Cell. Mol. Biol. (ISSN: 1165-158X)

Journal Homepage: www.cellmolbiol.org

Cellular and Molecular Biology

Review

Healthcare-associated infections: an overview of global strategies and challenges in minimizing infection transmission

Adil Abalkhail, Eman Marzouk*

Department of Public Health, College of Applied Medical Sciences, Qassim University, Buraydah, 51452 P.O. Box 6666, Saudi Arabia

Article Info

Article history:

Received: December 07, 2024
Accepted: August 30, 2025
Published: October 31, 2025

Use your device to scan and read the article online

Abstract

Healthcare-associated infections (HAIs) are a major cause of mortality, significantly impacting morbidity rates. They can occur during hospital care or 3 to 30 days after discharge. In developing countries, ten patients acquire at least one HAI for every 100 hospital admissions, compared to seven in high-income countries. The World Health Organization (WHO) defines HAIs as infections that may develop 2 to 3 days after admission or discharge, often undetected at hospital presentation. Many pathogens have developed antibiotic resistance, limiting effective treatments. This review summarizes international initiatives to combat HAIs, based on a literature review using Google Scholar and PubMed. Handwashing remains a key method for preventing HAIs, relying on strict adherence to hygiene protocols by nursing professionals. Maintaining a safe medical environment reduces the transmission of harmful bacteria, especially multi-drug-resistant pathogens. Hand hygiene and antibiotic stewardship are essential for preserving antibiotic effectiveness. Vaccine development can help mitigate HAIs by targeting multidrug-resistant organisms like Staphylococcus aureus and Clostridium difficile. A comprehensive understanding of prevention strategies and challenges is urgently needed.

Keywords: Healthcare-Associated Infections, Infection surveillance, Hand hygiene, Environmental hygiene, Antibiotic stewardship, Vaccines, Public health.

1. Introduction

Healthcare-associated infections (HAIs) are a leading cause of morbidity and mortality, ranking as the second most common cause of death globally [1-3]. They stem from poor hygiene, inadequate sterilization of medical equipment, and improper antibiotic use, and can be transmitted through person-to-person contact, zoonotic transmission, and contamination of food, water, and air. About 10% of patients with HAIs in emerging economies die from the infection [4], compared to 7% in high-income nations, according to the World Health Organization (WHO). This disparity highlights the challenges faced by these economies, which often lack resources and infrastructure for effective HAI management. In the U.S., HAIs affect 4.5% of the population, resulting in approximately 1.7 million infections and 90,000 to 99,000 deaths annually [5, 6]. In the European Economic Area, around 2.6 million new HAI cases are reported each year, leading to a loss of 2.5 million years of life [2, 6]. These statistics emphasize the urgent need for research, preventive measures, and public awareness regarding HAIs.

HAIs in low- and middle-income countries range from 5.7% to 19.1%, with limited data due to inadequate infrastructure [6-8]. The WHO reports that 51% of ICU patients develop HAIs, resulting in longer hospital stays and higher risks of secondary infections. About 95% of the 15 million annual deaths occur in developing countries, mainly from acute respiratory infections, diarrheal diseases, measles, AIDS, malaria, and tuberculosis [9]. In developed countries, around 6% of acute care patients report infections, while in developing countries, the risk can be up to 20 times higher, reaching 25% [10-12]. The CDC reports over 3 million annual HAIs in assisted living facilities, leading to disability or death [13]. HAIs contribute to antibiotic resistance, longer hospital stays, increased mortality and morbidity, and higher healthcare costs. Reducing HAIs and length of stay (LOS) can improve healthcare facility revenue [14]. They create significant economic burdens, including direct treatment costs and indirect costs like job loss [15]. In the U.S., HAIs cause 44,000 to 98,000 unexpected deaths, costing at least $17 billion, potentially up to $29 billion [16]. HAI rates are similar in high- and low-income countries, with high-income nations reporting 3.5% to 12% and least-developed countries ranging from 5.7% to 19.1% [17].

Annual surveys of HAIs at the University of Geneva Hospitals from 2006 to 2012 showed a pooled point preva-

* Corresponding author.
E-mail address: e.marzouk@qu.edu.sa (E.Marzouk).
Doi: http://dx.doi.org/10.14715/cmb/2025.71.10.2

lence of 7.46% and a period prevalence of 9.8% [18]. Lower respiratory tract infections were the most common, comprising 49% of HAIs, followed by urinary tract infections (19%), surgical site infections (13%), and bloodstream infections. This study outlines infection patterns, causes, and transmission methods, including direct contact, personal items, ingestion, airborne routes, and vector-borne transmission. The CDC has classified HAI sites into 13 categories, covering 50 types of infection sites. Common infections include skin and soft tissue infections, urinary tract infections, respiratory tract infections, gastroenteritis, meningitis, and surgical site infections [19]. The most frequent pathogens are *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*, though viruses like influenza and respiratory syncytial virus can also cause HAIs. Fungi, including *Aspergillus* species and *Candida albicans*, can cause nosocomial infections [20]. Common pathogens include methicillin-sensitive *Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococci* (VRE), and multidrug-resistant *Acinetobacter* species [16]. Carbapenem-resistant Acinetobacter baumannii is particularly concerning due to its link to opportunistic infections and HAIs [21].

In the Kingdom of Saudi Arabia (KSA), few studies have reported the prevalence of HAIs. A study by Sabra and Abdel-Fattah [22] in Taif Hospitals found that respiratory tract infections were the most common at 32.3%, followed by urinary tract infections (25.3%), blood infections (18.2%), and surgical site infections (12.9%). A comprehensive infection prevention and control strategy is essential to reduce HAIs, promoting hand hygiene, environmental disinfection, and proper training for healthcare workers (HCWs). HAIs are a significant public health concern, affecting patient safety and healthcare costs. This review summarizes the latest international initiatives to combat HAIs.

2. Healthcare-associated infection prevention strategies and challenges

Stakeholders in the healthcare system, including medical practitioners, patients, and the public, are increasingly concerned about the global burden of HAIs and their prevention [4, 23, 24]. The rise of multidrug-resistant bacteria complicates this issue, as they resist standard treatments like antibiotics, making them difficult to eliminate and increasing their prevalence. Many antibiotics in use are ineffective against these resistant strains, and few new antimicrobials are being developed due to misuse and overuse of existing antibiotics. *Klebsiella pneumoniae* is a particularly concerning resistant infection, especially in intensive care units [3, 25]. Preventing and controlling HAIs is a significant challenge that requires multiple strategies. The following sections will discuss common strategies identified in reputable studies to manage the HAI burden (Figure 1), providing insights into effective approaches.

2.1. Hand hygiene

In the mid-19th century, scholars in the U.S. and Europe conducted studies to address HAIs [26, 27]. They identified inadequate hand hygiene and improper use of medical equipment as common sources of HAIs. Despite conducting separate investigations, the researchers proposed a theory that HCWs might inadvertently spread bacteria by touching patients with contaminated hands, even when wearing gloves. There have been numerous studies over the past century showing that health care workers commonly transfer harmful microbes from one place to another [28-30]. Health care workers often come into contact with various patients and surfaces, making it easy to spread germs. Thus, proper hand hygiene and the use of protective equipment, like gloves and gowns, are crucial. Semmelweis was the first to highlight the importance of hand hygiene in preventing infections. He noted that infection-related mortality was higher in hospitals than at home due to poor hygiene and suggested that washing hands with a chlorine solution before patient examinations could reduce infections and save lives [31-33].

