multidrug resistant, [c]MRSA multidrug-resistant S. aures; [d]HAI Healthcare-associated infections; [e]ICU Intensive Care Unit; [f]VRE vancomycin-resistant enterococci, [g]IPC infection prevention and control, [h]HEPA high efficiency particulate air (filter)

When all mechanical interventions showing any reduction in at least one of the microorganisms tested were included, including those not statistically significant, this increased to 88% (7/8).[23,48] Two of the three studies that implemented human factors interventions,[38–40] showed a statistically significant reduction in HAI or colonization for all microorganisms tested.[38,40] The remaining study demonstrated no reduction.[39] Of the seven studies that implemented chemical interventions,[31–37] 6 (86%) demonstrated statistically significant reductions for at least one of the microorganisms tested.[31,33–37] If all the interventions that demonstrated a reduction (not significant) in all microorganisms tested were considered, this increased to 100%. Eight studies implemented bundled interventions, and 88% (7/8) demonstrated statistically significant reductions in HAI or colonization for at least one of the microorganisms tested,[41,43–48] although the study by Anderson et. al[48] only demonstrated significant reduction in one of the two test wards. The remaining study demonstrated no reduction.[42]

Sub-group analyses were conducted for the most frequently implemented interventions (Table 3): ultraviolet- C light (UVC), hydrogen peroxide (both liquid and gaseous), and human factors. UVC interventions were implemented in six studies.[23,24,27,29,30,48] Of these, one study was bundled.[48] The interventions were recommended for application by the authors in four (67%) of the studies.[24,27,29,48] Reductions in colonization/HAI were significant in those same four studies, though not for all microorganisms tested.[27,48]

Five studies assessed the implementation of gaseous hydrogen peroxide;[31,35,36,45,46] two were bundled interventions.[45,46] The interventions were recommended for application by authors in all studies, and all reductions were statistically significant. Three studies assessed liquid hydrogen peroxide.[32,33,46] The interventions were recommended in all studies, and the reductions in colonization/HAI were statistically significant in two studies.[33,46]

Human factors studies encompassed all interventions that included training and education, monitoring and feedback, and promotion of institutional safety climate. Nine studies assessed the implementation of human factors;[38–42,44–47] six were bundled interventions.[41,42,44–47] The interventions were recommended by the authors in 78% (7/9) of the studies, [38,40,41,44–47] though one only recommended it for VRE.[47] Reductions in colonization/HAI were significant in those same studies.

One study performed a cost analysis. The installation of high efficiency particulate air (HEPA) filters was found to decrease the cost per patient; it is to note that these findings were significant in both $ and €, but did not reach the threshold for significance in Turkish Lira.[26] Another article suggested that gaseous hydrogen peroxide decontamination was cost-effective for *C. difficile*, based on the estimated minimum cost of nosocomial *C. difficile* infection per year.[36]

Analysis by microorganism (Table 2)
Half of the studies (13/26) observed the impact of an intervention on methicillin-resistant *Staphylococcus aureus* (MRSA) and/or *S. aureus*.[25,27,29,30,32–34,37,41,42,46–48]

Table 3 Healthcare environmental hygiene interventions according to the individual type of intervention; systematic review

From: Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review

Interventions	Number	Type
UVC[a] [23, 24, 27, 29, 30, 48]	6	Mechanical
Training, monitoring, feedback [38,39,40]	3	Human factors
Gaseous hydrogen peroxide [31, 35, 36]	3	Chemical
Liquid hydrogen peroxide [32, 33]	2	Chemical
Negative pressure ventilation system [28]	1	Mechanical
Isolators and air curtains [25]	1	Mechanical
HEPA[a] filters [26]	1	Mechanical
TiO_2 antimicrobial surface coating [34]	1	Chemical
Copper antimicrobial surface coating [37]	1	Chemical
Training and education and color-coded wipes [42]	1	Bundle: human factors and mechanical
Training and education, monitoring and feedback and workflow changes [41]	1	Bundle: human factors and workflow
External cleaning with microfiber and hypochlorite, water filters, and deep cleaning [43]	1	Bundle: chemical and mechanical and workflow
Hypochlorite with training [44]	1	Bundle: chemical and human factors (minor)
Gaseous hydrogen peroxide, change in bleach cleaning solution, training and education, monitoring and feedback, increased surveillance, and workplace reminders [45]	1	Bundle: chemical and human factors
Gaseous hydrogen peroxide, liquid hydrogen peroxide, monitoring and feedback [46]	1	Bundle: chemical and human factors
Training and education, monitoring and feedback, enhanced cleaning practices, disposable wipes [47]	1	Bundle: human factors, chemical (minor), mechanical (minor)

Of these, 62% (8/13) were recommended for application by the study authors.[29,32–34,37,41,46,48] One study that recommended the intervention compared a disinfectant to a detergent,[46] and one which did not recommend the intervention was not powered to demonstrate a reduction in HAI.[30] 46% of the interventions (6/13) demonstrated a significant decrease in HAI/colonization.[29,33,34,37,41,46] In one study that did not, the rate of MRSA infection increased significantly, which is unsurprising, as the intervention was only implemented in *C. difficile* rooms in the arm of the study with the increase.[27]

Sixty-five percent of studies (17/26) observed the impact of an intervention on *C. difficile*.[23,27,29–36,38–40,42,44,47,48] Among these, 59% of the interventions (10/17) were recommended for application by the study authors.[27,29,31–33,35,36,38,40,44] Of the seven studies that were not recommended, one was not powered to be able to show a reduction in HAI and not all hospitals disinfected appropriately for *C. difficile* in another.[30,47] Fifty-three percent of the interventions (9/17) demonstrated a significant decrease in HAI/colonization.[27,29,31,33,35,36,38,40,44]

Forty-six percent of studies (12/26) observed the impact of a HEH intervention on VRE.[23,27,29,32–34,37,41,42,45,47,48] Of these, 75% (9/12) recommended the intervention.[27,29,32,33,37,41,45,47,48] 58% of studies (7/12) demonstrated a significant decrease in HAI/colonization.[29,33,37,41,45,47,48] One study demonstrated that the intervention reduced the rate of colonization but not of HAI.[41] One study demonstrated that VRE colonization was reduced even when compliance to the intervention was lower than necessary for significantly reducing other pathogens.[33]

Seven studies assessed the effect of interventions on Gram negative bacteria.[25,29,30,34,41,43,48] Three studies observed the impact of an intervention on *A. baumannii* (including carbapenem-resistant and multidrug-resistant strains),[34,41,48] and

three on Pseudomonas (two on *P. aeruginosa* and one on *Pseudonomas* spp.).[25,30,43] *Klebsiella*, extended spectrum beta-lactamase *Enterobacteriaceae*, *S. maltophilia*, *Proteus* sp. and coliform bacilli were each analyzed by only one study.[25,30,43] Fifty-seven percent of interventions (4/7) were recommended for application by the authors, each of which demonstrated a significant decrease in HAI/colonization.[29,41,43,48] One older study[28] evaluated the role of negative air pressure rooms to prevent *Varicella zoster* and *Herpes zoster* infection. Although statistical significance was not calculated, there were no new cases after the intervention and the method was recommended by the authors.[28] Another study demonstrated the effect of air control to prevent invasive fungal infections during construction and showed an effect among oncology-haematology patients.[26]

Analysis by quality (Table 4)

The quality scoring system (Table 1) considered study design, sample size, whether there was a control, how the study adjusted for confounding factors, and issues in reporting. Table 4 shows the detailed quality scoring system results for the 26 studies. Forty-two percent of the studies (11/26) were considered to be of high-quality (grade A or B, Table 4). All studies that were of quality "A" and 1 study of quality "B" were RCTs.[32,39,47,48] 27% of high-quality study interventions (3/11) were not recommended for application by the authors.[23,25,39] The interventions in 64% (7/11) of these studies significantly reduced colonization/HAI.[33–35,38,44,47,48] In 43% (3/7) of these studies, the reduction was only significant for specific bacteria.[34,44,47] Fifty-eight percent of the studies (15/26) were of lower quality (grade of C or D, Table 4). Eighty-six percent of these (13/15) significantly reduced colonization/HAI.[24,26–29,31,36,37,40,41,43,45,46] In one of these studies, the reduction was only significant for specific bacteria.[27]

A further analysis was conducted which included only the higher quality studies that used a true control, and the most commonly studied microorganisms (*S. aureus*, *C. difficile*, and VRE), in order to assess whether there was a significant reduction per pairing of each microorganism and intervention (Table 5). This resulted in 15 of pairings from five studies.[32,39,44,47,48] The distribution included five interventions for each *S. aureus*, *C. difficile*, and VRE. Eighty-seven percent of the pairings (13/15) demonstrated a reduction in colonization or HAI,[32,44,47,48] but only 27% of them (4/15) demonstrated a significant reduction in patient colonization or HAI.[44,47,48] Studies were too heterogenous to perform any kind of metanalysis, and in those high quality studies, no two interventions on the same microorganism were comparable. Future studies in the field should aim to calculate sample sizes and be adequately powered to be able to demonstrate such reductions.

Table 4 Quality scoring of included studies; systematic review; N = 26

From: Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review

Study title	Study design	Sample size	Control	Adjusted for confounding factors	Conflict of interest and reporting	Final grade
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 [32]	4	2	4	4	3	A
Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and *Clostridium difficile* (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study [48]	4	4	4	4	3	A
An environmental cleaning bundle and health-care-associated infections in hospitals (REACH): a multicentre, randomised trial [47]	4	4	4	4	3	A
Effectiveness of ultraviolet disinfection in reducing hospital-acquired *Clostridium difficile* and vancomycin-resistant Enterococcus on a bone marrow transplant unit [23]	1	2	0	4	4	B
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 [34]	1	2	0	4	4	B
Comparison of the effect of detergent versus hypochlorite cleaning on environmental contamination and incidence of *Clostridium difficile* infection [44]	3	0	4	2	2[a]	B
Protective isolation in a burns unit: the use of plastic isolators and air curtains [25]	3	1	4	2	2[a]	B
Implementation of hospital-wide enhanced terminal cleaning of targeted patient rooms and its impact on endemic *Clostridium difficile* infection rates [35]	0	4	0	4	4	B
Use of a daily disinfectant cleaner instead of a daily cleaner reduced hospital-acquired infection rates [33]	3	0	2	4	4	B
Environmental services impact on healthcare-associated *Clostridium difficile* reduction [38]	2	3	2	4	4	B
A Multicenter Randomized Trial to Determine the Effect of an Environmental Disinfection Intervention on the Incidence of Healthcare-Associated *Clostridium difficile* Infection [39]	4	4	4	0	3	B
Lack of nosocomial spread of Varicella in a pediatric hospital with negative pressure ventilated patient rooms [28]	1	1	2	0	2[b]	C
Evaluation of an ultraviolet room disinfection protocol to decrease nursing home microbial burden, infection and hospitalization rates [24]	1	2	0	0	3	C
Reduction in *Clostridium difficile* infection associated with the introduction of hydrogen peroxide vapour automated room disinfection [36]	1	2	0	0	3	C
Reducing health care-associated infections by implementing separated environmental cleaning management measures by using disposable wipes of four colors [42]	1	2	0	0	4	C
Impact of hydrogen peroxide vapor room decontamination on *Clostridium difficile* environmental contamination and transmission in a healthcare setting [31]	1	0	0	4	3	C
Pulsed-xenon ultraviolet light disinfection in a burn unit: Impact on environmental bioburden, multidrug-resistant organism acquisition and healthcare associated infections [30]	1	1	0	2	4	C
Implementation and impact of ultraviolet environmental disinfection in an acute care setting [29]	0	3	0	2	4	C
A Successful Vancomycin-Resistant Enterococci Reduction Bundle at a Singapore Hospital [45]	1	4	0	2	3	C
Controlling methicillin-resistant Staphylococcus aureus (MRSA) in a hospital and the role of hydrogen peroxide decontamination: an interrupted time series analysis [46]	0	2	0	4	4	C
A Quasi-Experimental Study Analyzing the Effectiveness of Portable High-Efficiency Particulate Absorption Filters in Preventing Infections in Hematology Patients during Construction [26]	0	2	0	4	4	C
Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit [37]	4	2	2	2	0	C
Control of endemic multidrug-resistant Gram-negative bacteria after removal of sinks and implementing a new water-safe policy in an intensive care unit [43]	1	3	0	2	4	C
Clostridium difficile infection incidence: impact of audit and feedback programme to improve room cleaning [40]	0	4	0	2	4	C
Implementation of human factors engineering approach to improve environmental cleaning and disinfection in a medical center [41]	1	0	0	0	4	D
Impact of pulsed xenon ultraviolet light on hospital-acquired infection rates in a community hospital [27]	1	2	0	0	2	D

[a]Information on COI not complete, with appropriate complementary information, this could be a 4

[b]Information on COI not complete, with appropriate complementary information, this could be a 4

Table 5 Effects of healthcare environmental hygiene interventions on healthcare-associated infections and patient colonization

From: Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review

Author	Micro-organism	Intervention	Total reduction	Significant reduction	Effect of the HEH intervention
Wilcox et al. [44]	*C. difficile*	Hypochlorite	Yes	Yes	Rate of colonization: NA Rate of HAI for both wards combined: 12.4–10 Unit of measure: 100 admissions RR: NA CI: NA *P* value: < 0.05
Anderson et al. [48]	*C. difficile*	UV	Yes	No	Rate of colonization and rate of HAI (combined): 31.6–30.4 Unit of measure: 10,000 exposure days RR: 1.0 CI: 95%CI 0.57–1.75 *P* value: 0.997
Boyce et al. [32]	*C. difficile*	Liquid hydrogen peroxide	Yes	No	Rate of colonization and rate of HAI (combined): 1.0–0.56 Unit of measure: number of cases per 1000 patient days RR: NA CI: NA *P* value: NA Composite outcome (colonization + HAI rate of all microbes): 10.3–8.0 incidence rate ratio 0.77; *P* = 0.068; 95%CI 0.579–1.029
Ray et al. [39]	*C. difficile*	Training, monitoring and feedback	No	No	No data available for the intervention period. rate of colonization: NA rate of HAI for preintervention period only (intervention vs. control hospitals): 5.6–5.8 Unit of measure: 10,000 patient days RR: NA CI: NA *P* value: 0.8
Mitchell et al. [47]	*C. difficile*	Bundle	No	No	Rate of colonization: NA Rate of HAI: 2.34–2.52 Unit of measure: 10,000 occupied bed-days RR: 1.07 CI: 95%CI 0·88–1.30 *P* value: 0.4655
Anderson et al. [48]	*S. aureus*	UV	Yes	No	Rate of colonization and rate of HAI (combined): 50.3–36.5 Unit of measure: 10,000 exposure days RR: 0.78 CI: 95%CI 0.58–1.05 *P* value: 0.104
Anderson et al. [48]	*S. aureus*	Bleach	Yes	No	Rate of colonization and rate of HAI (combined): 50.3–48.2 Unit of measure: 10,000 exposure days RR: 1.00 CI: 95%CI 0.82–1.21 *P* value: 0.967
Anderson et al. [48]	*S. aureus*	Bundle: UV + bleach	Yes	No	Rate of colonization and rate of HAI (combined): 50.3–46.9 Unit of measure: 10,000 exposure days RR: 0.97 CI: 95%CI 0.78–1.22 *P* value: 0.819
Boyce et al. [32]	*S. aureus* (MRSA)	Liquid hydrogen peroxide	Yes	No	Rate of colonization and rate of HAI (combined): 2.79–1.96 Unit of measure: number of cases per 1,000 patient days RR: NA CI: NA *P* value: NA Composite outcome (colonization + HAI rate of all microbes): 10.3–8.0 incidence rate ratio 0.77; *P* = 0.068; 95%CI 0.579–1.029
Mitchell et al. [47]	*S. aureus*	Bundle	Yes	No	Rate of colonization: NA rate of HAI: 0.97–0.80 Unit of measure: 10,000 occupied bed-days RR: 0.82 CI: 95%CI 0.60–1.12 *P* value:0.2180
Anderson et al. [48]	VRE	UV	Yes	No	Rate of colonization and rate of HAI (combined): 63.4–29.4 Unit of measure: 10,000 exposure days RR: 0.41 CI: 95%CI 015–1.13 *P* value: 0.084
Anderson et al. [48]	VRE	Bleach	Yes	Yes	Rate of colonization and rate of HAI (combined): 63.4–31.9 Unit of measure: 10,000 exposure days RR: 0.43 CI: 95%CI 0.19–1.00 *P* value: 0.049
Anderson et al. [48]	VRE	Bundle: UV + bleach	Yes	Yes	Rate of colonization and rate of HAI (combined): 63.4–39.0 Unit of measure: 10,000 exposure days RR: 0.36 CI: 95%CI 0.18–0.70 *P* value: 0.003
Boyce et al. [32]	VRE	Liquid hydrogen peroxide	Yes	No	Rate of colonization and rate of HAI (combined): 6.6–5.49 Unit of measure: number of cases per 1,000 patient days RR: NA CI: NA P value: NA Composite outcome (colonization + HAI rate of all microbes): 10.3–8.0 incidence rate ratio 0.77; *P* = 0.068; 95%CI 0.579–1.029
Mitchell et al. [47]	VRE	Bundle	Yes	Yes	Rate of colonization: NA rate of HAI: 0.35–0.22 Unit of measure: 10,000 occupied bed-days RR: 0.63 CI: 95%CI 0.41–0.97 *P* value: 0.0340

Studies were selected if they had a quality rating of "A" or "B" (Table 4), used a control and if they studied the three most commonly-examined microorganisms

Significance of individual experiments on commonly studied microorganisms per method of intervention; systematic review

Table 6 Relation between the reduction in environmental bioburden and patient colonization or healthcare- associated infection following an environmental hygiene intervention; systematic review

From: Impact of environmental hygiene interventions on healthcare-associated infections and patient colonization: a systematic review