The CDC prioritized identifying the illness's source over the importance of hand hygiene in preventing disease spread, which hindered outbreak control. They recommended improving handwashing procedures in healthcare facilities, emphasizing non-antimicrobial soaps before and after procedures, especially for high-risk patients. Alcohol-based products were suggested only when wash-hand basins were unavailable [34]. A 1995 study also recommended that patients with multidrug-resistant bacteria use antimicrobial soap or waterless antiseptics before leaving their rooms to reduce the spread of resistant bacteria, as waterless antiseptics are more effective than regular soap [35].

HAIs pose a significant threat to patient safety in hospitals globally, impacting both high- and low-income countries. They result in many hospitalizations each year, leading to increased morbidity, mortality, and costs for individuals and communities [36]. Hand hygiene is the most critical behavioral change HCWs can adopt to prevent HAIs. Research shows that strict adherence to hand hygiene can reduce hospital infections by 40% to 70% [37, 38]. However, healthcare professionals often fail to comply with hygiene standards over 40% of the time in many inpatient units. This underscores the need for consistent regulations, ongoing monitoring, and further research to improve public health standards.

2.2. Nurses' challenges in practicing hand hygiene

Nurses are the largest group of healthcare professionals, spending the most time with patients. A meta-analy-

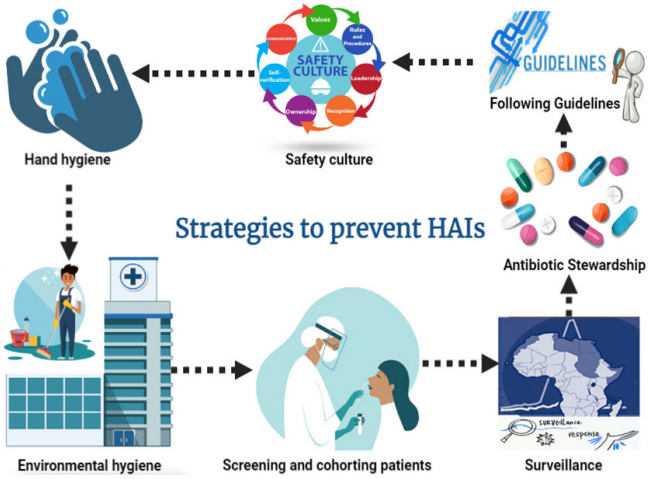

Fig. 1. Various strategies to prevent healthcare-associated infections (HAIs).

sis of six studies examined hand hygiene practices among nurses, including three randomized controlled trials and one pre- and post-intervention study [39]. Haque et al. [4] found that while individual and group interventions can promote hand hygiene, integrative strategies are more effective. A review of nineteen studies showed that student nurses have poor knowledge and behaviors regarding hand hygiene, often affected by organizational and interpersonal issues [40]. Noncompliance with hand hygiene guidelines is a global public health issue that raises the risk of HAIs. A consistent, multi-faceted policy and a robust surveillance program are necessary. Healthcare workers often spread HAIs, but they are more likely to follow guidelines when they are uniformly enforced. A surveillance program would help quickly identify and address issues. Nurses encounter various challenges related to hand hygiene, impacting their practices. The data was categorized as follows:

2.2.1. Challenges in the workplace

2.2.1.1. Shortage of materials

Nurses often struggle with hand hygiene due to a lack of essential resources like soap and functional sinks. They believe that more conveniently located sinks would improve compliance. Some find it difficult to reach restrooms at the end of shifts, leading them to wash their hands in other areas. Many nurses report that cold water and unpleasant odors from cleaning products discourage handwashing [41]. They feel that proper hygiene is ineffective when their hands remain wet while handling patients, forcing them to dry their hands on their clothing.

2.2.1.2. Lack of time and staff

Nurses faced heavy workloads, particularly during evening and night shifts, which affected their hand hygiene practices. Four studies showed that the high patient volume required significant time for handwashing. The stress of frequent hand hygiene led some nurses to skip washing their hands after each patient, opting to change gloves instead. In a study by Marjadi & McLaws [42], one nurse mentioned encouraging patients to dress their own wounds to save time and keep their hands clean. A lack of staff also hindered hand hygiene efforts.

2.2.2. Compliance challenge

Nurses are facing two challenges that make it difficult for them to follow the rules in regards to hand hygiene that make it difficult to follow these rules.

2.2.2.1. Insufficient role models

Complete compliance with hand hygiene was unattainable due to nurses' subjective assessments, resulting in inconsistent adherence, such as neglecting cleanliness when attaching intravenous infusions [41]. A nurse's evaluation suggested that the hospital hierarchy's poor performance contributed to these unfavorable results. González et al. [43] noted that physicians significantly influence the hand hygiene practices of other healthcare workers. In this study, 28 of the 55 participants were nurses. McLaws et al. [44] found that, among 80 participants, 36 were nurses, and doctors often failed to adhere to hand hygiene rules, lacking appropriate role models. One nurse noted that some doctors ignored their advice on hand hygiene [43]. Lohiniva et al. [45] reported that some nurses felt embarrassed to ask doctors for time to wash their hands. Findings from two studies suggest that best practices for hand hygiene should be implemented at all organizational levels. Nurses should follow leaders who exemplify proper practices, including doctors and infection control nurses. Having role models is beneficial, providing nurses with aspirational figures.

2.2.2.2. Unsatisfactory feedback

Several nurses [46] noted that constructive criticism could enhance progress and improve hand hygiene practices. Of the twenty-five participants, nine were nurses who found feedback on infection prevention and control beneficial, as it recognized strong performance and identified areas for improvement. Feedback is well-received when both parties are professionals [47]. The infection control nurse reported that her feedback was specific and motivating, consistently guiding nurses on proper hand hygiene.

2.3. Environmental hygiene

To prevent infections, especially HAIs, maintaining a clean environment is crucial [48]. Contaminated surfaces in hospitals can harbor antibiotic-resistant bacteria like *Clostridium difficile*, MRSA, and VRE, which can survive for long periods. These pathogens pose a significant risk to patients, particularly those with weakened immune systems, as they can easily contaminate absorbent materials and non-porous surfaces. [49, 50]. Urgent implementation of stringent sanitation procedures in hospitals is essential to reduce HAIs. The CDC and the Healthcare Infection Control Practices Advisory Committee stress that infection prevention and control are vital in all healthcare settings. These practices protect patients, healthcare personnel, and the community, forming the foundation of an effective healthcare system. They can significantly reduce the risk of healthcare-associated infections and their related morbidity and mortality. Routine deep cleaning in all facilities, including inpatient and outpatient areas, is an effective measure to prevent the spread of infectious diseases [51].

Hospital hygiene utilizes antibiotics, which can be single or multicomponent products that combat bacteria, viruses, or fungi. Cleaning products in hospitals include sprays, liquids, powders, and gases, with around 275 different ingredients [52]. A disinfection process can eliminate most metabolically active bacteria, excluding bacterial spores [53]. Hydrogen peroxide at 7.5% concentration is commonly used for high-level disinfection [54]. Isopropyl alcohol, at 70% to 90%, provides intermediate-level disinfection by killing all animal and vegetative germs, except some spores [54]. A quaternary ammonium microbial detergent can achieve low-level disinfection, eliminating most active bacteria, certain fungi, and viruses, but not inactive spores [54].

2.4. Antimicrobial stewardship

In recent years, many antimicrobial drugs have shown increased resistance to bacteria. Antimicrobial resistance (AMR) is a significant global health threat, as noted in the Political Declaration of the High-Level Committee on AMR (September 2017) and the World Health Assembly's Global Action Plan on AMR (May 2015). To combat antibiotic resistance, several legislative initiatives have been proposed to address the harmful effects of inadequate and

excessive antibiotic use, highlighting the need for optimization [55]. Antimicrobial stewardship (AMS) promotes the prudent use of antibiotics through interconnected practices that impact public health, the environment, and animal welfare globally. AMS strategies can reduce AMR and healthcare-associated infections (HAIs), improving patient outcomes and optimizing antibiotic use.

Antibiotic management strategies can significantly reduce antibiotic use, costs, and rates of antibiotic-resistant infections, as well as hospital stays [55, 56]. By limiting antibiotic use to necessary cases, the risk of resistance is diminished. Proper dosing and timing protocols can lead to cost savings and shorter hospital stays. Future studies should evaluate the long-term effects of Antimicrobial Stewardship (AMS) programs on mortality and infection rates [57]. The Al Habib Medical Group's stewardship plan focuses on improving patient care, reducing antimicrobial resistance, and optimizing drug use, including the establishment of an Antimicrobial Stewardship Team for monitoring and education [55, 56].

2.5. Infection surveillance systems

Surveillance in healthcare systems entails the systematic collection and analysis of information, which is crucial for developing effective strategies and evaluating public health activities. This ensures secure data distribution to those in need [58]. Effective surveillance in healthcare begins with evaluating the patient population, clinical interventions, and prevalent infections. This assessment is vital for establishing a strong surveillance framework. Healthcare institutions, including long-term care facilities, should consider various potential infections and their impact on prevention. HAIs surveillance is crucial for identifying and reducing infections through data collection, analysis, and dissemination. It also involves monitoring infection data to analyze trends and determine measures to control HAIs, contributing to quality improvement efforts [59].

The WHO [60] emphasizes that surveillance is essential for preventing HAIs by tracking disease spread, establishing endemic rates, and assessing control measures. However, many healthcare organizations, even in developed countries, still use manual surveillance methods, requiring infection control staff to spend excessive time reviewing records to identify potential HAIs and necessary patient isolation interventions. This reliance on manual processes hinders real-time data collection and analysis, reducing the effectiveness of surveillance systems and delaying reporting, which can compromise timely HAI treatment [61]. These reporting issues prevent the identification of preventable infections among high-risk patients, leading to misallocated resources. A 1985 study in U.S. hospitals (SENIC) showed that HAI surveillance, when paired with prompt feedback and effective infection control strategies, significantly reduced HAIs, with 25 hospitals achieving a 32% reduction in infection rates [62]. This study reported that 25 hospitals that assigned the three core components and including physicians and microbiologists, were successful in minimizing the hospital-acquired infection rates by 32% [62]. Surveillance programs in Germany have significantly reduced HAIs [63]. However, deficiencies in surveillance systems hinder infection control. Accurately tracking hospital staff immunization status allows institutions to monitor and improve practices, aiding in HAI prevention.

2.6. Identifying and cohorting patients for screening and follow-up

Growing concerns among politicians and the community stem from the failure to prevent HAIs during hospital stays, leading to high rates of morbidity and mortality from antimicrobial-resistant infections. Contributing factors include poor hand hygiene, non-adherence to infection prevention protocols, and insufficient resources, which have resulted in increasingly resistant bacterial strains. To reduce and manage HAIs, it is crucial to implement a culture monitoring program and isolate infected and high-risk patients [64].

The use of cultures and contact precautions for high-risk patients may help reduce multidrug-resistant organisms that cause hospital-acquired infections [65]. Active surveillance cultures should be implemented based on accurate assessments of public health impact and a comparison of costs and benefits with existing prevention strategies [66]. Researchers have concluded that thorough evaluations are necessary for their implementation. The prevalence of infections from multidrug-resistant organisms has been increasing in hospitals for years, yet a review of 20 articles shows that the effectiveness and cost-efficiency of active surveillance cultures are still unclear [67].

A controlled trial found that active surveillance cultures in intensive care patients did not identify harmful microorganisms linked to severe microbiological illnesses, suggesting they may not be effective in detecting bloodstream infections [68]. Consequently, alternative methods may be necessary. A four-year study indicated that active surveillance cultures are not needed to control MRSA infections in intensive care settings [69]. Countries implementing and destroying" measures have successfully reduced MRSA severity and hospitalizations [70]. This strategy involves identifying, isolating, and treating infected patients with antibiotics to prevent infection spread, proving effective in healthcare settings. Managing these measures after an MRSA outbreak includes testing patients and staff, evaluating high-risk cases, and making necessary assessments. Assessing HCWs on leave as potential carriers is crucial, along with decontamination and halting new admissions in areas with multiple identified carriers [71]. Hospitals often harbor multidrug-resistant bacteria, such as MRSA and VRE, posing outbreak risks. HCWs can transmit these bacteria through direct or indirect contact and contaminated surfaces, leading to healthcare-associated infections that may spread and increase outbreak risks.

3. Preventing infection through transmission-based precautions

Preventive measures are essential in healthcare to control infection spread. Transmission-based precautions (TBPs) effectively interrupt the transmission routes of infectious pathogens and include standard infection control precautions (SICPs) like vaccinations and personal protective equipment (PPE) [72]. A study [73] assessed commitment to infection prevention and control (IPC) practices among individuals and institutions, revealing significant differences in adherence and variations influenced by specific practices. Education and peer assessment enhanced commitment, while education alone or with additional support had limited impact. Education on respiratory dro-

plet dispersion showed little effect on awareness, and additional support minimally influenced adherence to preventive measures. TBPs are classified by transmission mode and include contact, aerosol, and respiratory droplet precautions [74]. Contact precautions prevent transmission through direct or indirect contact in urgent care settings, involving the use of gloves, gowns, appropriate sharps disposal, and biohazard waste containers, as well as reducing healthcare worker interactions with patients.

To minimize the risk of transmitting respiratory pathogens, implement Droplet Precautions when a patient coughs, sneezes, or talks. Daily decontamination, including wearing safety goggles and maintaining bed spacing, is essential. The Airborne Precaution System prevents the spread of pathogens like measles, chickenpox, tuberculosis, and SARS-CoV, which can remain airborne for extended periods [75]. Isolation rooms are crucial for patients requiring airborne precautions (AIIR) [76]. Healthcare facilities have various infection prevention and control (IPC) policies, each with specific procedures. Practitioners must follow minimum infection prevention practices when handling potential sources of infection. Noncompliance may stem from inadequate training, lack of awareness, or disinterest in infection prevention. Evaluating the components that ensure effective implementation of new IPC policies is vital [77].

Additional measures, such as surveillance, can help manage infections before they escalate. Khuan and Springhorn (2012) emphasized that monitoring HAIs is critical for a successful IPC strategy. Healthcare organizations should provide training to keep staff informed about infection control precautions. Ongoing training in IPC areas, such as hand hygiene and equipment decontamination, is essential for preventing infections among healthcare workers. Education and training ensure that workers are aware of new IPC procedures [78]. HCWs must understand the importance of knowledge in IPC. Regular training in hand hygiene, sharps safety, and equipment decontamination is vital for reducing infections. Educating all workers on new IPC procedures is essential. Research shows that effective infection prevention relies on monitoring and training, especially in initial phases [79]. The WHO highlights that organized IPC implementation is crucial for preventing HAIs and demonstrates readiness for disease outbreaks [60]. Key factors for successful IPC programs include organization, technical guidelines, human resources, disease surveillance, laboratory support, a clean environment, program evaluation, and public health collaboration.