Authors	Interventions	Bioburden measurement: ATP/culture	Microorganisms with significant reduction for colonization	Microorganisms with significant reduction for HAI	Total microorganisms evaluated for colonization or HAI
Lowbury et al. [25]	Isolators for burn patients	Settle plates of *S. aureus*	NA	NA	*Coliform bacilli*, *P. aeruginosa*, *Proteus* sp., *S. aureus*
Wilcox et al. [44]	Hypochlorite, training	Culture of *C. difficile*	NA	*C. difficile*	*C. difficile*
Boyce et al. [31]	Gaseous hydrogen peroxide (HPV)	Culture of *C. difficile*	No	*C. difficile*	*C. difficile*
Salgado et al. [37]	Copper alloy-coating	Culture of MRSA, VRE, *A. baumanni*, *P. aeruginosa*, *E. coli*	Composite (MRSA, VRE)	Composite (MRSA, VRE)	MRSA, VRE
Mitchell et al. [46]	Gaseous HP (HPV) and liquid HP; monitoring, feedback	Culture of MRSA	MRSA	MRSA	MRSA
Anderson et al. [48]	UV-C terminal room disinfection ± Bleach	Culture of MRSA, VRE, *C. difficile*, MDR *A. baumannii*	VRE and composite (MDR *A. baumannii*, *S. aureus*, VRE)	VRE for bleach and bleach + UV arms	*C. difficile*, MDR *A. baumannii*, *S. aureus*, VRE
Boyce et al. [32]	Liquid HP, feedback	Culture of MRSA, VRE, *C. difficile*	No	No	*C. difficile*, MRSA, VRE
Green et al. [30]	Pulsed Xenon UV	Culture of (Bacillus spp., coagulase negative staphylococci, Micrococcus spp., Corynebacterium aurimucosum, Dietzia cinnamea, Moraxella osloensis, Sphingomonas paucimobilis, mold, other presumed environmental isolates (listed as large Gram-positive cocci, Gram-positive rods, or unknown/not described); gram negative rod, MDRO, *C. difficile)*	No	No	*C. difficile*, ESBL *Enterobacteriacae*, MDR P.aeruginosa, MRSA, *S. maltophilia*
Kovach et al. [24]	Pulsed Xenon UV	ATP; culture of gram-positive cocci or rod, gram-positive bacilli	No	NA	NA
Ray et al. [39]	Training, monitoring, feedback	ATP; culture of *C. difficile*	No	No	*C. difficile*
Kim et al. [34]	Photocatalyst antimicrobial coating (TiO2)	Culture of Staphylococcus spp., Bacillus spp.	MRSA	No	*A. baumannii*, *C. difficile*, MRSA, VRE
Wong et al. [42]	Training, education, color-coded wipes	ATP	NA	No	*C. difficile*, MRSA, VRE
Hung et al. [41]	Education, feedback, redesigned workflow	ATP; aerobic colony counts (ACC) of unknown micro-organisms	Composite (CRABC, MRSA, VRE)	No	CRABC, MRSA, VRE

ATP adenosine triphosphate, *CRBAC* Carbapenem-resistant *Acinetobacter baumannii* complex, *MRSA* multidrug-resistant *S. aureus*, *VRE* vancomycin-resistant enterococci, *N/A* not available

Bioburden (Table 6)
Fifty percent (13/26) of studies observed the impact of HEH interventions on environmental bioburden.[24,25,30–32,34,37,39,41,42,44,46,48] 100% of them demonstrated that the interventions decreased environmental bioburden. Over half (7/13) of the studies demonstrated bioburden reductions paralleled directly with a significant reduction in colonization/HAI for at least one of the microorganisms of interest.[31,34,37,41,44,46,48]

Interpretation

This systematic review demonstrated that interventions in environmental hygiene were often associated with a reduction in HAI in a seemingly causal way. Over half of studies demonstrated a significant decrease in colonization or HAI for all of the microorganisms tested. These results are indicative of the importance of environmental hygiene in patient safety.

There were major issues with both the heterogeneity of the interventions and the settings, as well with the quality in a number

of the studies, hence the sub analyses. There are relatively few high quality studies in HEH compared to other fields, and even the use of RCTs in the field is exceedingly rare.[11] One high-quality study[49] in particular would have been useful for the review, but was excluded due to a hand hygiene intervention. Often, the primary study outcome evaluated environmental bioburden. Though HAI or patient colonization was a secondary outcome obtained from hospital data, these studies were not necessarily designed and powered to analyze this outcome. The measurable impact of HEH is likely to be more apparent if future studies are sufficiently powered.

Most of the studies that did not show a statistically significant reduction in HAI or patient colonization nonetheless recommended their interventions for application because they did greatly reduce environmental bioburden.[28,32,38] Though eight studies had controls,[25,32,37,39,42,44,47,48] many had before-and-after study designs,[23,24,26–31,34–36,40,41,43,45,46] and thus did not implement appropriate controls. Two used similar institutions as "proxy" controls.[33,38] Often, studies used the baseline rate of colonization or HAI before the intervention was implemented, and attempted to account for some confounding factors such as hand hygiene, antimicrobial use, and seasonality of the diseases of interest. In retrospect, it may have been more useful to only analyze more recent studies, because the two that were published before 2000[25,28] (in 1971 and 1985, respectively) were exploring different research questions and microorganisms.

The success of the interventions also depended on which microorganisms were studied, and how successfully or not specific pathogens spread through the healthcare environment. For example, VRE, known to spread through the environment, was sometimes more successfully reduced than pathogens known to frequently spread through hands from patient to patient. One study[26] testing air filters gave further support to the fact that not all microorganisms are able to be transmitted by air, unlike what some manufacturers claim.

Considering the subset analysis targeted on specific pathogens, it is important to note that not all studies were designed to demonstrate the efficacy of a particular intervention on colonization/HAI, as this was not always the primary outcome. Some interventions were recommended by the authors for application because they demonstrated a significant reduction in some pathogens but not in others. Though these outcomes were often coupled with a significant decrease in environmental bioburden, some studies were not sufficiently powered to demonstrate that the reduction was statistically significant.

Overall, the selected studies were very heterogenous; both in terms of the types of interventions and their quality. The review attempts to address some of these limitations by performing subset analyses. However, the results reflect the reality of this field; there is a significant amount of work left to be done. Though COVID-19 has generated an increased global interest in HEH, the bulk of newer studies were performed during a pandemic, and were not included in this review, as interventions conducted during outbreak situations were excluded.

Conclusion

Although more high quality studies are needed, this review demonstrates a strong relation between interventions to improve HEH and a reduction in both environmental bioburden and in patient colonization or HAI. Optimal HEH practices are an integral part of patient safety and a key component to improving infection prevention and control. Healthcare institutions may be able to lower their HAI rates by improving HEH practices. The domain of HEH deserves further and better-designed field research.

Availability of data and materials

The datasets generated and/or analysed during the current study are available in PROSPERO repository, https://www.crd.york.ac.uk/PROSPEROFILES/204909_STRATEGY_20200908.pdf. All other data are all data generated or analysed during this study are included in this published article and its Additional file 1.

Abbreviations

ATP: Adenosine triphosphate

COI: Conflict of interest

HAI: Healthcare-associated infections

HCWs: Healthcare workers

HEH: Healthcare environmental hygiene

HEPA: High efficiency particulate air (filter)

ICU: Intensive care unit

IPC: Infection prevention and control

MDR: Multidrug resistant

MRSA: Multidrug-resistant *S. aureus*

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analysis

QAC: Quaternary ammonium compound

RCT: Randomized controlled trial

UVC: Ultraviolet-C light

VRE: Vancomycin-resistant *enterococci*

WHO: World Health Organization

References

1. Whitehead, H., May, D. & Agahi, H. An exploratory study into the factors that influence patients' perceptions of cleanliness in an acute NHS trust hospital. *J of Facilities Management* **5**, 275–289 (2007).

2. World Health Organization. Health care-associated infections FACT SHEET. (2021).

3. Colzani, E. *et al.* Results from the 2015 Burden of Communicable Diseases in Europe (BCoDE) study: Edoardo Colzani. *European Journal of Public Health* **25**, (2015).

4. Cassini, A. *et al.* Burden of Six Healthcare-Associated Infections on European Population Health: Estimating Incidence-Based Disability-Adjusted Life Years through a Population Prevalence-Based Modelling Study. *PLOS Medicine* **13**, e1002150 (2016).

5. Allegranzi, B. *et al.* Burden of endemic health-care-associated infection in developing countries: systematic review and meta-analysis. *The Lancet* **377**, 228–241 (2011).

6. Marchetti, A. & Rossiter, R. Economic burden of healthcare-associated infection in US acute care hospitals: societal perspective. *J Med Econ* **16**, 1399–1404 (2013).

7. Zimlichman, E. *et al.* Health Care–Associated Infections: A Meta-analysis of Costs and Financial Impact on the US Health Care System. *JAMA Intern Med* **173**, 2039 (2013).

8. Thibaud Vermeil *et al.* Hand Hygiene in hospitals: anatomy of a revolution. (2018).

9. Zingg, W. *et al.* Hospital organisation, management, and structure for prevention of health-care-associated infection: a systematic review and expert consensus. *Lancet Infect Dis* **15**, 212–224 (2015).

10. Schreiber, P. W. *et al.* The preventable proportion of healthcare-associated infections 2005-2016: Systematic review and meta-analysis. *Infect Control Hosp Epidemiol* **39**, 1277–1295 (2018).

11. Peters, A. *et al.* Keeping hospitals clean and safe without breaking the bank; summary of the Healthcare Cleaning Forum 2018. *Antimicrob Resist Infect Control* **7**, (2018).

12. Adams, J., Jamie, B. & Yves, C. Essential environmental health standards in health care. (2008).

13. Environmental Hygiene in Healthcare | HAI | CDC. https://www.cdc.gov/hai/research/eic-meeting.html (2019).

14. Kramer, A., Schwebke, I. & Kampf, G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infect Dis* **6**, 130 (2006).

15. Kramer, A. & Assadian, O. Survival of Microorganisms on Inanimate Surfaces. *Use of Biocidal Surfaces for Reduction of Healthcare Acquired Infections* 7–26 (2014) doi:10.1007/978-3-319-08057-4_2.

16. Dancer, S. J. Controlling Hospital-Acquired Infection: Focus on the Role of the Environment and New Technologies for Decontamination. *Clin. Microbiol. Rev.* **27**, 665–690 (2014).

17. Mitchell, B. G., Dancer, S. J., Anderson, M. & Dehn, E. Risk of organism acquisition from prior room occupants: a systematic review and meta-analysis. *Journal of Hospital Infection* **91**, 211–217 (2015).

18. PRISMA. http://prisma-statement.org/PRISMAStatement/Checklist.

19. Salsgiver, E. *et al.* Comparing the Bioburden Measured by Adenosine Triphosphate (ATP) Luminescence Technology to Contact Plate-Based Microbiologic Sampling to Assess the Cleanliness of the Patient Care Environment. *Infect Control Hosp Epidemiol* **39**, 622–624 (2018).

20. Ford, C. D. *et al.* Decrease in Vancomycin-Resistant Enterococcus Colonization After Extensive Renovation of a Unit Dedicated to the Treatment of Hematologic Malignancies and

Hematopoietic Stem-Cell Transplantation. *Infect Control Hosp Epidemiol* **38**, 1055–1061 (2017).

21. STROBE Statement: Available checklists. https://www.strobe-statement.org/index.php?id=available-checklists.

22. Wang, J. *et al.* The Prevalence of Healthcare-Associated Infections in Mainland China: A Systematic Review and Meta-analysis. *Infect Control Hosp Epidemiol* 1–9 (2018) doi:10.1017/ice.2018.60.

23. Brite, J. *et al.* Effectiveness of ultraviolet disinfection in reducing hospital-acquired Clostridium difficile and vancomycin-resistant Enterococcus on a bone marrow transplant unit. *Infect Control Hosp Epidemiol* **39**, 1301–1306 (2018).

24. Kovach, C. R. *et al.* Evaluation of an ultraviolet room disinfection protocol to decrease nursing home microbial burden, infection and hospitalization rates. *BMC Infect Dis* **17**, 186 (2017).

25. Lowbury, E. J., Babb, J. R. & Ford, P. M. Protective isolation in a burns unit: the use of plastic isolators and air curtains. *J Hyg (Lond)* **69**, 529–546 (1971).

26. Özen, 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. *Turk J Haematol* **33**, 41–47 (2016).

27. Vianna, P. G., Dale, C. R., Simmons, S., Stibich, M. & Licitra, C. M. Impact of pulsed xenon ultraviolet light on hospital-acquired infection rates in a community hospital. *Am J Infect Control* **44**, 299–303 (2016).

28. Anderson, J. D., Bonner, M., Scheifele, D. W. & Schneider, B. C. Lack of nosocomial spread of Varicella in a pediatric hospital with negative pressure ventilated patient rooms. *Infect Control* **6**, 120–121 (1985).

29. Haas, J. P., Menz, J., Dusza, S. & Montecalvo, M. A. Implementation and impact of ultraviolet environmental disinfection in an acute care setting. *Am J Infect Control* **42**, 586–590 (2014).

30. Green, C., Pamplin, J. C., Chafin, K. N., Murray, C. K. & Yun, H. C. Pulsed-xenon ultraviolet light disinfection in a burn unit: Impact on environmental bioburden, multidrug-resistant organism acquisition and healthcare associated infections. *Burns* **43**, 388–396 (2017).

31. Boyce, J. M. *et al.* Impact of hydrogen peroxide vapor room decontamination on Clostridium difficile environmental contamination and transmission in a healthcare setting. *Infect Control Hosp Epidemiol* **29**, 723–729 (2008).

32. Boyce, J. M. *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* **45**, 1006–1010 (2017).

33. Alfa, M. J., Lo, E., Olson, N., MacRae, M. & Buelow-Smith, L. Use of a daily disinfectant cleaner instead of a daily cleaner reduced hospital-acquired infection rates. *Am J Infect Control* **43**, 141–146 (2015).

34. Kim, M. H. *et al.* 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* **18**, 610 (2018).

35. Manian, F. A., Griesnauer, S. & Bryant, A. Implementation of hospital-wide enhanced terminal cleaning of targeted patient rooms and its impact on endemic Clostridium difficile infection rates. *Am J Infect Control* **41**, 537–541 (2013).

36. McCord, J., Prewitt, M., Dyakova, E., Mookerjee, S. & Otter, J. A. Reduction in Clostridium difficile infection associated with the introduction of hydrogen peroxide vapour automated room disinfection. *J Hosp Infect* **94**, 185–187 (2016).

37. Salgado, C. D. *et al.* Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit. *Infect Control Hosp Epidemiol* **34**, 479–486 (2013).

38. Daniels, T., Earlywine, M. & Breeding, V. Environmental services impact on healthcare-associated Clostridium difficile reduction. *Am J Infect Control* **47**, 400-405.e1 (2019).

39. Ray, A. J. *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* **38**, 777–783 (2017).

40. Smith, A. *et al.* Clostridium difficile infection incidence: impact of audit and feedback programme to improve room cleaning. *Journal of Hospital Infection* **92**, 161–166 (2016).

41. Hung, I.-C. *et al.* Implementation of human factors engineering approach to improve environmental cleaning and disinfection in a medical center. *Antimicrob Resist Infect Control* **9**, 17 (2020).

42. Wong, S. S. *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* **7**, 34 (2018).

43. Shaw, E. *et al.* Control of endemic multidrug-resistant Gram-negative bacteria after removal of sinks and implementing a new water-safe policy in an intensive care unit. *Journal of Hospital Infection* **98**, 275–281 (2018).

44. Wilcox, M. H. *et al.* Comparison of the effect of detergent versus hypochlorite cleaning on environmental contamination and incidence of Clostridium difficile infection. *J Hosp Infect* **54**, 109–114 (2003).

45. Fisher, D. *et al.* A Successful Vancomycin-Resistant Enterococci Reduction Bundle at a Singapore Hospital. *Infect Control Hosp Epidemiol* **37**, 107–109 (2016).

46. Mitchell, B. G., Digney, W., Locket, P. & Dancer, S. J. Controlling methicillin-resistant Staphylococcus aureus (MRSA) in a hospital and the role of hydrogen peroxide decontamination: an interrupted time series analysis. *BMJ Open* **4**, e004522 (2014).

47. Mitchell, B. G. *et al.* An environmental cleaning bundle and health-care-associated infections in hospitals (REACH): a multicentre, randomised trial. *The Lancet Infectious Diseases* **19**, 410–418 (2019).

48. Anderson, D. J. *et al.* Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and Clostridium difficile (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. *Lancet* **389**, 805–814 (2017).

49. Martin, E. K. *et al.* Sustained improvement in hospital cleaning associated with a novel education and culture change program for environmental services workers. *Infect Control Hosp Epidemiol* **40**, 1024–1029 (2019).

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Contributions

AP, DP, PP and WZ worked on the conceptualization of search strategy and review. AP and DL developed the initial search strategy and did the title/abstract reviews. AP and MS performed the full text analysis. AP, MS, PP, JS, and MdK performed the data analysis and wrote the table. AP wrote the manuscript. All authors worked on editing the manuscript. All authors read and approved the final manuscript.

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Ethical approval was not needed for this review.
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All authors consent to publication of this paper.
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Supplementary information

Additional file 1:
Full search strategy for the systematic review on the impact of environmental hygiene interventions on healthcare-associated infections and patient colonization.

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Major Article

Results of an international pilot survey on health care environmental hygiene at the facility level

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Key Words:
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Background: Health care-associated infections (HAIs) are a major threat to patient safety worldwide. The importance of the health care environment in patient care is not always adequately addressed. Currently, no overview exists of how health care environmental hygiene (HEH) is performed around the world.
Methods: Our pilot survey tested a preliminary version of a framework for HEH self-assessment. It aimed to gather data to improve the framework as well as evaluate the strengths and challenges in HEH programs around the world, and across resource levels. The survey was developed by a group of experts, and based on the hand hygiene multimodal improvement strategy. The online survey was sent to 743 health care facilities (HCFs) from all of the World Bank income levels, aiming for at least 4 participants from each level. Overall responses were analyzed as a group as well as stratified per income level using OpenEpi.
Results: Overall, 51 HCFs from 35 countries participated. Almost all HCFs surveyed (50/51, 98%) were found lacking in some or all of the 5 components of the WHO multimodal strategy independent of income level. The results demonstrate the widespread challenges in HEH institutions are facing around the world.
Conclusion: The feedback from survey participants allowed for the improvement of the self-assessment tool. There is a clear need for more focus on and investment in HEH programs in HCFs worldwide.

BACKGROUND

Healthcare-associated infections (HAIs) are one of the main causes of patient morbidity and mortality worldwide.[1] The importance of healthcare environmental hygiene (HEH) for patient safety is becoming increasingly recognized in the literature,[2–5] but often remains a neglected component of infection prevention and control (IPC).[6] IPC programs are the foundation for preventing pathogen transmission which can lead to HAIs and antimicrobial resistance, as well as for ensuring preparedness for emergencies such as the COVID-19 pandemic.[7,8]

Many healthcare institutions do not focus adequately on the environment; it is common knowledge that departments

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responsible for HEH face numerous challenges including limited budgets, an unstable and often uneducated workforce, a lack of evidence-based practices, and a lack of access to safe and effective products.6 To date, there is no comprehensive global overview of how HEH is performed in healthcare facilities (HCFs) around the world, nor is there an aggregated body of qualitative data on the challenges institutions face, whether in terms of resources, social, or cultural factors.

According to the WHO, baseline assessments and regular monitoring and evaluation activities are an essential component of IPC implementation and quality improvement in healthcare.[9] Though not specifically addressing HEH, two IPC self-assessment tools have previously been implemented by the WHO in collaboration with the University of Geneva Hospitals and Faculty of Medicine IPC program.[9,10] The hand hygiene self-assessment framework (HHSAF) enables HCFs to generate a situational analysis of hand hygiene promotion capacities and practices according to a set of indicators.[10,11] Over the last decade, WHO has conducted three global surveys of the HHSAF, allowing insights into global hand hygiene practices worldwide.[12–14] In 2018, WHO launched the IPC self-assessment framework (IPCAF) to support the implementation of the IPC core components at national and acute HCF levels.[7,9] Both of these tools are structured questionnaires that allow HCFs to measure their current level of IPC or hand hygiene implementation, benchmarked against other HCFs, as well as provide the opportunity to measure progress of their HCFs over time.[12,14]

Our research team is currently working on the development of a similar tool for HEH, the Healthcare Environmental Hygiene Self-Assessment Framework (HEHSAF). The HEHSAF will aim to help facilities' HEH programs evaluate their strengths and challenges in their current way of working and their improvement over time. Its subsequent implementation will provide the first ever global snapshot of HEH at the facility level. Initially, the research team studied HEH in detail in a few reference hospitals and visited a number of HCFs around the world. In order to gather additional data, the current pilot survey was developed with input from a group of approximately ten international experts through the Clean Hospitals® project.[15]

This pilot survey's primary objective is to test a preliminary version of the HEHSAF in order to ensure that the tool would be inclusive and globally applicable across resource levels. Its secondary objective is to analyze preliminary data on how HEH programs work and what challenges they face. Feedback from HCFs to the pilot survey questions was assessed, and will be used to adjust the HEHSAF tool accordingly.

METHODS

The survey was conducted from April 16th - June 30th, 2021. A digital link to the online survey was sent to 743 HCFs from a database of 18,443 HCFs around the world that had participated in at least one of the HHSAF surveys.[16–18] The data the research group received included only country name, name of HCF and contact email.

Due to the exploratory nature of this work, a self-selecting survey approach was used instead of a population-based one; all types of HCFs were included with no mechanism to ensure even distribution among primary/ secondary/ tertiary care centers or private vs. public HCFs. The survey aimed to gather responses from a minimum

four HCFs from each of the four country income levels as defined by the World Bank.[19] All quantitative data from completed survey forms were included in the overall analysis as well as stratified by income level. OpenEpi was used for the analysis.

The two first HCFs per country were chosen from the database of all available countries; the database was not in any kind of discernible order. This approach resulted in an initial list of 343 HCFs from 163 countries. Any emails returned from the server and no longer in use were replaced with emails from other HCFs in the same country, and sent out during the second round of emails on April 29th. After the first round of invitations, the number of responses per country income level were recorded, and additional HCFs were invited to participate to ensure coverage for regions with less than four responses. All HCFs surveyed were included in the analysis, including those where individual responses were omitted. If one HCF completed the survey more than once, only the most recent was retained for analysis.

The 39-question-online survey was created using the SurveyHero® tool, and its contents organized around the elements of the WHO Multimodal Hand Hygiene Improvement Strategy.[20,21] It included questions on participant and facility characteristics, protocols, practices, staffing, training, management, work culture, as well as on the appropriateness of the survey (Appendix 1). The survey was in English; Google Translate was used when needed for the free text responses. For the subset analysis by income level, only the smallest and largest HCFs from Croatia's participants were included because of the disproportionately large number of participants (see below).

As this survey was conducted at the facility level, consent was not needed. All access to respondent data was restricted to the research team. Participation was voluntary and respondents were provided with clear background information on the purpose of the survey. All identifying data were anonymized and aggregated when made available for publication. The data are property of University of Geneva Hospitals and Faculty of Medicine.

RESULTS

A total of 51 HCFs from 35 countries completed the survey (Figure 1). Most countries had only one HCF respond, with the exception of the Democratic Republic of Congo (N=2), and Croatia (N=16). Though the survey was only sent to two Croatian HCFs, the one that responded shared the survey among other HCFs that were not initially contacted, accounting for the disproportionately high response rate from this country. Overall, only 36 of the 743 HCFs initially contacted completed the survey, resulting in a response rate of 4.8% (36/743). In total, 42 surveys were complete and nine had missing answers, mainly for questions concerning HCF characteristics, system change, and work culture.

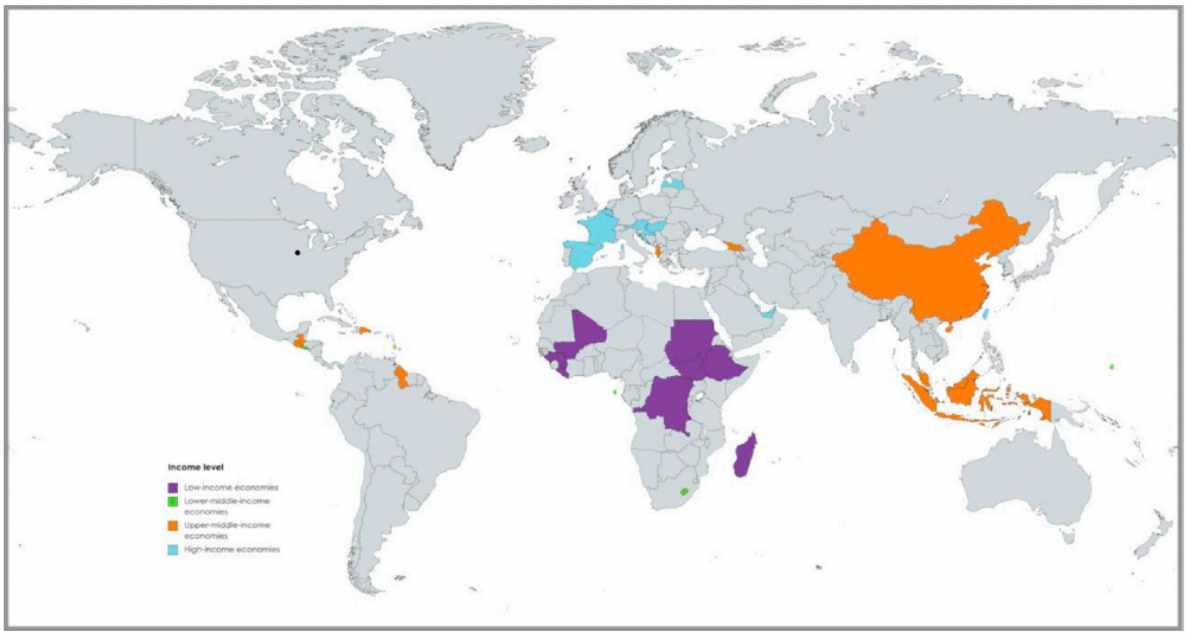

Fig 1. Health care facility participation in the pilot survey; geographic distribution; facilities N = 51; countries N = 35.

HCFs country distribution by income level was the following: high-income countries (13/35, 37%), upper-middle income countries (9/35, 26%), lower-middle income countries (5/35, 14%), and low-income countries (8/35, 23%).[19] The majority of HCFs (28/51, 55%) had between 100 and 500 beds. Over half of HCFs (33/49, 67%) always had HEH products and supplies available (Table 1).

Concerning participant characteristics, 96% (47/49) of respondents made decisions with regards to how their HCF was cleaned, indicating that the survey reached the intended target population. Almost half (23/51, 45%) were able to make budgetary decisions regarding HEH, and 64% (23/36) had over ten years of experience. Overall, 71% of respondents (35/49) felt that their HCF gave enough importance to HEH, and 47% (21/45) felt that the budget allocated for cleaning and disinfection was adequate (Table 1). Overall, 98% (50/51) of HCFs surveyed were found lacking in some or all of the five components of the WHO multimodal strategy independent of income level.

System change

These results concern the availability of appropriate cleaning products and supplies for HEH. Overall, products and supplies were always available in 67% (33/49) of HCFs, and rarely or not available in 6% (3/49) (Table 1). HEH products and supplies were designated as always appropriate in 63% (31/49), and rarely or not appropriate in 2% (1/49) of HCFs surveyed.

Table 1
Health care facility and respondent characteristics; total responses to questionnaire and subgroup analysis by income level; N = 51; pilot survey*

HEH element or practice	Total % (responses)	Estimate (95% CI)	Higher income % (responses)	Estimate (95% CI)	Lower income % (responses)	Estimate (95% CI)
Facility characteristics						
Number of beds						
> 500	25.49% (13/51)	13.53-37.45	47.83% (11/23)	27.41-68.24	0.00% (0/14)	0.00-23.16
101-500	54.90% (28/51)	41.25-68.56	26.09% (6/23)	8.14-44.03	78.57% (11/14)	57.08-100.00
0-100	17.64% (9/51)	7.19-28.11	21.74% (5/23)	4.883-38.6	21.43% (3/14)	4.66-50.80
Unknown	1.96% (1/51)	0.05-10.45	4.35% (1/23)	0.12-21.95	0.00% (0/14)	0.00-23.16
Availability of products and supplies						
Always	67.34% (33/49)	54.22-80.48	77.27% (17/22)	59.76-94.78	21.43% (3/14)	4.66-50.80
Sometimes	26.53% (13/49)	14.17-38.89	18.18% (4/22)	5.19-40.28	64.29% (9/14)	39.19-89.38
Never or rarely	6.12% (3/49)	1.28-16.87	4.55% (1/22)	0.12-22.84	14.29% (2/14)	1.78-42.81
Appropriateness of products and supplies						
Always	63.26% (31/49)	49.77-76.76	77.27% (17/22)	59.76-94.78	14.29% (2/14)	1.78-42.81
Sometimes	34.69% (17/49)	21.37-48.02	22.73% (5/22)	5.22-40.24	78.57% (11/14)	57.08-100.00
Never or rarely	2.04% (1/49)	1.28-16.87	0.00% (0/22)	0.00-15.44	7.14% (1/14)	0.18-33.87
Respondent characteristics						
Experience						
> 10 years in current position	63.88% (23/36)	48.20-79.58	73.69% (14/19)	53.89-93.48	66.66% (6/9)	2.54-64.13
IPC-related job description	44% (22/50)	30.24-57.76	43% (10/23)	23.22-63.74	29% (4/14)	8.39-58.1
Responsibilities						
HEH decision-making	95.91% (47/49)	90.38-100.00	90.47% (19/21)	77.92-100	100.00% (14/14)	100.00-100.00
Knowing HEH budget	48.97% (24/49)	34.98-62.98	38.10% (8/21)	17.33-58.86	50.00% (7/14)	23.81-76.19
Developing HEH budget	45.09% (23/51)	31.44-58.75	26.08% (6/23)	8.14-44.03	71.42% (10/14)	47.77-95.09
Number of people managed						
>50	36.73% (18/49)	23.24-50.23	28.57% (6/21)	9.25-47.89	57.14% (8/14)	16.94-68.78
10-50	26.53% (13/49)	14.17-38.89	19.05% (4/21)	5.45-41.91	21.43% (3/14)	4.66-50.80
<10	28.57% (14/49)	15.92-41.22	38.10% (8/21)	17.33-58.86	21.43% (3/14)	4.66-50.80
0	8.16% (4/49)	2.27-19.60	14.29% (3/21)	3.05-36.34	0.00% (0/14)	0.00-23.16
Opinions						
HCF gives sufficient importance to HEH	71.42% (35/49)	58.78-84.08	80.95% (17/21)	64.16-97.75	57.14% (8/14)	31.22-83.06
HEH budget is sufficient	46.66% (21/45)	32.09-61.24	44.44% (8/18)	21.49-67.40	15.38% (2/13)	1.92-45.45

NOTE. Only the smallest and largest of the Croatian hospital responses were included in the analyses by income level. All CI were calculated using Wald (Normal Approx.) method unless less than 5 in which case Fisher Exact (Clopper-Pearson) was used.
HEH, health care environmental hygiene; HCF, health care facility; IPC, Infection prevention and control.
*For the income level subset analysis, responses from countries were combined; high income and upper-middle income economies formed the "higher income countries" (HIC) group, and low income and lower-middle income countries formed the "lower income countries" (LIC) group.

Fifty-two percent (26/50) of HCFs responded that all HEH protocols were based on best practice and updated regularly, while 14% (7/50) reported that available protocols were not based on current best practice or were not available at all (Table 2). Seventy percent (35/50) of HCFs adapted all their HEH protocols to different risk zones, while 6% (3/50) did not.

Respondents reported using a number of products and supplies for surfaces (Table 2). Only one HCF (1/50) did not report using any type of disinfectant. Ninety-four percent (47/50) used detergent, either alone or in a product combined with a disinfectant (Table 2). For manual cleaning, 84% (42/50) of HCFs reported using wipes, cloths or sponges. Traditional mop and buckets were still used in most HCFs, and only 4% (2/50) reported using bucket-less mopping systems exclusively. Fifty-four percent (27/50) of HCFs used larger mechanical cleaning machines for cleaning floors or large surfaces. Half (25/50) of HCFs performed automated disinfection, either with UV or gaseous hydrogen peroxide (Table 2).

Table 2
Health care facility responses concerning environmental hygiene protocols and treatment of surfaces; total responses to questionnaire and subgroup analysis by income level; N = 51; pilot survey*

HEH element or practice	Total % (responses)	Estimate (95% CI)	Higher income % (responses)	Estimate (95% CI)	Lower income % (responses)	Estimate (95% CI)
Protocols						
Availability of HEH protocols						
Yes, based on current best practice and updated regularly	52.00% (26/50)	38.15-65.85	69.57% (16/23)	50.76-88.37	21.43% (3/14)	4.66-50.80
Yes, sometimes based on current best practice	34.00% (17/50)	20.87-47.13	21.74% (5/23)	4.883-38.6	50.00% (7/14)	23.81-76.19
Yes, not based on current best practice	8.00% (4/50)	2.22-19.23	0.00% (0/23)	0.00-14.82	21.43% (3/14)	4.66-50.80
No	6.00% (3/50)	1.26-16.55	8.70% (2/23)	1.07-28.04	7.14% (1/14)	0.18-33.87
Adaptation of HEH protocols to risk zones						
Adaptation to each risk zone	70.00% (35/50)	57.30-82.70	82.61% (19/23)	67.12-98.1	28.57% (4/14)	8.39-58.10
Adaptation exclusively to high-risk zones	24.00% (12/50)	12.16-35.84	13.04% (3/23)	2.78-33.59	57.14% (8/14)	31.22-83.06
No adaptation	6.00% (3/50)	1.26-16.55	4.35% (1/23)	0.11-21.95	14.29% (2/14)	1.78-42.81
Surfaces						
Cleaning and disinfecting products						
Bleach or chlorine-based disinfectant	82.00% (41/50)	71.35-92.65	73.91% (17/23)	55.97-91.86	92.86% (13/14)	79.37-100.00
Detergent	80.00% (40/50)	68.91-91.09	73.91% (17/23)	55.97-91.86	85.71% (12/14)	67.39-100.00
Product combining detergent and disinfectant	72.00% (36/50)	59.56-84.44	73.91% (17/23)	55.97-91.86	57.14% (8/14)	31.22-83.06
Quaternary ammonium disinfectant	50.00% (25/50)	36.14-63.86	60.87% (14/23)	40.93-80.81	28.57% (4/14)	8.39-58.10
Cleaning supplies for small surfaces						
Wipes or cloths	78.00% (39/50)	66.52-89.48	78.26% (18/23)	61.4-95.12	64.29% (9/14)	39.19-89.38
Sponges	42.00% (21/50)	28.32-55.68	39.13% (9/23)	19.19-59.07	28.57% (4/14)	8.39-58.10
Cleaning supplies for floors						
Mop and bucket systems	84.00% (42/50)	73.84-94.16	86.96% (20/23)	73.19-100.00	85.71% (12/14)	67.39-100.00
Bucketless mopping systems	32.00% (16/50)	19.07-44.93	17.39% (4/23)	4.95-38.78	28.57% (4/14)	8.39-58.10
Manual cleaning machines						
Cleaning machines for floors or large surfaces	54.00% (27/50)	40.19-67.81	60.87% (14/23)	40.93-80.81	7.14% (1/14)	0.18-33.87
Automated disinfection machines						
UVC	38.00% (19/50)	24.55-51.45	47.83% (11/23)	27.41-68.24	0.00% (0/14)	0.00-23.16
Gaseous hydrogen peroxide	32.00% (16/50)	19.07-44.93	30.43% (7/23)	11.63-49.24	0.00% (0/14)	0.00-23.16
Other						
Additional products and supplies used	16.00% (8/50)	5.84-26.16	13.04% (3/23)	2.78-33.59	7.14% (1/14)	0.18-33.87
No products and supplies available	0.00% (0/50)	0.00-7.11	0.00% (0/23)	0.00-14.82	0.00% (0/14)	0.00-23.16

NOTE. Only the smallest and largest of the Croatian hospital responses were included in the analyses by income level. All CI were calculated using Wald (Normal Approx.) method unless less than 5 in which case Fisher Exact (Clopper-Pearson) was used.
HEH, health care environmental hygiene; UVC, ultraviolet-C light.
*For the income level subset analysis, responses from countries were combined; high income and upper-middle income economies formed the "higher income countries" (HIC) group, and low income and lower-middle income countries formed the "lower income countries" (LIC) group.