To ensure infection control and patient safety, the WHO has prioritized the prevention of healthcare-associated infections (HAIs) since establishing the World Alliance for Patient Safety in 2005 [80]. The Care is Safer Care to reduce HAIs and communicable diseases. HCWs are often a primary source of nosocomial infections, transmitting HAIs between patients, particularly in ICUs [81]. Patients in these wards face a 5- to 10-fold higher risk of HAIs compared to other departments. ICU nurses, as key HCWs, are crucial for hygiene maintenance, infection monitoring, and microbiological sampling, significantly contributing to HAI prevention [82]. A decrease in nursing staff correlates with increased HAI occurrences, as nurses are essential in infection control.

To minimize infection risks between HCWs and patients, all staff—whether in direct or indirect contact—must follow established infection control strategies. Healthcare organizations should implement effective infection control programs to reduce HAIs and enhance safety [83]. Professionals must observe and report infectious disease outbreaks and adopt preventive measures, such as handwashing. The WHO mandates that healthcare institutions appoint a designated individual or team to ensure compliance with IPC. Strict adherence to these strategies can prevent up to 55% of HAIs [84].

Countries should recruit qualified personnel to manage infection control at the national level, including public health specialists and nurse practitioners. These professionals must have expertise in IPC and collaborate with public health authorities [85]. The WHO recommends establishing infection control policies to reduce disease incidence and ensure early detection. Prioritizing high-risk activities, such as safe injections and surgical operations, is essential for effective HAI control. WHO's Care is Safer Care hand hygiene compliance among healthcare workers [86].

4. The contribution of room ventilation to prevent airborne transmission

Scientific data show that indoor transmission is significantly higher than outdoor transmission [87]. Proper ventilation is the best way to prevent infection, as indoor environments pose a considerable risk for disease spread [88]. Hospital-acquired SARS-CoV-2 infections significantly contributed to the outbreak's initial spread. The SARS-CoV-2 working group in healthcare aimed to minimize contact and droplet exposure [89]. Airborne transmission remains a critical vector for virus spread, despite its recognition. Airborne transmission is a significant vector for virus spread. Resource-rich hospitals are increasingly isolating COVID-19 patients in negative-pressure chambers with controlled air exchange rates to prevent transmission, but information on SARS-CoV-2 contamination in these settings is limited.

The spread of SARS-CoV-2 has led authorities to protect healthcare professionals, a vulnerable group facing significant infection rates. This has strained health services, especially in low- and middle-income countries, which struggled to retain staff even before the pandemic [90, 91]. Understanding transmission risks is vital for developing mitigation strategies, including engineering controls and personal protective equipment. Poor ventilation poses a significant exposure risk to aerosolized particles. Recognizing the potential for airborne transmission is essential for creating effective safety guidelines in healthcare facilities. WHO recommends that hospital wards and outpatient clinics maintain ventilation rates of 60 litres per second per person, and 160 litres per second per person in outpatient areas during aerosol-generating procedures. Achieving these rates depends on air exchange efficiency, influenced by outdoor area, cross ventilation, and population density [92, 93].

5. An evaluation of sanitation procedures for reducing microbial bioburden in healthcare facilities

Infection prevention and control in healthcare is essential for mitigating risks from environmental pollution [*94, 95*]. Bacteria from infected patients can linger in the environment and spread through contact. Research shows that the risk of infection increases six-fold if the previous occu-

pant of a room had a serious infection. Studies show that environmental dissemination (air and surfaces) is crucial in the transmission of transitory microbes that can cause illness. A qualified healthcare professional must manually clean and disinfect areas to significantly reduce bioburden [*96, 97*]. Various microorganisms, such as *Clostridioides difficile* and MRSA, can survive for long on surfaces. Carling et al. reported that only 49% of surfaces in twenty-three acute care hospitals were effectively cleaned. Microorganisms are often transmitted between portable devices and surfaces, with bed rails, countertops, call lights, drapes, and bedside tables being the most frequently touched items.

6. Prevent HAIs by vaccinating HCWs

To prevent the spread of HAIs from multidrug-resistant bacteria, HCWs must be immunized for two main reasons [98]. First, HCWs often care for patients at risk of infectious diseases, including those who cannot be vaccinated, such as infants under six months. They also handle hazardous materials and are exposed to various infectious agents, which can lead to severe illness or death [99]. Herd immunity is relevant in healthcare, as immunized individuals reduce the risk of infection for vulnerable community members. Vaccination can also lower infectivity among those still susceptible. Second, HCWs face a high risk of contracting multidrug-resistant bacteria, making vaccination crucial. A study of 400 HCWs and 400 controls found no significant difference in infection rates between those caring for multidrug-resistant patients and those who did not [100].

This strategy faces several challenges. Vaccinations should reduce pathogen transmission among HCWs. While *Staphylococcus aureus* (*S. aureus*) HAIs mainly arise from endogenous sources [101], interactions with HCWs carrying S. aureus can increase patient colonization rates. Many outbreaks of S. aureus-related HAIs have been traced to contaminated HCWs [102], with infection prevalence among HCWs exceeding 30%. A vaccine for HCWs and patients must effectively reduce carriage to prevent the spread of infections and HAIs caused by exogenous *S. aureus*. However, current vaccines have shown limited impact on nasal carriage. About 15% of the general population and healthcare workers may asymptomatically carry toxigenic *C. difficile*, and current vaccine developments have not affected *C. difficile* carriage [103]. Most infections result from poor hand hygiene after handling patient strains and vomit, contributing to high transmission rates. Thus, the effectiveness of vaccines for HCWs in reducing *C. difficile* infections may be limited.

Establishing a vaccination program to prevent HCWs from contracting HAIs faces several challenges. There is no global standard for HCW vaccination; it is mandatory in some countries and merely recommended or not recommended in others. HCWs share the same vaccine hesitancy as the general population [104, 105]. Barriers to vaccination among HCWs include anxiety about side effects, negative experiences, perceptions of vaccines as a business strategy, the need for extra physician appointments, and a belief in low personal risk. During the COVID-19 outbreak, self-protection motivated HCWs to vaccinate. Predicting vaccine acceptance for patient protection is challenging, necessitating the identification of specific HCW demographics, especially in intensive care units and those in contact with immunocompromised patients.

Study limitations

This review article is not exhaustive and does not claim to be comprehensive. Due to the broad scope of HAI prevention strategies, it is impossible to cover all discussions in a single publication. Thus, the authors focus on the most significant aspects of the debate, providing a simplified overview.

Conclusions

Healthcare professionals, patients, and the public are increasingly concerned about HAIs due to the rise of multi-drug-resistant bacteria. This study highlights hygienic practices and antibiotic stewardship as key strategies to reduce HAIs and improve treatment outcomes. Enhanced hygiene limits pathogen transmission, while responsible antibiotic use prevents resistance. Effective infection surveillance and adherence to infection control measures are essential. Good hand hygiene is critical for preventing HAIs and minimizing germ transmission. Improving nursing practices and patient safety involves identifying factors that influence hand hygiene. Infection control must be prioritized until effective vaccinations are available. Future research should focus on infection monitoring and data analysis to enhance infection control and improve global healthcare.

Authors' contributions

AA and WA conceived and wrote the manuscript. AA and EM have been involved in revising the manuscript critically. All authors read and approved the final manuscript.