Ninety-two percent (45/49) of HCFs had equipment for the heat sterilization of instruments but only 69% (34/49) had adequate products available to do so (Table 3). Sixty-seven percent (33/49) had equipment for the chemical sterilization and 71% (35/49) had the necessary products available. In HCFs where equipment and supplies were available, 16% (8/49) could still not perform adequate sterilization, as the equipment was not in good working condition. Six percent (3/49) of HCFs outsourced sterilization (Table 3).

Ninety-eight percent (49/50) of HCFs used sharps containers, and 88% (44/50) separated normal waste from medical or hazardous waste (Table 3). Eighty-two percent (41/50) used waste collection services, but only 26% (13/50) recycled. Twenty six percent (13/50) of HCFs used landfill sites for waste disposal, and 22% (11/50) had an open dump site nearby. Eighteen percent (9/50) of institutions had machines to shred and sterilize waste (Table 3).

Eighty percent (40/50) of the surveyed HCFs had windows that could be opened, and the same proportion had a ventilation system (Table 4). Seventy percent (35/50) of HCFs used either HEPA filtration or other air filtration systems, such as air conditioners, when needed. Eighty-two percent (41/50) of HCFs surveyed had clean water, 84% (42/50) had running water and 56% (28/50) had water filters available when needed (Table 4). Sixty-two percent (31/50) of HCFs washed laundry with detergent and the same number used laundry disinfectant.

Fifty-six percent (28/50) had on-site washing machines, and 40% (20/50) of HCFs outsourced laundry to an external provider (Table 4).

Training and education

Eighty-four percent (41/49) of HCFs employed environmental services (EVS) staff directly, while others outsourced their EVS staff (Table 5). Eighty-six percent (43/50) of HCFs provided on-the-job training; other methods were used less frequently (Table 5). Six percent (3/50) of HCFs did not know what type of training their EVS staff received, or did not provide any training at all. Only 22% (11/50) of HCFs provided or required (if staff was outsourced) comprehensive formal training upon hiring; 28% (14/50) did not provide or require any formal training at all (Table 5). Forty-six percent (23/50) of HCFs provided regular additional training at least once per year, while 10% (5/50) did not propose any additional training. Seventy-five percent (36/48) of HCFs did not provide their EVS staff access to any certification programs. Unsurprisingly, the same proportion of institutions did not make it possible for EVS staff to advance into management roles.

Table 3
Health care facility responses concerning sterilization and waste management; total responses to questionnaire and subgroup analysis by income level; N = 51; pilot survey*

HEH element or practice	Total % (responses)	Estimate (95% CI)	Higher income % (responses)	Estimate (95% CI)	Lower income % (responses)	Estimate (95% CI)
Sterilization						
Heat sterilization of instruments						
Equipment available	91.83% (45/49)	84.17-99.50	82.61% (19/23)	67.12-98.1	100.00% (14/14)	100.00-100.00
Products available	69.38% (34/49)	56.48-82.29	78.26% (18/23)	61.4-95.12	42.86% (6/14)	16.94-68.78
Chemical sterilization of instruments						
Products available	71.42% (35/49)	58.78-84.08	82.61% (19/23)	67.12-98.1	35.71% (5/14)	10.62-60.81
Equipment available	67.34% (33/49)	54.22-80.48	82.61% (19/23)	67.12-98.1	28.57% (4/14)	8.39-58.10
Other						
Some supplies available, but sterilization inadequate	16.32% (8/49)	5.98-26.67	8.70% (2/23)	1.07-28.04	42.86% (6/14)	16.94-68.78
Proper sterilization not available	8.16% (4/49)	2.27-19.60	4.35% (1/23)	0.11-21.95	21.43% (3/14)	4.66-50.80
Sterilization is outsourced	6.12% (3/49)	1.28-16.87	13.04% (3/23)	2.78-33.59	0.00% (0/14)	0.00-23.16
Unknown	2.04% (1/49)	0.051-10.85	4.35% (1/23)	0.11-21.95	0.00% (0/14)	0.00-23.16
Waste management						
Waste management supplies						
Containers for sharps	98.00% (49/50)	94.12-100	100.00% (23/23)	100.00-100.00	92.86% (13/14)	79.37-100.00
Separation of normal and medical or hazardous waste	88.00% (44/50)	78.99-97.01	91.30% (21/23)	79.79-100.00	71.43% (10/14)	47.77-95.09
Machines to shred and sterilize	18.00% (9/50)	7.35-28.65	26.09% (6/23)	8.14-44.03	0.00% (0/14)	0.00-23.16
Waste management services						
Waste collection services	82.00% (41/50)	71.35-92.65	95.65% (22/23)	87.32-100.00	78.57% (11/14)	57.08-100.00
External treatment of medical waste only	44.00% (22/50)	30.24-57.76	43.48% (10/23)	23.22-63.74	28.57% (4/14)	8.39-58.10
External treatment of solid waste	40.00% (20/50)	26.42-53.58	30.43% (7/23)	11.63-49.24	28.57% (4/14)	8.39-58.10
Recycling	26.00% (13/50)	13.84-38.16	43.48% (10/23)	23.22-63.74	7.14% (1/14)	0.18-33.87
Access to a sewage treatment system	22.00% (11/50)	10.52-33.48	21.74% (5/23)	4.883-38.6	21.43% (3/14)	4.66-50.80
Unknown	0.00% (0/50)	0.00-7.11	0.00% (0/23)	0.00-14.82	0.00% (0/14)	0.00-23.16
Other solid waste disposal						
Use of landfill	26.00% (13/50)	13.84-38.16	30.43% (7/23)	11.63-49.24	28.57% (4/14)	8.39-58.10
Open dump sites < 100 meters of hospital	14.00% (7/50)	4.38-23.62	8.70% (2/23)	1.07-28.04	21.43% (3/14)	4.66-50.80
Open dump sites > 100 meters of hospital	8.00% (4/50)	2.22-19.23	8.70% (2/23)	1.07-28.04	7.14% (1/14)	0.18-33.87

NOTE. Only the smallest and largest of the Croatian hospital responses were included in the analyses by income level. All CI were calculated using Wald (Normal Approx.) method unless less than 5 in which case Fisher Exact (Clopper-Pearson) was used.
HEH, health care environmental hygiene.
*For the income level subset analysis, responses from countries were combined; high income and upper-middle income economies formed the "higher income countries" (HIC) group, and low income and lower-middle income countries formed the "lower income countries" (LIC) group.

Table 4
Health care facility responses concerning water and air management and laundry; total responses to questionnaire and subgroup analysis by income level; N = 51; pilot survey*

HEH element or practice	Total % (responses)	Estimate (95% CI)	Higher income % (responses)	Estimate (95% CI)	Lower income % (responses)	Estimate (95% CI)
Water						
Running water	84.00% (42/50)	73.84-94.16	78.26% (18/23)	61.4-95.12	85.71% (12/14)	67.39-100.00
Clean water	82.00% (41/50)	71.35-92.65	91.30% (21/23)	79.79-100.00	57.14% (8/14)	31.22-83.06
Additional water filtration when needed	56.00% (28/50)	42.24-69.76	78.26% (18/23)	61.4-95.12	21.43% (3/14)	4.66-50.80
Unknown	0.00% (0/50)	0.00-7.11	0.00% (0/23)	0.00-14.82	0.00% (0/14)	0.00-23.16
Air						
Windows than can be opened	80.00% (40/50)	68.91-91.09	65.22% (15/23)	45.75-84.68	92.86% (13/14)	79.37-100.00
Ventilation system	80.00% (40/50)	68.91-91.09	95.65% (22/23)	87.32-100.00	50.00% (7/14)	23.81-76.19
HEPA filtration where needed	60.00% (30/50)	46.42-73.58	86.96% (20/23)	73.19-100.00	21.43% (3/14)	4.66-50.80
Other air filtration systems	10.00% (5/50)	1.69-18.31	13.04% (3/23)	2.78-33.59	7.14% (1/14)	0.18-33.87
Unknown	2.00% (1/50)	0.05-10.65	4.35% (1/23)	0.11-21.95	0.00% (0/14)	0.00-23.16
Laundry						
Laundry products						
Detergent	62.00% (31/50)	48.55-75.45	52.17% (12/23)	31.76-72.59	64.29% (9/14)	39.19-89.38
Disinfectant	62.00% (31/50)	48.55-75.45	52.17% (12/23)	31.76-72.59	64.29% (9/14)	39.19-89.38
Laundry machines						
On-site washing	56.00% (28/50)	42.24-69.76	47.83% (11/23)	27.41-68.24	57.14% (8/14)	31.22-83.06
On-site drying	50.00% (25/50)	36.14-63.86	43.48% (10/23)	23.22-63.74	35.71% (5/14)	10.62-60.81
Laundry services						
Laundry outsourced	40.00% (20/50)	26.42-53.58	56.52% (13/23)	36.26-76.78	21.43% (3/14)	4.66-50.80
Unknown	4.00% (2/50)	0.49-13.71	4.35% (1/23)	0.11-21.95	7.14% (1/14)	0.18-33.87

NOTE. Only the smallest and largest of the Croatian hospital responses were included in the analyses by income level. All CI were calculated using Wald (Normal Approx.) method unless less than 5 in which case Fisher Exact (Clopper-Pearson) was used.
HEH, health care environmental hygiene; HEPA, high-efficiency particulate air.
*For the income level subset analysis, responses from countries were combined; high income and upper-middle income economies formed the "higher income countries" (HIC) group, and low income and lower-middle income countries formed the "lower income countries" (LIC) group.

Table 5
Health care facility responses concerning staffing and training in environmental hygiene; total responses to questionnaire and subgroup analysis by income level; N= 51; pilot survey*

HEH element or practice	Total % (responses)	Estimate (95% CI)	Higher income % (responses)	Estimate (95% CI)	Lower income % (responses)	Estimate (95% CI)
Staffing						
Employment of EVS staff						
In-house	83.67% (41/49)	73.33-94.02	69.57% (16/23)	50.76-88.37	100% (13/13)	100.00-100.00
Outsourced	16.32% (8/49)	5.98-26.67	30.43% (7/23)	11.63-49.24	0.00% (0/13)	0.00-24.71
Availability of certifications						
Regional or National	14.58% (7/48)	4.60-24.57	9.09% (2/22)	1.12-29.16	7.14% (1/14)	0.18-33.87
Institutional	10.41% (5/48)	1.78-19.06	9.09% (2/22)	1.12-29.16	14.29% (2/14)	1.78-42.81
None	75.00% (36/48)	62.75-87.25	81.82% (18/22)	65.7-97.93	78.57% (11/14)	57.08-100.00
Training						
Type of training						
On the job training	86.00% (43/50)	78.58-96.93	86.96% (20/23)	73.19-100	85.71% (12/14)	67.39-100.00
Manuals	52.00% (26/50)	38.15-65.85	56.52% (13/23)	36.26-76.78	35.71% (5/14)	10.62-60.81
Classroom	50.00% (25/50)	36.14-63.86	56.52% (13/23)	36.26-76.78	35.71% (5/14)	10.62-60.81
E-learning	18.00% (9/50)	7.35-28.65	26.09% (6/23)	8.14-44.03	7.14% (1/14)	0.18-33.87
Unknown	6.00% (3/50)	1.26-16.55	8.70% (2/23)	1.07-28.04	7.14% (1/14)	0.18-33.87
Other (no training given)	4.00% (2/50)	0.49-13.71	4.35% (1/23)	0.11-21.95	7.14% (1/14)	0.18-33.87
Formal training requirement						
Comprehensive training	22.00% (11/50)	10.52-33.48	30.43% (7/23)	11.63-49.24	7.14% (1/14)	0.18-33.87
Some training	50.00% (25/50)	36.14-63.86	47.83% (11/23)	27.41-68.24	57.14% (8/14)	31.22-83.06
No training	28.00% (14/50)	15.56-40.44	21.74% (5/23)	4.883-38.6	35.71% (5/14)	10.62-60.81
Additional training						
Once per year or more	46.00% (23/50)	32.19-59.81	56.52% (13/23)	36.26-76.78	14.29% (2/14)	1.78-42.81
Less than once per year	20.00% (10/50)	8.91-31.09	8.70% (2/23)	1.07-28.04	35.71% (5/14)	10.62-60.81
Only for specific contexts or environments	24.00% (12/50)	12.16-35.84	21.74% (5/23)	4.883-38.6	35.71% (5/14)	10.62-60.81
None	10.00% (5/50)	1.69-18.31	13.04% (3/23)	2.78-33.59	14.29% (2/14)	1.78-42.81

NOTE. Only the smallest and largest of the Croatian hospital responses were included in the analyses by income level. All CI were calculated using Wald (Normal Approx.) method unless less than 5 in which case Fisher Exact (Clopper-Pearson) was used.
HEH, health care environmental hygiene; EVS, environmental services.
*For the income level subset analysis, responses from countries were combined; high income and upper-middle income economies formed the "higher income countries" (HIC) group, and low income and lower-middle income countries formed the "lower income countries" (LIC) group.

Monitoring and feedback

Monitoring and feedback of EVS staff performance and effectiveness of cleaning practices is essential to ensure and improve quality of environmental cleaning. Overall, 87% (42/48) of HCFs monitored staff performance (Table 6). Sixty percent (29/48) of HCFs gave immediate feedback at the individual level and 27% (13/48) gave systematic feedback at the team level. Seventy-seven percent (37/48) of HCFs reported usually giving constructive feedback; other institutions either usually gave punitive or no feedback. Twenty-three percent (11/47) of HCFs always had EVS staff managers on-site, and 49% (23/47) were on-site less than once per week or not at all (Table 6).

Table 6
Health care facility responses concerning environmental hygiene monitoring, management and workplace reminders; total responses to questionnaire and subgroup analysis by income level; N = 51; pilot survey*

HEH element or practice	Total % (responses)	Estimate (95% CI)	Higher income % (responses)	Estimate (95% CI)	Lower income % (responses)	Estimate (95% CI)
Monitoring and feedback						
Frequency of visual monitoring						
4 times per year or more with additional monitoring methods	41.66% (20/48)	27.72-55.61	50.00% (11/22)	29.11-70.89	28.57% (4/14)	8.39-58.10
4 times per year or more	22.92% (11/48)	11.03-34.81	22.73% (5/22)	5.22-40.24	28.57% (4/14)	8.39-58.10
< 4 times per year	22.92% (11/48)	11.03-34.81	13.64% (3/22)	2.91-34.91	28.57% (4/14)	8.39-58.10
No visual monitoring	12.50% (6/48)	3.15-21.86	13.64% (3/22)	2.91-34.91	14.29% (2/14)	1.78-42.81
Manner of feedback typically given						
Immediately (individual level)	60.41% (29/48)	46.58-74.25	54.55% (12/22)	33.74-75.35	64.29% (9/14)	39.19-89.38
Systemically (team level)	27.08% (13/48)	14.51-39.65	36.36% (8/22)	16.26-56.46	21.43% (3/14)	4.66-50.80
No feedback given	12.50% (6/48)	3.15-21.86	9.09% (2/22)	1.12-29.16	14.29% (2/14)	1.78-42.81
Type of feedback typically given						
Constructive with a plan for improving performance	33.33% (16/48)	20-46.67	31.82% (7/22)	12.36-51.28	28.57% (4/14)	8.39-58.10
Constructive	43.75% (21/48)	29.72-57.78	50.00% (11/22)	29.11-70.89	35.71% (5/14)	10.62-60.81
Punitive	12.50% (6/48)	3.15-21.86	9.09% (2/22)	1.12-29.16	28.57% (4/14)	8.39-58.10
Not given	10.41% (5/48)	1.78-19.06	9.09% (2/22)	1.12-29.16	7.14% (1/14)	0.18-33.87
Management						
On-site management frequency						
Always (daily)	23.40% (11/47)	11.3-35.51	22.73% (5/22)	5.22-40.24	14.29% (2/14)	1.78-42.81
Often (numerous times per week)	27.66% (13/47)	14.87-40.45	27.27% (6/22)	8.66-45.88	28.57% (4/14)	8.39-58.10
Sometimes (once per week or less)	44.68% (21/47)	30.47-58.89	50.00% (11/22)	29.11-70.89	42.86% (6/14)	16.94-68.78
Never	4.26% (2/47)	0.52-14.54	0.00% (0/22)	0.00-15.44	14.29% (2/14)	1.78-42.81
Workplace reminders						
Physical reminders						
Required safety posters or instructions	84.00% (42/50)	73.84-94.16	82.61% (19/23)	67.12-98.1	78.57% (11/14)	57.08-100.00
Required materials and additional reminders	14.00% (7/50)	4.38-23.62	21.74% (5/23)	4.883-38.6	7.14% (1/14)	0.18-33.87
No workplace reminders	18.00% (9/50)	7.35-28.65	21.74% (5/23)	4.883-38.6	21.43% (3/14)	4.66-50.80
Number of hosted events around HEH per year						
One or more	10.20% (5/49)	1.73-18.68	18.18% (4/22)	5.19-40.28	7.14% (1/14)	0.18-33.87
Less than one	32.65% (16/49)	19.52-45.78	31.82% (7/22)	12.36-51.28	42.86% (6/14)	16.94-68.78
None	57.14% (28/49)	43.29-71	50.00% (11/22)	29.11-70.89	50.00% (7/14)	23.81-76.19

NOTE, Only the smallest and largest of the Croatian hospital responses were included in the analyses by income level. All CI were calculated using Wald (Normal Approx.) method unless less than 5 in which case Fisher Exact (Clopper-Pearson) was used.
HEH, health care environmental hygiene.
*For the income level subset analysis, responses from countries were combined; high income and upper-middle income economies formed the "higher income countries" (HIC) group, and low income and lower-middle income countries formed the "lower income countries" (LIC) group.

Reminders in the workplace

Eighty-six percent (42/49) of HCFs used only the required safety posters or instructions, while 18% (9/49) did not use workplace reminders at all (two institutions reported both answers, Table 6). Fourteen percent (7/50) of HCFs used additional reminders, such as multimedia devices. Fifty-seven percent (28/49) did not host any events around HEH at all, and only 10% (5/49) hosted more than one per year (Table 6).

Institutional safety climate

EVS and nursing staff had meetings more than once per month in 28% (14/50) HCFs, and no formal meetings at all in 24% (12/50, Table 7). Though they communicated frequently on the work floor in 52% (26/50) of HCFs, 16% (8/50) of respondents reported

that EVS staff and nursing staff did not speak the same language (Table 7).