Funding

This research received no external funding.

Conflicts of interest

The authors declare no conflict of interest.

References

1. Khan HA, Baig FK, Mehboob R (2017) Nosocomial infections: Epidemiology, prevention, control and surveillance. Asian Pac J Trop Biomed 7 (5): 478-482. doi: 10.1016/j.apjtb.2017.01.019
2. Haque M, Sartelli M, McKimm J, Bakar MA (2018) Health care-associated infections–an overview. Infect Drug Resist 11: 2321-2333. doi: 10.2147/IDR.S177247
3. Ripabelli G, Tamburro M, Guerrizio G, Fanelli I, Flocco R, Scutellà M, Sammarco ML (2018) Tracking multidrug-resistant Klebsiella pneumoniae from an Italian hospital: molecular epidemiology and surveillance by PFGE, RAPD and PCR-based resistance genes prevalence. Curr Microbiol 75: 977-987. doi: 10.1007/s00284-018-1493-y
4. Haque M, McKimm J, Sartelli M, Dhingra S, Labricciosa FM, Islam S, Jahan D, Nusrat T, Chowdhury TS, Coccolini F (2020) Strategies to prevent healthcare-associated infections: a narrative overview. Risk Manag Healthc Policy 13: 1765-1780. doi: 10.2147/RMHP.S257288
5. Klevens RM, Edwards JR, Richards Jr CL, Horan TC, Gaynes RP, Pollock DA, Cardo DM (2007) Estimating health care-associated infections and deaths in US hospitals, 2002. Public Health Rep 122 (2): 160-166. doi: 10.1177/003335490712200205
6. Gocoipa control, Patnaahcf level, World Health Organization GWH (2016) The burden of healthcare-associated infection. Avai-

lable from: https://www.ncbi.nlm.nih.gov/books/NBK401766/. Accessed February 10, 2019.
7. Cassini A, Plachouras D, Eckmanns T, Abu Sin M, Blank H-P, Ducomble T, Haller S, Harder T, Klingeberg A, Sixtensson M (2016) 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 Med 13 (10): e1002150. doi: 10.1371/journal.pmed.1002150
8. Haque M, McKimm J, Godman B, Abu Bakar M, Sartelli M (2019) Initiatives to reduce postoperative surgical site infections of the head and neck cancer surgery with a special emphasis on developing countries. Expert Rev Anticancer Ther 19 (1): 81-92. doi: 10.1080/14737140.2019.1540487
9. Raka L, Mulliqi-Osmani G (2012) Infection control in developing world. In: Sudhakar C (ed) Infection Control - Updates. InTech, Rijeka. Available from: https://pdfs.semanticscholar.org/8703/b74aa2341cd22782026073673017 64387a86.pdf. Accessed February 10, 2019.
10. Kritsotakis EI, Kontopidou F, Astrinaki E, Roumbelaki M, Ioannidou E, Gikas A (2017) Prevalence, incidence burden, and clinical impact of healthcare-associated infections and antimicrobial resistance: a national prevalent cohort study in acute care hospitals in Greece. Infect Drug Resist 10: 317-326. doi: 10.2147/IDR.S144550
11. Allegranzi B, Zayed B, Bischoff P, Kubilay NZ, de Jonge S, de Vries F, Gomes SM, Gans S, Wallert ED, Wu X (2016) New WHO recommendations on intraoperative and postoperative measures for surgical site infection prevention: an evidence-based global perspective. Lancet Infect Dis 16 (12): e288-e303. doi: 10.1016/S1473-3099(16)30398-X
12. Cheng VC, Lau SK, Woo PC, Yuen KY (2007) Severe acute respiratory syndrome coronavirus as an agent of emerging and reemerging infection. Clin Microbiol Rev 20 (4): 660-694. doi: 10.1128/CMR.00023-07
13. Murray CJ, Ikuta KS, Sharara F, Swetschinski L, Aguilar GR, Gray A, Han C, Bisignano C, Rao P, Wool E (2022) Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet Infect Dis 22 (12): 1579-1588. doi: 10.1016/S1473-3099(21)00432-7
14. Zhang Y, Du M, Johnston JM, Andres EB, Suo J, Yao H, Huo R, Liu Y, Fu Q (2020) Estimating length of stay and inpatient charges attributable to hospital-acquired bloodstream infections. Antimicrob Resist Infect Control 9 (1): 1-8. doi: 10.1186/s13756-020-00793-w
15. Giraldi G, Montesano M, Sandorfi F, Iachini M, Orsi G (2019) Excess length of hospital stay due to healthcare acquired infections: methodologies evaluation. Ann Ig 31 (5): 507-516. doi: 10.7416/ai.2019.2318
16. Elstrøm P, Astrup E, Hegstad K, Samuelsen Ø, Enger H, Kacelnik O (2019) The fight to keep resistance at bay, epidemiology of carbapenemase producing organisms (CPOs), vancomycin resistant enterococci (VRE) and methicillin resistant Staphylococcus aureus (MRSA) in Norway, 2006-2017. PLoS One 14 (2): e0211741. doi: 10.1371/journal.pone.0211741
17. Fineschi V (2019) Healthcare-associated infections: antibiotic poly-therapies, antibiotic prophylaxis and appropriate policy for risk management to fight adverse events. Curr Pharm Biotechnol 20 (8): 606-608. doi: 10.2174/1389201020666190321144558
18. Zingg W, Huttner BD, Sax H, Pittet D (2014) Assessing the burden of healthcare-associated infections through prevalence studies: what is the best method? Infect Control Hosp Epidemiol 35 (6): 674-684. doi: 10.1086/676883
19. Khan HA, Ahmad A, Mehboob R (2015) Nosocomial infections and their control strategies. Asian Pac J Trop Biomed 5 (7): 509-514. doi: 10.1016/j.apjtb.2015.05.007
20. Suleyman G, Alangaden G, Bardossy AC (2018) The role of environmental contamination in the transmission of nosocomial pathogens and healthcare-associated infections. Curr Infect Dis Rep 20 (6): 1-11. doi: 10.1007/s11908-018-0623-x
21. Perez S, Innes GK, Walters MS, Mehr J, Arias J, Greeley R, Chew D (2020) Increase in hospital-acquired carbapenem-resistant Acinetobacter baumannii infection and colonization in an acute care hospital during a surge in COVID-19 admissions—New Jersey, February–July 2020. Morb Mortal Wkly Rep 69 (48): 1827-1831. doi: 10.15585/mmwr.mm6948e1
22. Sabra SM, Abdel-Fattah MM (2012) Epidemiological and microbiological profile of nosocomial infection in Taif hospitals, KSA (2010-2011). World J Med Sci 7 (1): 1-9.
23. Esfandiari A, Salari H, Rashidian A, Asl HM, Foroushani AR, Sari AA (2018) Eliminating healthcare-associated infections in Iran: a qualitative study to explore stakeholders' views. Int J Health Policy Manag 7 (1): 27-34. doi: 10.15171/ijhpm.2017.112
24. Esfandiari A, Rashidian A, Asl HM, Foroushani AR, Salari H, Sari AA (2016) Prevention and control of health care–associated infections in Iran: A qualitative study to explore challenges and barriers. Am J Infect Control 44 (10): 1149-1153. doi: 10.1016/j.ajic.2016.05.019
25. Di Tella D, Tamburro M, Guerrizio G, Fanelli I, Sammarco ML, Ripabelli G (2019) Molecular epidemiological insights into colistin-resistant and carbapenemases-producing clinical Klebsiella pneumoniae isolates. Infect Drug Resist 12: 3783-3795. doi: 10.2147/IDR.S212671
26. McLaws M-L (2015) The relationship between hand hygiene and health care-associated infection: it's complicated. Infect Drug Resist 8: 7-18. doi: 10.2147/IDR.S61668
27. Labarraque A (1829) Instructions and observations regarding the use of the chlorides of soda and l Porter J, ed.[French] New Haven. Baldwin and Treadway.
28. Mathur P (2011) Hand hygiene: back to the basics of infection control. Indian J Med Res 134 (5): 611-620.
29. Rigby R, Pegram A, Woodward S (2017) Hand decontamination in clinical practice: a review of the evidence. Br J Nurs 26 (8): 448-451. doi: 10.12968/bjon.2017.26.8.448
30. Rosenthal VD, Guzman S, Safdar N (2005) Reduction in nosocomial infection with improved hand hygiene in intensive care units of a tertiary care hospital in Argentina. Am J Infect Control 33 (7): 392-397. doi: 10.1016/j.ajic.2005.03.002
31. Haque M, Sartelli M, McKimm J, Bakar MA (2018) Health care-associated infections–an overview. Infect Drug Resist 11: 2321-2333. doi: 10.2147/IDR.S177247
32. Owen H (2014) Unexpected consequences of simulator use in medical education: a cautionary tale. Simul Healthc 9 (3): 149-152. doi: 10.1097/SIH.0000000000000011
33. Owen H (2014) Unexpected consequences of simulator use in medical education: a cautionary tale. Simul Healthc 9 (3): 149-152. doi: 10.1097/SIH.0000000000000011
34. Garner JS (1986) CDC guideline for prevention of surgical wound infections, 1985. Infect Control Hosp Epidemiol 7 (3): 193-200. doi: 10.1086/647852
35. Boyce JM, Pittet D (2002) Guideline for hand hygiene in healthcare settings: recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Infect Control Hosp Epidemiol 23 (S12): S3-S40. doi: 10.1086/503164
36. Hongsuwan M (2018) Developing and evaluating effective interventions to reduce healthcare-associated infection in a resource-limited hospital in Thailand. Open University

(UK). Available from: https://oro.open.ac.uk/55283/7/Thesis_Maliwan20Hongsuwan%2C%20B6976542.pdf
37. Kampf G, Löffler H, Gastmeier P (2009) Hand hygiene for the prevention of nosocomial infections. Dtsch Arztebl Int 106 (40): 649-655. doi: 10.3238/arztebl.2009.0649
38. Iliyasu G, Dayyab FM, Habib ZG, Tiamiyu AB, Abubakar S, Mijinyawa MS, Habib AG (2016) Knowledge and practices of infection control among healthcare workers in a tertiary referral center in North-Western Nigeria. Ann Afr Med 15 (1): 34-40. doi: 10.4103/1596-3519.161726
39. OD RN, Jones D, Martello M, Biron A, Lavoie-Tremblay M (2017) A systematic review on the effectiveness of interventions to improve hand hygiene compliance of nurses in the hospital setting. J Nurs Scholarsh 49 (2): 143-152. doi: 10.1111/jnu.12284
40. Labrague LJ, McEnroe-Petitte DM, Van de Mortel T, Nasirudeen AMA (2018) A systematic review on hand hygiene knowledge and compliance in student nurses. Int Nurs Rev 65 (3): 336-348. doi: 10.1111/inr.12453
41. Salmon S, McLaws M-L (2015) Qualitative findings from focus group discussions on hand hygiene compliance among health care workers in Vietnam. Am J Infect Control 43 (10): 1086-1091. doi: 10.1016/j.ajic.2015.06.020
42. Marjadi B, McLaws M-L (2010) Hand hygiene in rural Indonesian healthcare workers: barriers beyond sinks, hand rubs and in-service training. J Hosp Infect 76 (3): 256-260. doi: 10.1016/j.jhin.2010.06.023
43. González ML, Finerman R, Johnson KM, Melgar M, Somarriba MM, Antillon-Klussmann F, Caniza MA (2016) Understanding hand hygiene behavior in a pediatric oncology unit in a low-to mid-income country. J Nurs Educ Pract 6 (9): 1-7. doi: 10.5430/jnep.v6n9p1
44. McLaws M-L, Farahangiz S, Palenik CJ, Askarian M (2015) Iranian healthcare workers' perspective on hand hygiene: a qualitative study. J Infect Public Health 8 (1): 72-79. doi: 10.1016/j.jiph.2014.08.002
45. Lohiniva A, Bassim H, Hafez S, Kamel E, Ahmed E, Saeed T, Talaat M (2015) Determinants of hand hygiene compliance in Egypt: building blocks for a communication strategy. East Mediterr Health J 21 (9): 665-670. doi: 10.26719/2015.21.9.665
46. Sickder HK, Lertwathanawilat W, Sethabouppha H, Viseskul N (2017) Nurses' surgical site infection prevention practices in Bangladesh. Pac Rim Int J Nurs Res 21 (3): 244-257.
47. Ay P, Teker AG, Hidiroglu S, Tepe P, Surmen A, Sili U, Korten V, Karavus M (2019) A qualitative study of hand hygiene compliance among health care workers in intensive care units. J Infect Dev Ctries 13 (02): 111-117. doi: 10.3855/jidc.10396
48. Moffa M, Guo W, Li T, Cronk R, Abebe LS, Bartram J (2017) A systematic review of nosocomial waterborne infections in neonates and mothers. Int J Hyg Environ Health 220 (8): 1199-1206. doi: 10.1016/j.ijheh.2017.08.008
49. Cunliffe AJ, Askew PD, Stephan I, Iredale G, Cosemans P, Simmons LM, Verran J, Redfern J (2021) How do we determine the efficacy of an antibacterial surface? A review of standardised antibacterial material testing methods. Antibiotics 10 (9): 1069. doi: 10.3390/antibiotics10091069
50. Ling ML, Apisarnthanarak A, Thu LTA, Villanueva V, Pandjaitan C, Yusof MY (2015) APSIC guidelines for environmental cleaning and decontamination. Antimicrob Resist Infect Control 4: 1-9. doi: 10.1186/s13756-015-0074-z
51. Kohn WG, Harte JA, Malvitz DM, Collins AS, Cleveland JL, Eklund KJ (2004) Cover story guidelines for infection control in dental health care settings—2003. J Am Dent Assoc 135 (1): 33-47. doi: 10.14219/jada.archive.2004.0030
52. Kim I-J (2021) Hospital flooring safety and health: knowledge gaps and suggestions. Int J Occup Saf Ergon 27 (4): 1116-1135. doi: 10.1080/10803548.2020.1795446
53. Tweij-Thu-Alfeqar Razzaq A-J, Shnan D, Ali A-BM (2019) Sterilization of surgical tools: removing bacterial endospores with a combination of povidone-iodine, chlorhexidine gluconate, ethanol, and methanol. J Pure Appl Microbiol 13 (4): 2499-2506.
54. Rutala WA, Weber DJ (2019) Disinfection, sterilization, and antisepsis: an overview. Am J Infect Control 47: A3-A9. doi: 10.1016/j.ajic.2018.07.021
55. Schuts EC, Hulscher ME, Mouton JW, Verduin CM, Stuart JWC, Overdiek HW, van der Linden PD, Natsch S, Hertogh CM, Wolfs TF (2016) Current evidence on hospital antimicrobial stewardship objectives: a systematic review and meta-analysis. Lancet Infect Dis 16 (7): 847-856. doi: 10.1016/S1473-3099(16)00157-6
56. Davey P, Brown E, Charani E, Fenelon L, Gould IM, Holmes A, Ramsay CR, Wiffen PJ, Wilcox M (2013) Interventions to improve antibiotic prescribing practices for hospital inpatients. Cochrane Database Syst Rev (4): CD003543. doi: 10.1002/14651858.CD003543.pub3
57. Karanika S, Paudel S, Grigoras C, Kalbasi A, Mylonakis E (2016) Systematic review and meta-analysis of clinical and economic outcomes from the implementation of hospital-based antimicrobial stewardship programs. Antimicrob Agents Chemother 60 (8): 4840-4852. doi: 10.1128/AAC.00447-16
58. Bansal S, Chowell G, Simonsen L, Vespignani A, Viboud C (2016) Big data for infectious disease surveillance and modeling. J Infect Dis 214 (Suppl 4): S375-S379. doi: 10.1093/infdis/jiw400
59. Mitchell BG, Hall L, Halton K, MacBeth D, Gardner A (2016) Time spent by infection control professionals undertaking healthcare associated infection surveillance: a multi-centred cross sectional study. Infect Dis Health 21 (1): 36-40. doi: 10.1016/j.idh.2015.11.001
60. World Health Organization (2016) Health care without avoidable infections: the critical role of infection prevention and control. World Health Organization.
61. Mitchell BG, Hall L, Halton K, MacBeth D, Gardner A (2016) Time spent by infection control professionals undertaking healthcare associated infection surveillance: a multi-centred cross sectional study. Infect Dis Health 21 (1): 36-40. doi: 10.1016/j.idh.2015.11.001
62. Rosenthal VD, Duenas L, Sobreyra-Oropeza M, Ammar K, Navoa-Ng JA, de Casares ACB, de Jesús Machuca L, Ben-Jaballah N, Hamdi A, Villanueva VD (2013) Findings of the International Nosocomial Infection Control Consortium (INICC), Part III Effectiveness of a multidimensional infection control approach to reduce central line—associated bloodstream infections in the neonatal intensive care units of 4 developing countries. Infect Control Hosp Epidemiol 34 (3): 229-237. doi: 10.1086/669091
63. Korniewicz DM (2013) Infection control for advanced practice professionals. DEStech Publications, Inc.
64. Tacconelli E (2009) Screening and isolation for infection control. J Hosp Infect 73 (4): 371-377. doi: 10.1016/j.jhin.2009.03.010
65. Infection Control Today (2009) Active surveillance cultures: friend or foe? Available from: https://www.infectioncontroltoday.com/epidemiology-surveillance/active-surveillance-cultures-friend-orfoe. Accessed March 14, 2019.
66. Edmond M, Lyckholm L, Diekema D (2008) Ethical implications of active surveillance cultures and contact precautions for controlling multidrug resistant organisms in the hospital setting. Public Health Ethics 1 (3): 235-245. doi: 10.1093/phe/phn017
67. McGinigle KL, Gourlay ML, Buchanan IB (2008) The use of active surveillance cultures in adult intensive care units to reduce