Upward communication with direct superiors was possible in 25% (12/48) of HCFs, and with superiors above direct management in 17% (8/48, Table 7). No upward communication was possible in 13% (6/48). Forty-four percent (21/48) of EVS staff could initiate changes in their institution; 27% (13/48) could not.

Table 7
Health care facility responses concerning institutional safety climate toward environmental hygiene; total responses to questionnaire and subgroup analysis by income level; N = 51; pilot survey*

HEH element or practice	Total % (responses)	Estimate (95% CI)	Higher income % (responses)	Estimate (95% CI)	Lower income % (responses)	Estimate (95% CI)
Institutional safety climate						
Work floor communication						
EVS and nursing staff speak the same language	84.00% (42/50)	73.84-94.16	82.61% (19/23)	67.12-98.1	71.42% (10/14)	47.77-95.09
Frequent communication on the work floor between EVS and nursing staff	52.00% (26/50)	38.15-65.85	56.52% (13/23)	36.26-76.78	28.57% (4/14)	8.39-58.10
Little communication on the work floor between EVS and nursing staff	24.00% (12/50)	12.16-35.84	30.43% (7/23)	11.63-49.24	28.57% (4/14)	8.39-58.10
Formal meetings between EVS staff and nursing staff						
Once per month or more	16.00% (8/50)	5.84-26.16	4.35% (1/23)	0.11-21.95	28.57% (4/14)	8.39-58.10
Less than once per month	10.00% (5/50)	1.69-18.31	17.39% (4/23)	4.95-38.78	0.00% (0/14)	0.00-23.16
None	24.00% (12/50)	12.16-35.84	30.43% (7/23)	11.63-49.24	78.57% (11/14)	57.08-100.00
Informal meetings between EVS staff and nursing staff						
Once per month or more	12.00% (6/50)	2.99-21.01	13.04% (3/23)	2.78-33.59	7.14% (1/14)	0.18-33.87
Less than once per month	10.00% (5/50)	1.69-18.31	17.39% (4/23)	4.95-38.78	0.00% (0/14)	0.00-23.16
Upward communication						
Frequent with direct superiors	31.25% (15/48)	18.14-44.36	22.73% (5/22)	5.22-40.24	35.71% (5/14)	10.62-60.81
Possible with direct superiors	25.00% (12/48)	12.75-37.25	40.91% (9/22)	20.37-61.45	14.29% (2/14)	1.78-42.81
Frequent with superiors above direct management	14.58% (7/48)	4.60-24.57	13.64% (3/22)	2.91-34.91	7.14% (1/14)	0.18-33.87
Possible with superiors above direct management	16.66% (8/48)	6.12-27.21	13.64% (3/22)	2.91-34.91	21.43% (3/14)	4.66-50.80
Impossible	12.50% (6/48)	3.15-21.86	9.09% (2/22)	1.12-29.16	21.43% (3/14)	4.66-50.80
Career development						
Established pathways exist for EVS staff to advance into management roles	25.00% (12/48)	12.75-37.25	33.33% (7/21)	13.17-53.49	14.29% (2/14)	1.78-42.81
Ability of EVS staff to initiate institutional changes						
EVS staff members can initiate changes	43.75% (21/48)	29.72-57.78	31.82% (7/22)	12.36-51.28	35.71% (5/14)	10.62-60.81
EVS staff members cannot initiate changes	27.08% (13/48)	14.51-39.65	36.36% (8/22)	16.26-56.46	28.57% (4/14)	8.39-58.10
Not sure	29.16% (14/48)	16.31-42.02	31.82% (7/22)	12.36-51.28	35.71% (5/14)	10.62-60.81

NOTE. Only the smallest and largest of the Croatian hospital responses were included in the analyses by income level. All CI were calculated using Wald (Normal Approx.) method unless less than 5 in which case Fisher Exact (Clopper-Pearson) was used.
HEH, health care environmental hygiene; EVS, environmental services.
*For the income level subset analysis, responses from countries were combined; high income and upper-middle income economies formed the "higher income countries" (HIC) group, and low income and lower-middle income countries formed the "lower income countries" (LIC) group.

Subset analysis by income level

For the subset analysis by income level, high income and upper-middle income countries were combined to form the "higher income countries" group (HIC), and low income and lower-middle income countries were combined to form the "lower income countries" (LIC) group.

All (14/14) survey participants from LIC and 90% (19/21) of survey participants from HIC were able to make decisions regarding HEH (Table 1). Less respondents from LIC [57% (8/14) vs. 81% (17/21)] felt that their facility gave enough importance to HEH. Fourteen percent (2/14) of respondents from LIC and 55% (10/18) from HIC felt that the budget allocated for cleaning and disinfection is adequate (Table 1).

Most LIC HCFs used chlorine-based disinfectant, though its use was also widespread among HIC HCFs [93% (13/14) vs. 74% (17/23), respectively, Table 2]. Combined detergent/disinfectant products were used more often in HIC than in LIC [74% (17/23) vs. 57% (8/14), respectively]. Larger cleaning machines or automated disinfection devices were almost exclusively used by HIC [61% (14/23) vs. 7% (1/14), respectively, Table 2].

Eighty-two percent (19/23) of respondents from HIC vs. 28% (4/14) from LIC had access to both heat and chemical sterilization equipment (Table 3). 100% (14/14) LIC respondents had access to heat sterilization equipment, but the products to

use them were only available in 43% (6/14) of HCFs (Table 3).

It was encouraging to see that all (23/23) respondents from HIC and 93% (13/14) from LIC had access to sharps containers, and that 91% (21/23) of HIC HCFs vs 71% (10/14) of LIC HCFs separated normal from medical/ hazardous waste (Table 3). Twenty-six percent (6/23) of HIC HCFs and none (0/14) in LIC had machines to shred and sterilize hazardous waste so that it could be disposed of together with non-hazardous waste. Forty-three percent (10/23) of respondents in HIC recycled, vs. 7% (1/14) in LIC (Table 2).

Most HCFs from HIC and over half from LIC had clean water [91% (21/23) vs. 57% (8/14), respectively, Table 4]. Water filtration was available far more often in HIC [78% (18/23) vs. 21% (3/14), respectively]. More facilities in HIC than in LIC had access to filtered water [78% (18/23) vs. 21% (3/14), respectively, Table 4].

Concerning air, HCFs in LIC were more likely able to open their windows for air circulation [78% (11/14) vs. 65% (15/23), respectively, Table 4]. Almost all respondents in HIC had a ventilation system, but only half from LIC did [95% (22/23) vs. 50% (7/14), respectively]. This difference was even more marked concerning the implementation of HEPA filtration systems; [87% (20/23) vs. 21% (3/14), respectively, Table 4].

There was less of a marked difference between income levels concerning laundry; 48% (11/23) of respondents from HIC and 57% (8/14) from LIC had on site washing machines. HIC HCFs outsourced their laundry services more often [56% (13/23) vs. 21% (3/14), Table 4].

Respondents from HIC indicated that their protocols were based on current best practice, updated regularly and adapted to each risk zone 69% (16/23) of the time, while under 21% (3/14) of the respondents from LIC indicated this (Table 2). Thirty percent (7/23) of HIC respondents outsourced their EVS staff, while this practice did not occur in LIC HCFs (Table 5). Classroom training, manuals and e-learning tools were used more often in HIC HCFs: [56% (13/23) vs. 36% (5/14); 56% (13/23) vs. 36% (5/14); 26% (6/23) vs. 7% (1/14), respectively, Table 5]. Still, only 30% (7/23) of HCFs in HIC and 7% (1/14) in LIC indicated that EVS staff received comprehensive formal training (Table 5).

Managers for EVS staff were equally present [27% (6/22) vs. 28% (4/14)] in LIC HCFs, respectively, Table 6), but daily on-site management was rare for both groups: 23% (5/22) in HIC vs. 14% (2/14) in LIC. Only 64% of staff (14/22) from HIC and 50% (7/14) from LIC reported possible or frequent communication with direct superiors (Table 7). This percentage declined to 27% (6/22) and 29% (4/14), respectively, concerning communication with upper-level management (Table 7).

DISCUSSION

As that there are likely well over 50,000 HCFs in the world,[22] our sample size (51 HCFs) was too small to be representative, but is greater than the sample size commonly recommended for questionnaire pre-testing (N=30).[23] In the first round of 343 invitations, there was already an adequate response rate from high and middle-high income countries, but compiling responses from lower resource areas required far more invitations, resulting in a somewhat lower estimated response rate, and highlighting the issues of gathering data from lower-resource regions. Even though HCFs may have had internet connectivity, filling out such a long survey in suboptimal conditions, such as on a smart phone or with an interrupted connection, is

difficult. Still, the minimum of four HCFs per income level were included as originally planned, which was one of the strengths of the survey.

Though most of the studies correlating HEH to healthcare-associated infections are recent, there is a growing number of interventions that show the importance of HEH in patient safety.[24–32] Respondents' titles varied, which was to be expected in such a heterogeneous sample, though they frequently corresponded to roles such as IPC nurse, IPC department director, and IPC head nurse. Most survey respondents maintained that HEH is given sufficient consideration in most HCFs, and that available products and supplies were always appropriate for their intended task. This perception that the status quo is sufficient is contrary to both the aforementioned literature, and to the responses obtained by the survey. HEH practices are often implemented a certain way out of habit, and managers have not always had the opportunity to learn to optimize these practices. Just over half of surveyed HCFs reported that their protocols were based on best practices and updated regularly, indicating that HEH is still not a priority for HCFs, and that its importance may be severely underestimated. It is also important to note that the average resource level of a country may differ with the resource level of an individual HCF. For example, some responses from HIC indicated that there were still issues with clean water or waste management.

There were interesting results for sterilization: more HCFs had heat sterilization equipment available than the products needed, and the opposite was true for chemical sterilization. This may indicate that there is a greater challenge keeping heat sterilization operations running than installing them in the first place, and that chemical sterilization is often more dependent on the products than on the equipment for optimal application. It is also possible that there may have been some overlap in what the respondents considered to be "equipment" and "products".

It was surprising that the percentages of HCFs with running water was higher in lower-income income settings, and that relatively few respondents overall reported having access to a sewage treatment system. This may be because of a lack of understanding of the terms "sewage treatment" and "running water"; those questions will be adjusted in the future. The proportion of HCFs that did not separate normal waste from medical or hazardous waste or that had open dump sites nearby highlighted issues in the waste management system. In areas where the management of medical waste is difficult, it can be desirable to have access to machines which shred and sterilize medical waste, so that it can then be disposed of with normal waste. These machines are specifically produced with limited resource environments in mind. The low presence of complex machines in LIC in general may be not only due to their cost, but to the ability to repair and maintain them if the appropriate logistical channels are not in place.

Bundled or multimodal strategies have become more common, and are increasingly accepted as essential for optimizing successful implementation of HEH strategies.[24–27,33–35] Training and quality control are essential for a successful HEH program, but the survey showed these areas were often lacking. Though EVS staff were often reported as being employed directly by HCFs, the survey question did not allow for respondents to indicate if only part of the workforce was outsourced, possibly

underestimating the percentage. Almost one-third of HCFs did not provide or require any formal training at all, and only one quarter offered their staff opportunities for career development. There were also indicators of major issues with management and quality control as half of EVS staff managers were reported as being on-site either less than once per week or not at all. Sometimes, EVS staff and nursing staff did not speak the same language and therefore could not communicate adequately, which would directly impact the facility's institutional safety climate. Most HCFs surveyed did not provide EVS staff access to certification programs, although these could foster career development, recognition and reduce turnover.

The response rate of this survey, and the fact that its design cannot accurately reflect the world population or the population of HCFs, remain its most important limitations. There is a rather large selection bias as the HCFs contacted were all from a list of institutions which have a strong interest in IPC. This bias probably skewed the results positively, and it is likely that the average levels of HEH programs may well be below those identified in the survey, making this first attempt at gathering information all the more important. The language of this survey was English, so it was biased towards HCFs where English is understood. Nevertheless, we are satisfied that this pilot study reached its main objective helping further develop the HEHSAF and ready it for future translation and distribution.

The survey responses based on the perception of the respondents were also limited by their level of knowledge. Furthermore, because the subject is so broad, some definitions may vary from one participant to the next. For example, the items some respondents designated as "equipment" or "products" may overlap. Sometimes respondent answers were not completely coherent. For example, when learning about feedback to EVS workers, six respondents reported giving no feedback, but when asked what kind of feedback was given to EVS workers in a separate question, only five respondents reported giving no feedback. This is typically the kind of issue that can arise during a survey, especially when it is not in the native language of the participant.

In the future implementation of the HEHSAF, one of the main challenges will be ensuring a higher participation rate for low and middle-low income economies. We plan on addressing these issues by making the tool available in a number of languages, and collaborating with international organizations and industry that are active in the different regions.

CONCLUSION

This pilot survey was invaluable for preparing the HEHSAF tool for further testing and highlighted the need for major improvement in HEH programs worldwide. From the data gathered, it is obvious that there are major resource, structural and cultural challenges to HEH implementation. Though there are major differences among HEH programs, issues with access to products and equipment, training, monitoring and workplace culture remain ubiquitous. There was a definite need for improvement in most of the HCFs which responded, and their feedback was helpful for helping us advance the development of the HEHSAF tool. Development of evidence-based guidelines and the development and implementation of the HEHSAF tool will help to better address this in the future. Changes to HEH must be multimodal in nature and

take into account the culture and resource levels of each HCF. More research is needed to quantify the cost and value of such programs, and to identify the best tools and models for implementation.

DATA STATEMENT

Due to the sensitive nature of the questions asked in this study, survey respondents were assured and identifying raw data would remain confidential and would not be shared. We are happy to share our results with all identifying data removed upon request.

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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.2022.02.029.

SUPPORTING INFORMATION

Supplementary electronic material (Appendix) Survey questionnaire

1. Allegranzi, B., Nejad, S. B. & Pittet, D. The Burden of Healthcare-Associated Infection. in *Hand Hygiene: A Handbook for Medical Professionals* 1–7 (Wiley-Blackwell, 2017). doi:10.1002/9781118846810.ch1.

2. Environmental Hygiene in Healthcare. HAI. Centers for Disease Control. (2019). https://www.cdc.gov/hai/research/eic-meeting.html

3. Carling, P. C. Health Care Environmental Hygiene: New Insights and Centers for Disease Control and Prevention Guidance. *Infect Dis Clin North Am* 35, 609–629 (2021).

4. Han, J. H. *et al.* Cleaning Hospital Room Surfaces to Prevent Health Care–Associated Infections. *Ann Intern Med* 163, 598–607 (2015).

5. Dancer, S. J. Controlling Hospital-Acquired Infection: Focus on the Role of the Environment and New Technologies for Decontamination. *Clin. Microbiol. Rev.* 27, 665–690 (2014).

6. Peters, A. *et al.* Keeping hospitals clean and safe without breaking the bank; summary of the Healthcare Cleaning Forum 2018. *Antimicrob Resist Infect Control* 7, (2018).

7. World Health Organization. Guidelines on core components of infection prevention and control programmes at the national and acute health care facility level. (2016). https://apps.who.int/iris/handle/10665/251730

8. Huang, S. S., Datta, R. & Platt, R. Risk of Acquiring Antibiotic-Resistant Bacteria From Prior Room Occupants. *Archives of Internal Medicine* 166, 1945–1951 (2006).

9. World Health Organization. WHO Infection Prevention and Control Assessment Framework at the Acute Health Care Facility Level. (2018). https://www.who.int/publications/i/item/WHO-HIS-SDS-2018.9

10. World Health Organization. WHO | WHO Hand Hygiene Self-Assessment Framework. *WHO* http://www.who.int/gpsc/5may/hhsa_framework/en/ (2018).

11. Stewardson, A. J., Allegranzi, B., Perneger, T. V., Attar, H. & Pittet, D. Testing the WHO Hand Hygiene Self-Assessment Framework for usability and reliability. *J. Hosp. Infect.* 83, 30–35 (2013).

12. Kilpatrick, C. *et al.* Global hand hygiene improvement progress: two surveys using the WHO Hand Hygiene Self-Assessment Framework. *J. Hosp. Infect.* 100, 202–206 (2018).

13. World Health Organization. WHO HH Global Survey Instructions. (2019).

14. de Kraker, M. E. A. *et al.* Implementation of Hand Hygiene in healthcare facilities: Results from the WHO Hand Hygiene Self-Assessment Framework global survey 2019. *Lancet Infecitous Diseases* (In Press), (2022).

15. CleanHospitals. *Clean Hospitals* https://cleanhospitals.com/ (2019).

16. World Health Organization. Summary Report: Hand Hygiene Self-Assessment Framework Survey 2015/2016 A report from the WHO Infection Prevention and Control Global Unit. (2016).

https://www.who.int/gpsc/5may/hand-hygiene-report.pdf?ua=1

17. World Health Organization. WHO Hand Hygiene Self-Assessment Framework Global Survey Summary Report 2011. (2012). https://www.who.int/gpsc/5may/summary_report_HHSAF_global_survey_May12.pdf?ua

18. WHO | 2019 WHO Global Survey on Infection Prevention and Control (IPC) and Hand Hygiene. *WHO* http://www.who.int/infection-prevention/campaigns/ipc-global-survey-2019/en/.

19. World Bank Country and Lending Groups – World Bank Data Help Desk. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

20. World Health Organization. WHO multimodal improvement strategy. (2009). https://www.who.int/infection-prevention/publications/ipc-cc-mis.pdf

21. Allegranzi, B. & Pittet, D. WHO Multimodal Promotion Strategy. in *Hand Hygiene: A Handbook for Medical Professionals* 230–243 (Wiley-Blackwell, 2017). doi:10.1002/9781118846810.ch33.

22. Hospitals in select countries worldwide 2019. *Statista* https://www.statista.com/statistics/1107086/total-hospital-number-select-countries-worldwide/.

23. Perneger, T. V., Courvoisier, D. S., Hudelson, P. M. & Gayet-Ageron, A. Sample size for pre-tests of questionnaires. *Qual Life Res* 24, 147–151 (2015).

24. Anderson, D. J. *et al.* Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and Clostridium difficile (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. *Lancet* 389, 805–814 (2017).

25. Mitchell, B. G., Digney, W., Locket, P. & Dancer, S. J. Controlling methicillin-resistant Staphylococcus aureus (MRSA) in a hospital and the role of hydrogen peroxide decontamination: an interrupted time series analysis. *BMJ Open* 4, e004522 (2014).

26. Mitchell, B. G. *et al.* An environmental cleaning bundle and health-care-associated infections in hospitals (REACH): a multicentre, randomised trial. *The Lancet Infectious Diseases* 19, 410–418 (2019).

27. Wilcox, M. H. *et al.* Comparison of the effect of detergent versus hypochlorite cleaning on environmental contamination and incidence of Clostridium difficile infection. *J Hosp Infect* 54, 109–114 (2003).

28. Manian, F. A., Griesnauer, S. & Bryant, A. Implementation of hospital-wide enhanced terminal cleaning of targeted patient rooms and its impact on endemic Clostridium difficile infection rates. *Am J Infect Control* 41, 537–541 (2013).

29. Kim, M. H. *et al.* 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* 18, 610 (2018).

30. Alfa, M. J., Lo, E., Olson, N., MacRae, M. & Buelow-Smith, L. Use of a daily disinfectant cleaner instead of a daily cleaner reduced hospital-acquired infection rates. *Am J Infect Control* 43, 141–146 (2015).

31. Daniels, T., Earlywine, M. & Breeding, V. Environmental services impact on healthcare-associated Clostridium difficile reduction. *Am J Infect Control* 47, 400-405.e1 (2019).

32. Mitchell, B. G., Dancer, S. J., Anderson, M. & Dehn, E. Risk of organism acquisition from prior room occupants: a systematic review and meta-analysis. *Journal of Hospital Infection* 91, 211–217 (2015).

33. Shaw, E. *et al.* Control of endemic multidrug-resistant Gram-negative bacteria after removal of sinks and implementing a new water-safe policy in an intensive care unit. *Journal of Hospital Infection* 98, 275–281 (2018).

34. Fisher, D. *et al.* A Successful Vancomycin-Resistant Enterococci Reduction Bundle at a Singapore Hospital. *Infect Control Hosp Epidemiol* 37, 107–109 (2016).

35. Hung, I.-C. *et al.* Implementation of human factors engineering approach to improve environmental cleaning and disinfection in a medical center. *Antimicrob Resist Infect Control* 9, 17 (2020).

9. The Healthcare Environmental Hygiene Self-assessment Framework

Shaded questions indicate elements that will NOT be scored.

The Healthcare Environmental Hygiene Self-Assessment Framework

Please answer the following questions to the best of your abilities. All participant respondent data will be kept confidential. All data will be anonymized and aggregated upon publication. Healthcare environmental hygiene (HEH) includes everything in the healthcare facility environment including the surfaces around the patient, waste management, instrument sterilization, laundry, as well as access to clean air and clean water. Thank you for your time!

Definitions:

Bucketless mopping systems: flat mops where the cloths or mop heads are pre-moistened and easily changed
Clean water: water that is safe to drink or used for clean healthcare
Cold Sterilization: a method of sterilization that requires the reusable semi-critical items to be immersed in officially-approved liquid chemicals. Examples: glutaraldehydes, peracetic acid, and hydrogen peroxide-based solutions
HEH equipment: machines or permanent structures for cleaning or disinfection. Examples: washer-disinfectors, autoclaves, polishing machines, or automated disinfection devices
HEH products: consumable products for cleaning or disinfection. Examples: cleaners and detergents or other chemical solutions
HEH supplies: tools for cleaning or disinfection. Examples: wipes, rags or sponges
Landfill: a site where solid waste is buried between layers of earth to build up low-lying land
Occupational health disorders: events or exposure that occurs in the workplace that causes or contributes to a condition or worsens a preexisting condition. Examples: asthma from chemical fumes, burns, back problems from cleaning
On-site wastewater treatment system: systems used to treat water and return it back into the environment. They can also be referred to septic system. Examples: flushing toilets, showers or running water
Open dump site: a site where solid waste is disposed of in an uncontrolled manner that does not protect the environment
Patient zone: All of the objects in the environment that are in close proximity or touched by the patient, and likely to be contaminated by the patient's bacteria
Reusable cloths: cloths that can be laundered and used multiple time times
Running water: water that comes into a building through pipes
Sponges: made of either synthetic material or cellulose (similar to sponges used for washing dishes)

Abbreviations:

EVS staff: Environmental services staff (cleaners)
HEH: Healthcare environmental hygiene
HEHSAF: Healthcare environmental hygiene self- assessment framework
IPC: Infection prevention and control

1. GENERAL INFORMATION		
1.1	Name of the country you are working in	Free text
1.2	Your name and surname	Free text
1.3	Your email address	Free text
1.4	Name of healthcare facility and location	Free text
1.5	Please enter the geographic location of your institution from this site (click on the search box and enter your healthcare facility in the search bar; copy and paste the three words given in the free text box) : https://what3words.com/	Free text
1.6	What kind of healthcare facility is your institution?	Primary care center
		Secondary care center
		Tertiary care center
		Long-term care facility
		Other (please specify)
1.7	How many beds does your healthcare facility have ?	0 (outpatient facility)
		0 to 50
		51 to 250
		251 to 1000
		1001 to 2500
		More than 2500
1.8	Which department is responsible for HEH?	Environmental services department
		IPC department
		Other
1.9	Your job title/function	Infection prevention specialist
		EVS manager (cleaning manager)
		Healthcare facility administrator
		Engineer
		Others (Please specify)
1.10	Total years of experience in your currentrole or a similar role	0 to 2
		2 to 5
		5 to 10
		10 to 20
		more than 20

1.11	How many TOTAL EVS/cleaning staff (full-time equivalent positions) work in HEH at your healthcare facility? (INCLUDING: waste management, laundry or sterilization. EXCLUDING: staff working in transport and groundskeepers)	0 to 10
		11 to 50
		51 to 100
		101 to 200
		More than 200
		Don't know
1.12	How many EVS/cleaning staff (full-time equivalent positions) work specifically in PATIENT AREAS at your healthcare facility? (EXCLUDING: waste management, laundry, sterilization, staff working in transport and groundskeepers)	Free text
		Don't know
1.13	Who is responsible for cleaning within the PATIENT ZONE?	Nurses
		Nursing assistants
		EVS/cleaning staff
1.14	Do HEALTHCARE STAFF perform routine cleaning beyond the patient zone ?	Yes
		No
		Don’t know
1.15	Do you know what the budget is for your institution's HEH program ?	Yes
		No
1.16	Which decisions can you make with regards to how the healthcare facility is cleaned? (Please check all that apply)	Budget decisions
		Purchasing/procurement decisions
		Decisions regarding cleaning/ disinfection protocols
		None
1.17	Do you feel that your healthcare facility gives enough importance to HEH?	Gives no importance to HEH
		Gives little importance to HEH
		Gives some importance to HEH
		Gives significant importance to HEH
		Gives great importance to HEH

1.18	**disinfection is adequate?**	Yes, definitely
		Yes, possibly
		No
1.19	**What are your main microorganisms of concern regarding healthcare-associated infections (HAIs)?**	A. baumanii
		C.difficile
		K. pneumoniae
		MRSA
		P. aeruginosa
		S. aureus
		VRE
		Others (please specify)
1.20	**What is the overall prevalence rate of HAIs for your institution?**	0% to 5%
		5% to 10%
		10% to 20%
		20% to 30%
		More than 30%
		Don't know
2. SYSTEM CHANGE: Institutional capacity and practices		
2.1	**Does your facility have an IPC department?**	Yes
		No
2.2	**Do the IPC department and the EVS/cleaning department have regular contact? (meetings/emails, phone calls, etc.)**	Yes, daily
		Yes, once per week or more
		Yes, once per month or more
		Yes, but infrequently
		No
		There is no IPC department
2.3	**Calculation of EVS employment density- if you have precise numbers for question 1.8 and 1.15, please divide the number of PATIENT BEDS by the # EVS staff in PATIENT AREAS**	Free text/ automatic online calculation
2.4	**Do you follow international and/or national guidelines for healthcare environmental hygiene?**	Yes
		No
		Don't know

2.5	**Does your healthcare facility have different protocols for different risk zones (Example: offices vs. patient rooms vs. operating theaters)?**	Healthcare environmental hygiene protocols do not vary from one zone to the next
		Some protocols are adapted to high-risk zones, such as operating theaters/transplant wards
		All healthcare environmental hygiene protocols are adapted to each risk zone
		Don't know
2.6	**Are there additional protocols available for the person who cleans the patient zone?**	Yes
		No
		Don’t know
2.6	**Is there plan in place to improve HEH in your facility?**	Yes
		No
		Don't know
2.8	**Does your facility have an antibiotic stewardship program in place?**	Yes
		No
		Don't know
2.9	**Which factor counts the most in the decision process when purchasing/ procuring HEH products and supplies?**	Price
		Efficacy
		Surface compatibility
		Safety of product
		Environmental impact
		Relationship with current suppliers
		Don't know
2.1	**What measures does your facility implement to improve sustainability?**	Prioritize products and supplies that are produced locally
		Consider the reusability and longevity of equipment and supplies
		Implement measures to reduce waste
		Choose less toxic products
		Choose products that are more easily biodegradable
		Prioritize the appropriate maintenance of existing equipment

3. SYSTEM CHANGE: Surfaces		
3.1	**Surfaces in the healthcare facility are smooth, intact and able to be cleaned**	All of them
		Most of them
		Many surfaces are rough or damaged
3.2	**Does your healthcare facility have sufficient cleaning and disinfection products and supplies available?**	Cleaning/ disinfection products and supplies are not or only rarely available
		Products and supplies are sometimes available
		Products and supplies are always available
		Don't know
3.3	**Are the available products and supplies appropriate for their intended task?**	Cleaning/ disinfection products and supplies are not or only rarely appropriate
		Products and supplies are sometimes appropriate
		Products and supplies are always appropriate
		Don't know
3.4	**Are HIGH-TOUCH surfaces are cleaned with a detergent and disinfected?**	Yes, always
		Cleaning and disinfection are performed at the same time with a combined detergent/disinfectant product
		Sometimes
		No
3.5	**Are surfaces in HIGH-RISK AREAS cleaned with a detergent before they are disinfected?**	Yes, always
		Cleaning and disinfection are performed at the same time with a combined detergent/disinfectant product
		Sometimes
		No
3.6	**For cleaning FLOORS in normal risk areas (NOT in operating theaters or other high risk settings) what PRODUCTS do you use?**	Water only
		Detergent only
		Disinfectant only
		Both detergent and disinfectant
		A single combined detergent/disinfectant product
		Microfiber and water only
		Don’t know

3.7	**For cleaning FLOORS in normal risk areas (NOT in operating theaters or other high risk settings) what EQUIPMENT do you use? Please check all that apply.**	Sponges
		Bucketless mopping systems where mop head is changed between every room (see definition)
		Rope mops and buckets where mop head is NOT changed between every room
		Manual cleaning with additional automated disinfection
		Don't know
3.8	**For cleaning hard HIGH TOUCH SURFACES, what PRODUCTS do you use?**	Water only
		Detergent only
		Disinfectant only
		Both detergent and disinfectant
		A single combined detergent/disinfectant product
		Microfiber and water only
3.9	**For cleaning hard HIGH TOUCH SURFACES, what EQUIPMENT do you use most often?**	Microfiber
		Sponges
		Reusable cloths
		Disposable wipes
3.10	**For cleaning hard HIGH TOUCH SURFACES, what additional equipment do you use? Please check all that apply.**	Automated disinfection without manual cleaning
		Manual cleaning with additional automated disinfection
		Other products/ tools/ machines (please specify)
3.11	**What disinfectants are available for SURFACES?**	Bleach/ chlorine based disinfectant
		Quaternary ammonium disinfectant
		Hydrogen Peroxide
		Phenolics
		Glutaraldehyde
		Other (please specify)

3.12	**What additional supplies/equipment are available for SURFACES?**	Larger mechanical cleaning machine(s) for cleaning floors/ large surfaces
		UV disinfection machine(s)
		Gaseous hydrogen peroxide disinfection machine(s)
		Antimicrobial surfaces
		None of the above
		Don't know
		Other products/ tools/ machines (please specify)
4. SYSTEM CHANGE: Specific Environments		
4.1	**For sterilization performed IN-HOUSE. Please check all that apply. Equipment that needs to be sterilized is:**	Cleaned before sterilization
		Always packaged before sterilization
		Sometimes packaged before sterilization
		Cold sterilization (see definition)
		Sterilized using a validated protocol
		Quality of sterilization is tested for regularly
		Not applicable; sterilization is outsourced
4.2	**If sterilization is OUTSOURCED. Please check all that apply. Equipment that needs to be sterilized is:**	There is a signed contract between the HCF and the contractor
		Objects to be sterilized are pre-treated in-house
		There is an in-house quality check after the reception of sterilized items
		Not applicable; sterilization is performed in-house
4.3	**Sterilization for thermostable medical devices is mainly:**	Steam sterilization (autoclave)
		Dry heat sterilization
		Chemical sterilization/disinfection
		Ethylene oxide/formaldehyde
4.4	**If sterilization is outsourced, please ONLY click the last option. What supplies are available for STERILIZATION? Please check all that apply.**	Products/equipment for the sterilization of instruments
		Adequate maintenance strategy for the sterilization of instruments
		Not applicable: Sterilization is outsourced

4.5	**What is your capacity for STERILIZATION?**	My facility can adequately perform sterilization
		My facility can USUALLY adequately perform sterilization
		My healthcare facility cannot perform adequate sterilization (equipment is not in good working order, etc.)
		Not applicable: my facility does not require a capacity for sterilization
		Sterilization is outsourced, and this is an adequate solution
		Sterilization is outsourced, but there are sometimes issues with quality
		Don't know
4.6	**What supplies are available for WATER? Please check all that apply.**	Clean water (drinking quality)
		Running water (faucets and plumbing system, sinks, etc.)
		Hot water
		Additional water filtration when needed in high risk environments (haemodialysis, etc.)
		Don't know
4.7	**How is WATER QUALITY controlled?**	There is a microbiological surveillance plan for Legionella in place
		Temperature of water is verified at the source
		Temperature of water is verified when it comes out of the faucets/taps
		Stagnant places in water system are identified and addressed
4.8	**Do you have knowledge of the layout of the water distribution system in the hospital**	Yes
		No
		Don't know
4.9	**What supplies are available for AIR in low risk areas?**	Windows that cannot be opened, no other central ventilation
		Windows than can be opened, no other central ventilation
		Windows cannot be opened but there are central ventilation systems
		Windows that can be opened and there are central ventilation systems
		Don't know

4.10	**What supplies are available for AIR in high risk environment (operating rooms, isolation wards, areas with immunocompromised patients)? Please check all that apply.**	High Efficiency Particulate Air (HEPA) filtration where needed
		Unidirectional or laminar air flow
		Mobile air treatment device/ other
		Negative/ positive pressure room(s)
		Air conditioner
		No specific measures
		Don't know
4.11	**If laundry is outsourced, please ONLY click the last option. What products and supplies are available for LAUNDRY? Please check all that apply.**	Laundry detergent
		Laundry disinfectant (such as chlorine)
		On-site washing machines
		On-site drying machines
		Detergent and disinfectant are not consistently available
		No laundry system is in place
		Not applicable: Laundry services are provided by an external provider
		Don't know
4.12	**How is WASTE managed in your HCF?**	External treatment of all solid waste
		External treatment of medical waste ONLY
		No external treatment of waste
		Don't know
4.13	**How is WASTE separted in your HCF?**	Separation of normal and medical/hazardous waste
		HCF uses a machine to shred and sterilize medical waste, so no additional separation is needed
		No separation of waste
		Don't know
4.14	**What supplies/systems are available for WASTE MANAGEMENT? Please check all that apply.**	Containers for sharps
		Color-coding of bags for waste (hazardous/medical vs. normal)
		Waste collection services
		Open dump sites within 150 meters of healthcare facility (see definition)
		Landfill sites for waste disposal (see definition)
		Access to an on-site wastewater treatment system (flushing toilets, showers or running water)
		Recycling
		Don't know

4.2	**Is there a program to monitor the quality of effluent/wastewater in your HCF?**	Yes
		No
		Don't know
5. TRAINING & EDUCATION OF EVS (EVS/CLEANING) STAFF		
5.1	**Is your EVS/cleaning staff in-house or outsourced ?**	In-house (EVS/cleaning staff are employed by the healthcare facility)
		Outsourced (EVS/cleaning staff are employed by an external company)
		EVS/cleaning staff is partially in-house and partially outsourced
		Don't know
5.2	**Does your HCF have a budget for training?**	Yes
		No
		Don't know
5.3	**What types of training do EVS/cleaning staff receive? (Please check all that apply)**	Classroom
		On the job training
		E-learning
		Manuals
		No training received
		Don't know
		Other (please specify)
5.4	**Is the training for EVS/cleaning staff provided by formally educated trainers?**	Yes
		No
		Don't know
5.5	**Are EVS/cleaning staff trained in hand hygiene?**	Yes
		No
		Don't know
5.6	**Is there training in environmental INFECTION CONTROL for EVS/cleaning staff?**	Yes
		No
		Don't know
5.7	**What is the comparative salary of EVS/cleaning staff vs. nurses? EVS/cleaning staff earn...**	75% of what nurses earn
		50% of what nurses earn
		25% of what nurses earn
		Don't know

5.8	**Does your healthcare facility provide or require formal training for EVS/cleaning staff upon hiring ?**	No formal training
		Some formal training
		Comprehensive formal training
		Don't know
5.9	**training for EVS/cleaning staff (not including the training upon hiring)?**	No further additional training
		Additional training is given less than once per year
		Additional training is only given for specific contexts/ environment
		Regular additional training is given at least once per year
		Don't know
5.1	**Do EVS/cleaning staff have the possibility to complete certification programs?**	No available certification
		Institutional certification
		Regional/national certification
		Don't know
5.1	**Do the staff responsible for DEVICE REPROCESSING have the possibility to complete certification programs?**	No available certification
		Institutional certification
		Regional/national certification
		Don't know
5.1	**Are there established pathways for EVS/cleaning staff to advance into management roles?**	Yes
		No
		Don't know
5.1	**How many years do EVS staff stay at your facility on average?**	0 to 2
		2 to 5
		5 to 10
		10 to 20
		More than 20
6. MONITORING AND FEEDBACK OF EVS STAFF		
6.1	**Are EVS staff monitored ?**	Yes
		No
		Don't know
6.2	**How are EVS staff monitored?**	Individually only
		At the team level only
		Both at the individual and the team level
		Don't know