methicillin-resistant Staphylococcus aureus-related morbidity, mortality, and costs: a systematic review. Clin Infect Dis 46 (11): 1717-1725. doi: 10.1086/586892

68. Soroksky A, Nagornov S, Klinowski E, Leonov Y, Ilgiyaev E, Yossepowitch O, Goltsman G (2014) Active surveillance cultures in critically ill patients: pathogens, patterns, and correlation with eventual bloodstream infections. [Journal info missing]
69. Vickers NJ (2017) Animal communication: when I'm calling you, will you answer too? Curr Biol 27 (14): R713-R715. doi: 10.1016/j.cub.2017.06.014
70. Vos MC, Ott A, Verbrugh HA (2005) Successful search-and-destroy policy for methicillin-resistant Staphylococcus aureus in The Netherlands. J Clin Microbiol 43 (4): 2034-2038. doi: 10.1128/JCM.43.4.2034-2038.2005
71. Pittet D, Donaldson L (2006) Challenging the world: patient safety and health care-associated infection. Int J Qual Health Care 18 (1): 4-8. doi: 10.1093/intqhc/mzi059
72. Assiri AM, Choudhry AJ, Alsaleh SS, Alanazi KH, Alsaleh SS (2014) Evaluation of infection prevention and control programmes (IPC), and assessment tools for IPC-programmes at MOH-health facilities in Saudi Arabia. Open J Nurs 2014: 390-397. doi: 10.4236/ojn.2014.47044
73. Moralejo D, El Dib R, Prata RA, Barretti P, Corrêa I (2018) Improving adherence to standard precautions for the control of health care-associated infections. Cochrane Database Syst Rev 2: CD010768. doi: 10.1002/14651858.CD010768.pub2
74. Shadi MS, Geneid A, Rubin JS, Ibrahim RA (2022) Infection control, hand hygiene practice and PPE use among phoniatricians and ENT specialists during the COVID-19 pandemic, a UEP survey. Egypt J Otolaryngol 38 (1): 1-9. doi: 10.1186/s43163-022-00275-7
75. McCloskey B, Zumla A, Stephens G, Heymann DL, Memish ZA (2013) Applying lessons from SARS to a newly identified coronavirus. Lancet Infect Dis 13 (5): 384-385. doi: 10.1016/S1473-3099(13)70065-9
76. Minnesota Department of Health (2016) Publications database—Center for Public Health Practice. Minnesota Dept. of Health.
77. Rimi NA, Sultana R, Luby SP, Islam MS, Uddin M, Hossain MJ, Zaman RU, Nahar N, Gurley ES (2014) Infrastructure and contamination of the physical environment in three Bangladeshi hospitals: putting infection control into context. PLoS One 9 (2): e89085. doi: 10.1371/journal.pone.0089085
78. Abalkhail A, Al Imam MH, Elmosaad YM, Jaber MF, Hosis KA, Alhumaydhi FA, Alslamah T, Alamer A, Mahmud I (2021) Knowledge, attitude and practice of standard infection control precautions among health-care workers in a university hospital in Qassim, Saudi Arabia: a cross-sectional survey. Int J Environ Res Public Health 18 (22): 11831. doi: 10.3390/ijerph182211831
79. Allegranzi B, Gayet-Ageron A, Damani N, Bengaly L, McLaws M-L, Moro M-L, Memish Z, Urroz O, Richet H, Storr J (2013) Global implementation of WHO's multimodal strategy for improvement of hand hygiene: a quasi-experimental study. Lancet Infect Dis 13 (10): 843-851. doi: 10.1016/S1473-3099(13)70163-4
80. Mukerji A, Narciso J, Moore C, McGeer A, Kelly E, Shah V (2013) An observational study of the hand hygiene initiative: a comparison of preintervention and postintervention outcomes. BMJ Open 3 (5): e003018. doi: 10.1136/bmjopen-2013-003018
81. Abalkhail A, Mahmud I, Alhumaydhi FA, Alslamah T, Alwashmi AS, Vinnakota D, Kabir R (2021) Hand hygiene knowledge and perception among the healthcare workers during the COVID-19 pandemic in Qassim, Saudi Arabia: a cross-sectional survey. Healthcare 9 (12): 1627. doi: 10.3390/healthcare9121627
82. Blot S, Ruppé E, Harbarth S, Asehnoune K, Poulakou G, Luyt C-E, Rello J, Klompas M, Depuydt P, Eckmann C (2022) Healthcare-associated infections in adult intensive care unit patients: changes in epidemiology, diagnosis, prevention and contributions of new technologies. Intensive Crit Care Nurs 70: 103227. doi: 10.1016/j.iccn.2022.103227
83. Alslamah T, Abalkhail A (2022) The national strategies for and challenges in infection prevention and control of the healthcare system in the Kingdom of Saudi Arabia (review study). Vaccines 10 (8): 1302. doi: 10.3390/vaccines10081302
84. Markwart R, Saito H, Harder T, Tomczyk S, Cassini A, Fleischmann-Struzek C, Reichert F, Eckmanns T, Allegranzi B (2020) Epidemiology and burden of sepsis acquired in hospitals and intensive care units: a systematic review and meta-analysis. Intensive Care Med 46 (8): 1536-1551. doi: 10.1007/s00134-020-06050-8
85. Storr J, Twyman A, Zingg W, Damani N, Kilpatrick C, Reilly J, Price L, Egger M, Grayson ML, Kelley E (2017) Core components for effective infection prevention and control programmes: new WHO evidence-based recommendations. Antimicrob Resist Infect Control 6 (1): 6. doi: 10.1186/s13756-017-0177-6
86. Clancy C, Delungahawatta T, Dunne CP (2021) Hand-hygiene-related clinical trials reported between 2014 and 2020: a comprehensive systematic review. J Hosp Infect 111: 6-26. doi: 10.1016/j.jhin.2021.06.015
87. Bulfone TC, Malekinejad M, Rutherford GW, Razani N (2021) Outdoor transmission of SARS-CoV-2 and other respiratory viruses: a systematic review. J Infect Dis 223 (4): 550-561. doi: 10.1093/infdis/jiaa742
88. Bhagat RK, Wykes MD, Dalziel SB, Linden P (2020) Effects of ventilation on the indoor spread of COVID-19. J Fluid Mech 903: F1. doi: 10.1017/jfm.2020.720
89. World Health Organization (2020) Rational use of personal protective equipment (PPE) for coronavirus disease (COVID-19): interim guidance, 19 March 2020. World Health Organization.
90. Bandyopadhyay S, Baticulon RE, Kadhum M, Alser M, Ojuka DK, Badereddin Y, Kamath A, Parepalli SA, Brown G, Iharchane S (2020) Infection and mortality of healthcare workers worldwide from COVID-19: a systematic review. BMJ Glob Health 5 (12): e003097. doi: 10.1136/bmjgh-2020-003097
91. Nguyen LH, Drew DA, Graham MS, Joshi AD, Guo CG, Ma W, Mehta RS, Warner ET, Sikavi DR, Lo CH (2020) Risk of COVID-19 among front-line health-care workers and the general community: a prospective cohort study. Lancet Public Health 5 (9): e475-e483. doi: 10.1016/S2468-2667(20)30164-X
92. Urrego J, Ko AI, Carbone AdSS, Paião DSG, Sgarbi RVE, Yeckel CW, Andrews JR, Croda J (2015) The impact of ventilation and early diagnosis on tuberculosis transmission in Brazilian prisons. Am J Trop Med Hyg 93 (4): 739-747. doi: 10.4269/ajtmh.15-0230
93. Escombe AR, Oeser CC, Gilman RH, Navincopa M, Ticona E, Pan W, Martínez C, Chacaltana J, Rodríguez R, Moore DAJ (2007) Natural ventilation for the prevention of airborne contagion. PLoS Med 4 (2): e68. doi: 10.1371/journal.pmed.0040068
94. Rutala WA, Weber DJ (2019) Best practices for disinfection of noncritical environmental surfaces and equipment in health care facilities: a bundle approach. Am J Infect Control 47: A96-A105. doi: 10.1016/j.ajic.2019.01.003
95. Magill SS, Edwards JR, Bamberg W, Beldavs ZG, Dumyati G, Kainer MA, Lynfield R, Maloney M, McAllister-Hollod L, Nadle J (2014) Multistate point-prevalence survey of health care–associated infections. N Engl J Med 370 (13): 1198-1208. doi: 10.1056/NEJMoa1306801
96. Rutala WA, Weber DJ (2019) Disinfection, sterilization, and antisepsis: an overview. Am J Infect Control 47: A3-A9. doi: 10.1016/j.ajic.2018.07.021

97. Quinn MM, Henneberger PK, Braun B, Delclos GL, Fagan K, Huang V, Knaack JL, Kusek L, Lee SJ, Le Moual N (2015) Cleaning and disinfecting environmental surfaces in health care: toward an integrated framework for infection and occupational illness prevention. Am J Infect Control 43 (5): 424-434. doi: 10.1016/j.ajic.2015.01.031
98. Amandine GB, Gagnaire J, Pelissier C, Philippe B, Elisabeth BN (2022) Vaccines for healthcare associated infections without vaccine prevention to date. Vaccine: X 11: 100168. doi: 10.1016/j.jvacx.2022.100168
99. Elbehiry A, Marzouk E, Abalkhail A, El-Garawany Y, Anagreyyah S, Alnafea Y, Almuzaini AM, Alwarhi W, Rawway M, Draz A (2022) The development of technology to prevent, diagnose, and manage antimicrobial resistance in healthcare-associated infections. Vaccines 10 (12): 2100. doi: 10.3390/vaccines10122100
100. Decker B, Lau A, Dekker J, Spalding C, Sinaii N, Conlan S, Henderson D, Segre J, Frank K, Palmore T (2018) Healthcare personnel intestinal colonization with multidrug-resistant organisms. Clin Microbiol Infect 24 (1): 82.e1-82.e4. doi: 10.1016/j.cmi.2017.05.022
101. Verhoeven PO, Gagnaire J, Botelho-Nevers E, Grattard F, Carricajo A, Lucht F, Pozzetto B, Berthelot P (2014) Detection and clinical relevance of Staphylococcus aureus nasal carriage: an update. Expert Rev Anti Infect Ther 12 (1): 75-89. doi: 10.1586/14787210.2014.855628
102. Paranthaman K, Bentley A, Milne L, Kearns A, Loader S, Thomas A, Thompson F, Logan M, Newitt S, Puleston R (2014) Nosocomial outbreak of staphylococcal scalded skin syndrome in neonates in England, December 2012 to March 2013. Euro Surveill 19 (33): 20854. doi: 10.2807/1560-7917.ES2014.19.33.20854
103. Galdys AL, Curry SR, Harrison LH (2014) Asymptomatic Clostridium difficile colonization as a reservoir for Clostridium difficile infection. Expert Rev Anti Infect Ther 12 (8): 967-980. doi: 10.1586/14787210.2014.938021
104. Paterson P, Meurice F, Stanberry LR, Glismann S, Rosenthal SL, Larson HJ (2016) Vaccine hesitancy and healthcare providers. Vaccine 34 (52): 6700-6706. doi: 10.1016/j.vaccine.2016.10.042
105. Killian M, Detoc M, Berthelot P, Charles R, Gagneux-Brunon A, Lucht F, Pulcini C, Barbois S, Botelho-Nevers E (2016) Vaccine hesitancy among general practitioners: evaluation and comparison of their immunisation practice for themselves, their patients and their children. Eur J Clin Microbiol Infect Dis 35 (11): 1837-1843. doi: 10.1007/s10096-016-2736-y