6.3	**Which of the following monitoring tools does your institution use, in non-outbreak situations? (check all that apply)**	Visual monitoring WITHOUT a scoring scale
		Visual monitoring WITHOUT a scoring scale + fluorescent marking / ATP
		Visual monitoring WITH a scoring scale
		Visual monitoring WITH a scoring scale + fluorescent marking / ATP
6.4	**How is each EVS/cleaning staff member's performance monitored?**	No monitoring
		Irregular visual monitoring (less than 4 times per year)
		Regular visual monitoring (4 times per year or more)
		Regular visual monitoring as well as additional monitoring methods
		Don't know
6.5	**How feedback is given to EVS/cleaning staff?**	No feedback is given
		Immediately at the individual level only
		Systemically at the team level only
		Both at the individual and the team level
		Don't know
6.6	**What kind of feedback is given to EVS/cleaning staff?**	No feedback is given
		Feedback given is usually punitive
		Feedback given is usually constructive
		Feedback is constructive and includes a plan for improving performance
		Don't know
6.7	**Is there on-site supervision of EVS/cleaning staff?**	Never
		Sometimes (once or less per week)
		Often (numerous times per week)
		Always (daily)
		Don't know
7. REMINDERS IN THE WORKPLACE		
7.1	**Does your institution use workplace reminders for HEH (such as posters, pocket leaflets, screen savers etc.)?**	No workplace reminders
		The required safety posters/ instructions
		Additional reminders are also used (please specify)
		Don't know

7.2	**Does your healthcare facility use workplace reminders for cleaning staff safety for these fields:**	Chemical exposure protection
		Safe handling of sharps
		Spill removal techniques
		Others (please specify)
		None
7.3	**Does your healthcare facility use personal task reminders (to-do lists) for cleaning staff:**	Yes, always
		Yes, sometimes
		No
		Don't know
7.4	**Does your healthcare facility host events around HEH?**	No
		Yes, less than 1 event per year (please describe)
		Yes, 1 event per year or more (please describe)
		Don't know
8. INSTITUTIONAL SAFETY CLIMATE		
8.1	**How often do EVS/cleaning staff and nursing staff have meetings?**	No meetings between EVS/cleaning staff and nursing staff
		Meetings less than once per month
		Meetings once per month or more
		Don't know
8.2	**How is the communication between EVS/cleaning staff and nursing staff?**	No communication between EVS/cleaning staff and nursing staff
		Little communication on the work floor
		Frequent communication on the work floor
		Don't know
8.3	**Do EVS/cleaning staff and nursing staff speak the same language?**	Yes; verbal communication is easy
		Sometimes; communication may be difficult at times
		No; verbal communication is difficult
8.4	**Are EVS/cleaning staff able to speak or raise concerns directly with managers ?**	Upward communication is easy
		Upward communication is somewhat difficult
		Upward communication is impossible
		Don't know
8.5	**Can EVS/cleaning staff initiate changes in the institution?**	No
		Yes
		Don't know

8.6	**Is innovation in the field of HEH encouraged in your establishment? This can include changes and improvement in products, techniques, workflow, social innovation, etc.**	Yes, often
		Yes, sometimes
		No
		Don't know
8.7	**Please specify the year and the type of the last HEH innovation/change implemented in your facility :**	(Please specify)
8.8	**Is the prevention of occupational health disorders a priority in your healthcare facility (see definition):**	Yes, always
		Yes, sometimes
		No

10. General conclusion and perspectives

The main conclusions which can be drawn from the research conducted are the following:

- Different types of interventions in the healthcare environment can reduce HAIs and patient colonization
- More high-quality studies are needed to explore the scope and extent of the impact of HEH interventions in increasing patient safety
- It is likely that almost all HCFs have room to significantly improve their HEH programs.
- Having ample access to resources does not automatically translate into high quality HEH programs.

10a. General results of the systematic review(72)

Nine-hundred and fifty-two records were assessed after deduplication, and 44 studies were included for full text analysis. A total of 26 articles were included in the review. The majority of studies demonstrated a reduction of patient colonization or HAI. The included studies tested either mechanical interventions (n=8), chemical interventions (n=7), human factors interventions (n=3), or bundled interventions (n=8). All of the studies that examined HAI only did so in patients, not HCWs. Two studies were published before the year 1990, and the remaining studies were published after 2013.

The studies looked at clinically relevant microorganisms; 81% (21/26) analyzed either *S. aureus*, VRE and/or *C. difficile*. The effect of interventions on Gram negative bacteria were assessed in seven studies. Eighty-eight percent of studies (23/26) reported a decrease of MDRO-colonization or HAI for at least one of the microorganisms tested, and 58% (15/26) reported a significant decrease of MDRO-colonization or HAI for all of the microorganisms tested.

(72)Forty-two percent (11/26) of the studies were of good quality according to the scoring system. Eighty-one percent (21/26) of study interventions were recommended by the authors. Still, studies with high-quality designs were comparatively rare; of the 26 total studies, only five were RCTs and only six used a true control. Sixty-five percent (17/26) had before and after study designs. Studies were often not powered adequately to measure statistically significant reductions in colonization and/or HAI, and further high-quality studies are needed.

Concerning the secondary outcome, half (13/26) of the studies included in the review measured the impact of HEH interventions on environmental bioburden. All of these studies demonstrated a reduction in bioburden following the HEH intervention. Fifty-four percent (7/13) of the studies

demonstrated bioburden reductions were directly correlated with a significant reduction in colonization/HAI for at least one of the microorganisms of tested.

10.b Potential impact of the systematic review

The systematic review on the role of HEH interventions of HAI and patient colonization was important for showing the current state of the literature and level of evidence that we have for recommending environmental interventions to improve patient safety. This was crucial in serving as a basis for the work being conducted by the Clean Hospitals project. In order to improve how HCFs around the world perform their HEH, it is imperative to prove that doing so will save lives and reduce costs. The review also allowed us to identify which types of interventions seemed promising, but need more evidence. Just a few years ago, it would have been almost impossible to imagine that multicenter randomized controlled trials would be conducted in HEH, and subsequently published in top international journals.(53,55) It is to be expected that over the next few years an increasing number of scientifically rigorous studies in HEH will be performed, and that the field will continue to develop.

Still this work is far from complete. Realistically, there is still relatively little evidence for individual environmental interventions. The most commonly studied intervention concerned UVC disinfection, and there were only six studies total. Training/education and automated gaseous hydrogen peroxide were implemented in three studies total, and any other interventions or bundles were implemented in 2 studies or less. Additionally, most of the studies were still of lower quality and often not powered to show significant outcomes to the interventions. Having performed the review will allow people to situate their own research in the context of what has been done, and hopefully encourage them to continue developing the field in an increasingly evidence-based direction.

10c. General results of the pilot survey(71)

Fifty-one HCFs from 35 countries responded to the survey. Thirty three countries only had a single HCF respond; the Democratic Republic of Congo had two responses, and Croatia had 16. Although the survey was only sent to two Croatian HCFs, the disproportionately high response rate from Croatia stems from one of them sharing the survey among hospitals that were not initially contacted. Only 36 of the HCFs that were initially contacted for the survey completed it, resulting in a response rate of 4.8% (36/743).

Forty two of the 51 questionnaires were completed; nine had missing answers, mainly for questions concerning HCF characteristics, system change, and work culture. The majority of HCFs surveyed (28/51, 55%) had between 100 and 500 beds. Distribution by the income level of the HCFs' countries was the following: 37% (13/35) from high-income countries, 26% (9/35)

from upper-middle income countries, 14% (5/35) from lower-middle income countries, and 23% (8/35) from low-income countries.

Ninety six percent (47/49) of survey respondents made decisions with regards to how their HCF was cleaned, 64% (23/36) had over ten years of experience and almost half (23/51, 45%) were able to make budget decisions regarding their facility's HEH program. These results indicated that the survey reached the intended target population. Fourteen percent (2/14) of respondents from LIC and 55% (10/18) from HIC felt that the budget allocated for cleaning and disinfection was adequate in their facility.

Almost all HCFs showed in their answers that there were major issues with their environmental hygiene programs These results were not impacted by the income level of the country in which the HCF was located. Though issues related to resources are obviously more of a challenge in low-resource environments, it is fallacious to assume that the availability of resources is sufficient for implementing a high-quality HEH program.

10d. Key results concerning HEH practices:

- 98% (50/51) of HCFs were found to be lacking in one or more of the five components of the multimodal strategy.
- Products and supplies for HEH were always available in 67% (33/49) of HCFs.
- 52% (26/50) of HCFs reported that HEH protocols were based on best practice and updated regularly, while 14% (7/50) reported that they were not based on best practice or were not available at all.
- 70% (35/50) of HCFs adapted all their HEH protocols to different risk zones.
- Only one HCF (1/50) did not report using any type of disinfectant.
- Mops and buckets for cleaning floors were still used in most HCFs; only 4% (2/50) reported exclusively using bucket-less mopping systems.
- 61% (14/23) of facilities in higher-income countries used larger cleaning machines or automated disinfection devices while only 7% (1/14) of HCFs in lower' income countries did.
- In HCFs that had the equipment for sterilization, 16% (8/49) could still not perform adequate sterilization because the equipment was not in good working order.
- 82% of respondents from higher-income countries had access to both heat and chemical sterilization equipment; 28% (4/14) from lower-income countries did.
- 88% (44/50) of HCFs separated normal waste from medical or hazardous waste.

- Only 43% (10/23) of respondents in higher-income countries recycled; 7% (1/14) in lower-income countries did.
- 22% (11/50) of HCFs reported having an open dump site nearby.
- 18% (9/50) of institutions had machines to shred and sterilize waste but only higher-income countries were using them.
- 70% (35/50) of HCFs had access to some kind of air filtration system when needed.
- 82% (41/50) of HCFs surveyed had clean water, and 56% (28/50) had water filters available when needed.
- 95% (22/23) of respondents in higher-income countries had a ventilation system, but only half (7/14) from lower-income countries did. This difference was even more marked concerning the implementation of HEPA filtration systems; 87% (20/23) vs. 21% (3/14), respectively.
- 30% (7/23) of HCFs higher-income countries respondents outsourced their environmental services (EVS) staff, while this practice did not occur in HCFs in lower-income countries.
- Only 30% (7/23) of HCFs in higher-income countries and 7% (1/14) in lower-income countries indicated that EVS staff received comprehensive formal training.
- 6% (3/50) of respondents reported that they did not know what type of training EVS staff received; 4% (2/50) reported that the facility or management did not provide any training at all.
- 75% (36/48) of HCFs did not provide their EVS staff access to any certification programs. The same proportion of institutions did not make it possible for EVS staff to advance into management roles.
- 87% (42/48) of HCFs monitored staff performance, and 60% (29/48) of HCFs gave immediate feedback at the individual level.
- 49% (23/47) of HCFs had EVS managers on-site less than once per week or not at all.
- 18% (9/49) did not use any workplace reminders, including the minimum required safety posters or instructions.
- EVS and nursing staff had no formal meetings in 24% (12/50) of HCFs.
- Concerning communication on the work floor, 16% (8/50) of respondents reported that EVS staff and nursing staff did not speak the same language.
- Upward communication with direct superiors was possible in only 25% (12/48) of HCFs.

10e. Potential impact of the pilot survey in HEH

It was encouraging to see that out of the 26 studies, seven were bundled interventions. From both the global implementation of hand hygiene in healthcare and other work done in infection prevention (IPC), specifically on central line-associated bloodstream infections, surgical site infections, ventilator-associated pneumonia, and urinary tract infections, it is increasingly clear that infection prevention needs to be multimodal in nature, and take into account numerous technical, human and institutional elements in order to be successful.(77–80)

The survey proved very useful in improving and developing the subsequent versions of the HEHSAF. Although a sample size of 51 HCFs is tiny in a global context, the fact that all but one showed major issues or dysfunction in their HEH programs is quite indicative of a serious global problem, especially when taking into account the fact that the HCFs that participated were selected from a group of facilities with past participation in IPC activities at the international level.

10f. Limitations

Though efforts were made to make both the review and the pilot survey as comprehensive as possible with the available time and resources, there are of course a number of limitations that should be taken into account. The systematic review was limited because it only looked at two databases, and did not take any of the grey literature into account. No doubt there are numerous HCFs that implement changes in their HEH programs where the effects of those changes might have correlated with a reduction in HAI or patient colonization.

The pilot survey was limited because it was far too small of a sample size to draw any meaningful conclusions about practices in different geographical areas. Because it was an exploratory study, there was no mechanism to ensure that primary/ secondary/ tertiary care centers or private/ public HCFs were represented evenly. The HCFs that responded were likely better at IPC than others, as they had already participated in at least one of the global surveys. Croatia was majorly overrepresented because the survey was shared at an event, creating challenges for analysis.

Overall, developing tools that cover a broad scope and are meant to be able to be applied universally is challenging as some granularity will inevitably be lost, and some elements will be more relevant for some participants than others.

10g. Future development of the HEHSAF

Our aim for the HEHSAF is to implement it as a cross-sectional survey using an online survey platform. It will be open to any acute health care facility globally and participation will be voluntary. A scoring system is currently being developed by the Clean Hospitals Academic Taskforce. The HEHSAF will then be validated in some of our partner hospitals around the world.

This work could be followed by broad dissemination of the HEHSAF, as well as monitoring and evaluation in order to document progress and inform efforts moving forward. Ideally, an iteration of the HEHSAF could serve as one of the WHO's self-assessment tools, much like the HHSAF for hand hygiene(81) or the Infection Prevention and Control Assessment Framework (IPCAF) for the IPC core components.[79] Expanding these tools to include HEH would offer a more complete toolkit for facilities to improve their IPC, and help to reduce antimicrobial resistance, and fight HAIs. If this occurs, then it could be conceivable that the HEHSAF could be included in future versions of the WHO Global Survey.(82,83) In order to be useful in such a survey the HEHSAF tool first needs to be validated and tested extensively. In parallel, recommendations and further tools would need to be developed for HCFs to improve on the individual elements in the self-assessment framework that are challenging for them. Without the building of these additional tools, the HEHSAF will be limited to informing HCFs of their weaknesses instead of accompanying them towards improvement. Such additional tools will likely take numerous years to research and develop as well.

Once the HEHSAF is sufficiently established, next steps could be to develop more specific self-assessment tools and their associated information/ training resources for specific environments. Although the HEHSAF covers all the main areas of HEH, it is concentrated mainly on surface cleaning and disinfection; it remains far more general for specific fields such as sterilization and device reprocessing, air control, and water control. These fields are more specialized, and many smaller HCFs may not have in-house experts in all of those domains. Therefore, developing and providing the aforementioned assessment frameworks and resources could be useful tools to support HCFs in improving their current practices.

10h. Conclusions

IPC is facing an increasing number of challenges; a growing, aging population, continued barriers to HCFs obtaining adequate resources, and antimicrobial resistance mean that more individuals are at-risk for contracting HAIs than ever before. Increasing the focus on the underdeveloped areas in IPC such as environmental hygiene is crucial for the future of patient safety and for the sustainability of healthcare systems and the environment; all of which are elements that connect into the larger vision of the UN sustainable development goals.(84)

Through my work with Prof. Pittet's team and the Clean Hospitals project over these last years, I am happy to be able to say that I have been able to contribute in some small way to the continued goals of IPC and patient safety. The work completed for my PhD is only the beginning of this project, and I look forward to continuing my research and advocacy in and for HEH. It is my hope that HCFs will realize the importance of the role of the healthcare environment in patient safety and commit to improving their HEH programs. COVID-19 pandemic brought unprecedented global awareness to IPC and HEH, and it is crucial that the momentum and interest generated will continue. Hopefully future work in HEH will not only be concentrated on finding new technologies that kill pathogens more safely and effectively, but also on implementing these technologies in a context where the human and institutional factors of practices and implementation are approached systemically and holistically.

11. References

1. Allegranzi B, Nejad SB, Pittet D. The Burden of Healthcare-Associated Infection. In: Hand Hygiene: A Handbook for Medical Professionals [Internet]. Hoboken, NJ USA: Wiley-Blackwell; 2017. p. 1–7. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118846810.ch1

2. World Health Organization. World Health Organization. WHO guidelines on hand hygiene in health care: first global patient safety challenge: clean care is safer care Geneva, Switzerland [Internet]. WHO; 2009. Available from: http://apps.who.int/iris/bitstream/10665/44102/1/9789241597906_eng.pdf

3. Cassini A, Plachouras D, Eckmanns T, Sin MA, Blank HP, Ducomble T, et al. Burden of Six Healthcare-Associated Infections on European Population Health: Estimating Incidence-Based Disability-Adjusted Life Years through a Population Prevalence-Based Modelling Study. PLOS Medicine. 2016 Oct 18;13(10):e1002150.

4. World Health Organization. Health care-associated infections FACT SHEET [Internet]. WHO; 2021. Available from: https://www.who.int/gpsc/country_work/gpsc_ccisc_fact_sheet_en.pdf

5. Colzani E, Cassini A, Pini A, Maringhini G, Lewandowsky D, Kramarz P, et al. Results from the 2015 Burden of Communicable Diseases in Europe (BCoDE) study: Edoardo Colzani. European Journal of Public Health [Internet]. 2015 Oct 1 [cited 2021 Jul 28];25(suppl_3). Available from: https://doi.org/10.1093/eurpub/ckv167.038

6. Allegranzi B, Nejad SB, Combescure C, Graafmans W, Attar H, Donaldson L, et al. Burden of endemic health-care-associated infection in developing countries: systematic review and meta-analysis. The Lancet. 2011 Jan 15;377(9761):228–41.

7. Marchetti A, Rossiter R. Economic burden of healthcare-associated infection in US acute care hospitals: societal perspective. J Med Econ. 2013 Dec;16(12):1399–404.

8. Zimlichman E, Henderson D, Tamir O, Franz C, Song P, Yamin CK, et al. Health Care–Associated Infections: A Meta-analysis of Costs and Financial Impact on the US Health Care System. JAMA Intern Med. 2013 Dec 9;173(22):2039.

9. World Health Organization, Regional Office for the Western Pacific, World Health Organization, Regional Office for South-East Asia. Practical guidelines for infection control in health care facilities. Manila; New Delhi: World Health Organization, Regional Office for Western Pacific ; World Health Organization, Regional Office for South-East Asia; 2004.

10. Centers for Disease Control and Prevention. Environmental Hygiene in Healthcare. HAI [Internet]. 2019 [cited 2021 Oct 12]. Available from: https://www.cdc.gov/hai/research/eic-meeting.html

11. Rampling A, Wiseman S, Davis L, Hyett AP, Walbridge AN, Payne GC, et al. Evidence that hospital hygiene is important in the control of methicillin-resistant Staphylococcus aureus. Journal of Hospital Infection. 2001 Oct 1;49(2):109–16.

12. Dancer SJ. Importance of the environment in meticillin-resistant Staphylococcus aureus acquisition: the case for hospital cleaning. The Lancet Infectious Diseases. 2008 Feb 1;8(2):101–13.

13. Perl TM. The threat of vancomycin resistance. Am J Med. 1999 May 3;106(5A):26S-37S; discussion 48S-52S.

14. Warnick F. Vancomycin-resistant enterococcus. Clin J Oncol Nurs. 1997 Jul;1(3):73–7.

15. Simor AE, Lee M, Vearncombe M, Jones-Paul L, Barry C, Gomez M, et al. An outbreak due to multiresistant Acinetobacter baumannii in a burn unit: risk factors for acquisition and management. Infect Control Hosp Epidemiol. 2002 May;23(5):261–7.

16. Lankford MG, Collins S, Youngberg L, Rooney DM, Warren JR, Noskin GA. Assessment of materials commonly utilized in health care: implications for bacterial survival and transmission. Am J Infect Control. 2006 Jun;34(5):258–63.

17. Martínez JA, Ruthazer R, Hansjosten K, Barefoot L, Snydman DR. Role of environmental contamination as a risk factor for acquisition of vancomycin-resistant enterococci in patients treated in a medical intensive care unit. Arch Intern Med. 2003 Sep 8;163(16):1905–12.

18. Engelhart S, Krizek L, Glasmacher A, Fischnaller E, Marklein G, Exner M. Pseudomonas aeruginosa outbreak in a haematology-oncology unit associated with contaminated surface cleaning equipment. J Hosp Infect. 2002 Oct;52(2):93–8.

19. Dancer SJ. How do we assess hospital cleaning? A proposal for microbiological standards for surface hygiene in hospitals. Journal of Hospital Infection. 2004 Jan 1;56(1):10–5.

20. Pratt RJ, Pellowe CM, Wilson JA, Loveday HP, Harper PJ, Jones SRLJ, et al. epic2: National Evidence-Based Guidelines for Preventing Healthcare-Associated Infections in NHS Hospitals in England. Journal of Hospital Infection. 2007 Feb 1;65:S1–59.

21. Dettenkofer M, Block C. Hospital disinfection: efficacy and safety issues. Curr Opin Infect Dis. 2005 Aug;18(4):320–5.

22. Hota B. Contamination, disinfection, and cross-colonization: are hospital surfaces reservoirs for nosocomial infection? Clin Infect Dis. 2004 Oct 15;39(8):1182–9.

23. Sehulster L, Chinn RYW, CDC, HICPAC. Guidelines for environmental infection control in health-care facilities. Recommendations of CDC and the Healthcare Infection Control

Practices Advisory Committee (HICPAC). MMWR Recomm Rep. 2003 Jun 6;52(RR-10):1–42.

24. Gebel J, Gemein S, Exner M. Surface cleaning and disinfection: insight into the situation in Germany and Europe. Healthcare infection. 2013 Mar 1;18(1):31–6.

25. Gebel J, Exner M, French G, Chartier Y, Christiansen B, Gemein S, et al. The role of surface disinfection in infection prevention. GMS Hyg Infect Control. 2013 Apr 29;8(1):Doc10.

26. Vardoulakis S, Sheel M, Lal A, Gray D. COVID-19 environmental transmission and preventive public health measures. Aust N Z J Public Health. 2020 Aug 24;10.1111/1753-6405.13033.

27. Kumar S, Singh R, Kumari N, Karmakar S, Behera M, Siddiqui AJ, et al. Current understanding of the influence of environmental factors on SARS-CoV-2 transmission, persistence, and infectivity. Environ Sci Pollut Res. 2021 Feb 1;28(6):6267–88.

28. Noorimotlagh Z, Mirzaee SA, Jaafarzadeh N, Maleki M, Kalvandi G, Karami C. A systematic review of emerging human coronavirus (SARS-CoV-2) outbreak: focus on disinfection methods, environmental survival, and control and prevention strategies. Environ Sci Pollut Res. 2021 Jan 1;28(1):1–15.

29. 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. Journal of Hospital Infection. 2021 Jul 1;113:104–14.

30. Thomas RE, Thomas BC, Conly J, Lorenzetti D. Hospital and Long-Term Care Facility Environmental Service Workers' Training, Skills, Activities, and Effectiveness in Cleaning and Disinfection: A Systematic Review. Journal of Hospital Infection [Internet]. 2022 Mar 17 [cited 2022 Apr 6];0(0). Available from: https://www.journalofhospitalinfection.com/article/S0195-6701(22)00076-7/fulltext

31. Schoyer E, Hall K. Environmental Cleaning and Decontamination to Prevent Clostridioides difficile Infection in Health Care Settings: A Systematic Review. Journal of Patient Safety. 2020 Sep;16(3):S12.

32. Dancer SJ, King MF. Systematic review on use, cost and clinical efficacy of automated decontamination devices. Antimicrob Resist Infect Control. 2021 Feb 12;10(1):34.

33. Gülsoy Z, Karagozoglu S. The efficiency of cleaning in intensive care units: A systematic review. Enferm Intensiva (Engl Ed). 2021 May 31;S1130-2399(21)00056-0.

34. Hewage SCN, Cao LTT, Jones RM, Fraser AM. Factors associated with environmental service worker cleaning practices in health care settings: A systematic review of the literature. Am J Infect Control. 2021 Jul;49(7):919–27.

35. Chau JPC, Liu X, Lo SHS, Chien WT, Wan X. Effects of environmental cleaning bundles on reducing healthcare-associated Clostridioides difficile infection: a systematic review and meta-analysis. J Hosp Infect. 2020 Dec;106(4):734–44.

36. Shimabukuro PMS, Duarte ML, Imoto AM, Atallah ÁN, Franco ESB, Peccin MS, et al. Environmental cleaning to prevent COVID-19 infection. A rapid systematic review. Sao Paulo Med J. 2020 Dec;138(6):505–14.

37. Wong VWY, Huang Y, Wei WI, Wong SYS, Kwok KO. Approaches to multidrug-resistant organism prevention and control in long-term care facilities for older people: a systematic review and meta-analysis. Antimicrob Resist Infect Control. 2022 Jan 15;11(1):7.

38. Thoma R, Seneghini M, Seiffert SN, Vuichard Gysin D, Scanferla G, Haller S, et al. The challenge of preventing and containing outbreaks of multidrug-resistant organisms and Candida auris during the coronavirus disease 2019 pandemic: report of a carbapenem-resistant Acinetobacter baumannii outbreak and a systematic review of the literature. Antimicrob Resist Infect Control. 2022 Jan 21;11(1):12.

39. Anderson DM, Cronk R, Best L, Radin M, Schram H, Tracy JW, et al. Budgeting for Environmental Health Services in Healthcare Facilities: A Ten-Step Model for Planning and Costing. Int J Environ Res Public Health. 2020 Mar 20;17(6):E2075.

40. Wang C, Zhang F, Breland A, Lineaweaver WC. Efficacy of Infection Control Measures in Managing Outbreaks of Multidrug-Resistant Organisms in Burn Units. Ann Plast Surg. 2021 Jun 1;86(4S Suppl 4):S454–7.

41. de Souza Hajar K, Quartim de Moraes Bruna C, Uchikawa Graziano K. Infection Transmission Associated With Contaminated Ultrasound Probes: A Systematic Review. AORN J. 2022 Jan;115(1):42–51.

42. Obenza A, Cruz P, Buttner M, Woodard D. Microbial contamination on ambulance surfaces: a systematic literature review. J Hosp Infect. 2022 Apr;122:44–59.

43. Hiwar W, King MF, Shuweihdi F, Fletcher LA, Dancer SJ, Noakes CJ. What is the relationship between indoor air quality parameters and airborne microorganisms in hospital environments? A systematic review and meta-analysis. Indoor Air. 2021 Sep;31(5):1308–22.

44. Aganovic A, Cao G, Fecer T, Ljungqvist B, Lytsy B, Radtke A, et al. Ventilation design conditions associated with airborne bacteria levels within the wound area during surgical procedures: a systematic review. J Hosp Infect. 2021 Jul;113:85–95.

45. Queiroz Júnior JRA de, Melo IO, Calado GHDS, Cavalcanti LRC, Sobrinho CRW. Identification and resistance profile of bacteria isolated on stethoscopes by health care professionals: Systematic review. Am J Infect Control. 2021 Feb;49(2):229–37.

46. Ramos CCR, Roque JLA, Sarmiento DB, Suarez LEG, Sunio JTP, Tabungar KIB, et al. Use of ultraviolet-C in environmental sterilization in hospitals: A systematic review on efficacy and safety. Int J Health Sci (Qassim). 2020 Dec;14(6):52–65.

47. Centers for Disease Control and Prevention (CDC) and the Infection Control Africa, Centers for Disease Control and Prevention (CDC), Infection Control Africa Network (ICAN). Best Practices for Environmental Cleaning in Healthcare Facilities in Resource-Limited Settings. [Internet]. Atlanta, GA: US Department of Health and Human Services, CDC; Cape Town, South Africa: Infection Control Africa Network.; 2019. Available from: https://www.cdc.gov/hai/prevent/resource-limited/index.html and http://www.icanetwork.co.za/icanguideline2019/

48. Centers for Disease Control and Prevention. Core Components of Environmental Cleaning and Disinfection in Hospitals [Internet]. 2020 [cited 2022 Apr 6]. Available from: https://www.cdc.gov/hai/prevent/environment/surfaces.html

49. DIN 13063, Krankenhausreinigung – Anforderungen an die Reinigung und desinfizierende Reinigung in Krankenhäusern und anderen medizinischen Einrichtungen (Unpublished manuscript). DIN-Normenausschuss Rettungsdienst und Krankenhaus (NARK); 2021.

50. National Health Service (UK). National Standards of Healthcare Cleanliness 2021 [Internet]. UK National Health Service; 2021. Available from: https://www.england.nhs.uk/wp-content/uploads/2021/04/B0271-national-standards-of-healthcare-cleanliness-2021.pdf

51. CleanHospitals [Internet]. Clean Hospitals. 2019 [cited 2022 Jan 4]. Available from: https://cleanhospitals.com/

52. Peters A, Otter J, Moldovan A, Parneix P, Voss A, Pittet D. Keeping hospitals clean and safe without breaking the bank; summary of the Healthcare Cleaning Forum 2018. Antimicrob Resist Infect Control [Internet]. 2018 Nov 8 [cited 2020 Jul 15];7. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6225655/

53. 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. The Lancet Infectious Diseases. 2019 Apr 1;19(4):410–8.

54. 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 Sep 1;45(9):1006–10.

55. Anderson DJ, Chen LF, Weber DJ, Moehring RW, Lewis SS, Triplett PF, et al. Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and Clostridium difficile (the Benefits of Enhanced Terminal Room Disinfection

study): a cluster-randomised, multicentre, crossover study. Lancet. 2017 Feb 25;389(10071):805–14.

56. Ray AJ, Deshpande A, Fertelli D, Sitzlar BM, Thota P, Sankar C 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 Jul;38(7):777–83.

57. Dettenkofer M, Wenzler S, Amthor S, Antes G, Motschall E, Daschner FD. Does disinfection of environmental surfaces influence nosocomial infection rates? A systematic review. Am J Infect Control. 2004 Apr;32(2):84–9.

58. Mitchell BG, Dancer SJ, Anderson M, Dehn E. Risk of organism acquisition from prior room occupants: a systematic review and meta-analysis. Journal of Hospital Infection. 2015 Nov 1;91(3):211–7.

59. Falagas ME, Thomaidis PC, Kotsantis IK, Sgouros K, Samonis G, Karageorgopoulos DE. Airborne hydrogen peroxide for disinfection of the hospital environment and infection control: a systematic review. J Hosp Infect. 2011 Jul;78(3):171–7.

60. Tomczyk S, Zanichelli V, Grayson ML, Twyman A, Abbas M, Pires D, et al. Control of Carbapenem-resistant Enterobacteriaceae, Acinetobacter baumannii, and Pseudomonas aeruginosa in Healthcare Facilities: A Systematic Review and Reanalysis of Quasi-experimental Studies. Clin Infect Dis. 2019 Feb 15;68(5):873–84.

61. Dehghani MH, Karri RR, Roy S. Environmental and Health Management of Novel Coronavirus Disease (COVID-19). Academic Press; 2021. 520 p.

62. Peters A, Lotfinejad N, Palomo R, Zingg W, Parneix P, Ney H, et al. Decontaminating N95/FFP2 masks for reuse during the COVID-19 epidemic: a systematic review. Antimicrob Resist Infect Control. 2021 Oct 11;10(1):144.

63. Peters A, Palomo R, Ney H, Lotfinejad N, Zingg W, Parneix P, et al. The COVID-19 pandemic and N95 masks: reusability and decontamination methods. Antimicrobial Resistance & Infection Control. 2021 May 29;10(1):83.

64. Peters A, Vetter P, Guitart C, Lotfinejad N, Pittet D. Understanding the emerging coronavirus: what it means for health security and infection prevention. Journal of Hospital Infection. 2020 Apr 1;104(4):440–8.

65. Peters A, Parneix P, Otter J, Pittet D. Putting some context to the aerosolization debate around SARS-CoV-2. J Hosp Infect. 2020 Jun;105(2):381–2.

66. Tartari E, Fankhauser C, Masson-Roy S, Márquez-Villarreal H, Fernández Moreno I, Rodriguez Navas ML, et al. Train-the-Trainers in hand hygiene: a standardized approach to

guide education in infection prevention and control. Antimicrobial Resistance & Infection Control. 2019 Dec 30;8(1):206.

67. World Health Organization. WHO multimodal improvement strategy [Internet]. 2009. Available from: https://www.who.int/infection-prevention/publications/ipc-cc-mis.pdf?ua=1

68. de Kraker MEA, Tartari E, Tomczyk S, Twyman A, Francioli L, Cassini A, et al. Implementation of Hand Hygiene in healthcare facilities: Results from the WHO Hand Hygiene Self-Assessment Framework global survey 2019. Lancet Infecitous Diseases. 2022;(In Press).

69. World Health Organization. Summary Report: Hand Hygiene Self-Assessment Framework Survey 2015/2016 A report from the WHO Infection Prevention and Control Global Unit [Internet]. WHO; 2016. Available from: https://apps.who.int/iris/bitstream/handle/10665/330067/WHO-HIS-SDS-2016.7-eng.pdf

70. Kilpatrick C, Tartari E, Gayet-Ageron A, Storr J, Tomczyk S, Allegranzi B, et al. Global hand hygiene improvement progress: two surveys using the WHO Hand Hygiene Self-Assessment Framework. Journal of Hospital Infection. 2018 Oct 1;100(2):202–6.

71. Peters A, Schmid MN, de Kraker MEA, Parneix P, Pittet D. Results of an international pilot survey on healthcare environmental hygiene at the facility level. Am J Infect Control (In Press). American Journal of Infection Control; (In Press).

72. 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. Antimicrobial Resistance & Infection Control. 2022 Feb 19;11(1):38.

73. National Instiute for Health Research, University of York, York, UK. Prospero: International prospective register of systematic reviews [Internet]. 2022. Available from: https://www.crd.york.ac.uk/prospero/

74. World Health Organization. WHO Hand Hygiene Self-Assessment Framework Global Survey Summary Report 2011 [Internet]. WHO; 2012. Available from: https://www.who.int/gpsc/5may/summary_report_HHSAF_global_survey_May12.pdf?ua

75. WHO | 2019 WHO Global Survey on Infection Prevention and Control (IPC) and Hand Hygiene [Internet]. WHO. [cited 2019 Mar 1]. Available from: http://www.who.int/infection-prevention/campaigns/ipc-global-survey-2019/en/

76. World Bank Country and Lending Groups – World Bank Data Help Desk [Internet]. [cited 2021 Apr 12]. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

77. International Society for Infectious Diseases. Bundles in Infection Prevention and Safety [Internet]. ISID. 2018 [cited 2022 Apr 11]. Available from: https://isid.org/guide/infectionprevention/bundles/

78. Allegranzi B, Gayet-Ageron A, Damani N, Bengaly L, McLaws ML, Moro ML, et al. Global implementation of WHO's multimodal strategy for improvement of hand hygiene: a quasi-experimental study. Lancet Infect Dis. 2013 Oct;13(10):843–51.

79. World Health Organization. Guide to Implementation: A Guide to the Implementation of the WHO Multimodal Hand Hygiene Improvement Strategy [Internet]. WHO; 2009. Available from: https://www.who.int/gpsc/5may/Guide_to_Implementation.pdf

80. The Joint Commission. Preventing Central Line–Associated Bloodstream Infections: Useful Tools, An International Perspective [Internet]. The Joint Commission; 2013. Available from: https://www.jointcommission.org/-/media/tjc/documents/resources/hai/clabsi_monographpdf.pdf

81. World Health Organization. WHO | WHO Hand Hygiene Self-Assessment Framework [Internet]. WHO. 2018 [cited 2018 Oct 15]. Available from: http://www.who.int/gpsc/5may/hhsa_framework/en/

82. Tomczyk S, Twyman A, Kraker MEA de, Rehse APC, Tartari E, Toledo JP, et al. The first WHO global survey on infection prevention and control in health-care facilities. The Lancet Infectious Diseases [Internet]. 2022 Feb 21 [cited 2022 Apr 12];0(0). Available from: https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(21)00809-4/fulltext

83. Kraker MEA de, Tartari E, Tomczyk S, Twyman A, Francioli LC, Cassini A, et al. Implementation of hand hygiene in health-care facilities: results from the WHO Hand Hygiene Self-Assessment Framework global survey 2019. The Lancet Infectious Diseases [Internet]. 2022 Feb 21 [cited 2022 Apr 11];0(0). Available from: https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(21)00618-6/fulltext

84. United Nations. THE 17 GOALS. United Nations Sustainable Development [Internet]. United Nations. [cited 2022 Apr 19]. Available from: https://sdgs.un.org/goals