Hospital Infection Control in the Era of Antimicrobial Resistance: Emerging Pathogens, Biofilms, Antimicrobial Stewardship, and Advanced Prevention Strategies-A Systematic Review Study

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ABSTRACT

Hospital-acquired infections (HAIs) are still an issue in health care systems due to their link with antimicrobial resistance (AMR), long hospital stays, higher treatment expenses and morbidity and mortality of patients. The appearance of multidrug-resistant bacteria, fungi which are resistant to multiple medications and biofilm forming microorganisms have added to the challenge of preventing and treating infections. The goal of this systematic review is to discuss emerging pathogens in the hospitals, microbial biofilms, and antimicrobial stewardship practices as well as established and emerging infection prevention strategies. The following are all relevant to hand hygiene, environmental cleaning, disinfection and sterilization, surveillance, appropriate use of the antimicrobial agent, device-associated infection prevention, the use of rapid diagnostic technologies and advanced approaches to infection prevention. The evidence reviewed reinforces the need to implement antimicrobial stewardship and infection prevention and control strategies together, instead of just antimicrobial treatment. Appropriate infection control procedures, health worker training, early pathogen identification and regular adherence to infection control protocols could be useful in limiting the spread of infection and unnecessary antibiotic use. The availability of such emerging technologies, such as fast molecular diagnostics, surveillance with artificial intelligence and biofilm-targeting strategies could prove to be of significance, but must be clinically proven and assessed in terms of cost-effectiveness. In conclusion, a comprehensive and evidence-based approach with sufficient resources, regular surveillance, and a commitment from the hospital is essential for achieving sustainable hospital infection control. More high-quality studies are required to determine the long-term effectiveness and feasibility of newer interventions in a variety of health care systems.

Keywords: Hospital-acquired infections, Infection prevention and control, Antimicrobial stewardship, Microbial biofilms, Multidrug-resistant pathogens, Rapid diagnostics, Infection surveillance, Hospital hygiene.

1. INTRODUCTION

Hospital-acquired infections (HAIs) continue to be a significant problem in the provision of safe and effective health care and the impact of antimicrobial resistance (AMR) is making the use of some of the most effective and commonly used medicines less effective. While the primary role of a hospital is to diagnose, treat and prevent infectious diseases, it can offer conditions that further spread infectious microorganisms. Healthcare workers' hands, environmental surfaces, invasive procedures, patients, and other colonized or infected people can be sources of pathogens that are transmitted to patients who are in the care of healthcare facilities. Depending on the type of infection and circumstances of exposure, these infections may manifest while the person is hospitalized or after the person leaves the hospital. Examples of these include surgical site infections, catheter-associated urinary tract infections, central line-associated bloodstream infections and ventilator-associated pneumonia. Infections can cause longer hospital stays, more hospital expense, more complexity in getting better, and preventable illness and death. The World Health Organization (WHO, 2024) highlights that HAIs continue to be a significant threat in healthcare facilities and that with the use of effective infection prevention and control (IPC) programmes, good hygiene practices and access to essential water, sanitation and hygiene services, many HAIs can be prevented.

As the threat of AMR continues to increase, the prevention and management of HAIs has become even more complex. Antimicrobial resistance is when microorganisms are able to survive or grow in the presence of antimicrobials that would normally prevent or stop them from doing so. It can impact bacteria, viruses, fungi, and parasites; while the concern with bacterial resistance is especially relevant for the managements of many hospital-associated infections. Using antibiotics inappropriately, unnecessary prescribing of antibiotics, poor practices in prescribing and using antibiotics and the spread of resistant organisms can play a role in the selection and dissemination of antimicrobial resistance. Resistant infections are more difficult to treat as there are fewer effective treatment options, and patients may need more tests to diagnose the infection, different medications or treatments, or longer hospitalization. The Global Antibiotic Resistance Surveillance Report 2025, published by the WHO, reviewed over 23 million cases of infections confirmed by microbiology laboratories in participating countries, underscoring the need for standardized surveillance to gain insights into resistance patterns and inform public health interventions (World Health Organization [WHO], 2025a). Therefore, AMR is not just an antibiotic selection issue, but is also closely associated with infection prevention, diagnostic capacity, antimicrobial stewardship and capacity of healthcare facilities to detect and limit the spread of antimicrobial resistant pathogens.

MDROs are especially likely to develop and spread in healthcare facilities because patients with various infections, underlying conditions, compromised immune systems, and who are frequently exposed to antimicrobial drugs are congregated in these locations. Methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant Enterococcus (VRE), carbapenem-resistant Klebsiella pneumoniae, resistant Acinetobacter baumannii and Pseudomonas aeruginosa are notable resistant pathogens. The organisms can be transmitted to other individuals by colonized or infected patients, contaminated surfaces, medical devices, and poorly-controlled healthcare practices. Other microorganisms can also survive in the hospital setting or colonize on implanted medical devices, catheters, and other medical equipment, causing them to be harder to eradicate. Biofilms are microbial communities that grow in a protective matrix which may hinder penetration of the antimicrobial and lead to tolerance to the antimicrobial and environmental stress. Furthermore, surfacing or resurfacing infectious diseases can quickly become widespread if there is a lack of surveillance and isolation measures. Healthcare facilities are considered key environments for the spread of resistant pathogens and coordinated surveillance efforts, along with the use of the right type of antimicrobials and infection control measures are recommended by the Centers for Disease Control and Prevention (CDC, 2024). So, in addition to the individual infection, the route of entry, survival and spread of pathogens within healthcare facilities must be addressed for effective management.

Infection prevention and control in the hospital is therefore an integral part of the provision of safe and effective healthcare services. Examples of fundamental measures are hand hygiene, appropriate use of personal protective equipment, instrument sterilisation and disinfection, environmental cleaning, safe injection practices, isolation precautions and management of invasive devices. The interventions are best delivered within an integrated programme with the support of trained staff, sufficient supplies, institutional leadership and on-going compliance monitoring. In addition to these, antimicrobial stewardship activities help facilitate the selection, dosage and route of antimicrobial therapy, and the avoidance of unnecessary exposure. Laboratory surveillance, prompt detection of resistant organisms and communicating laboratory results of resistance can also assist the clinical decision-making and prevent transmission. WHO (2024) emphasizes that IPC programmes need to be closely connected with other interventions related to antimicrobial resistance, water and sanitation and health care quality. However, implementation could be limited by limited resources, overcrowding, lack of adequate staffing, lack of adherence to protocols and gaps in microbiological surveillance. The need to test and assess existing and emerging prevention strategies, such as rapid molecular diagnostics, novel environmental decontamination methods, antimicrobial surface technologies, and digital surveillance systems is underscored by these difficulties.

In this context, the need for a systematic review is highlighted, to synthesize the evidence available on hospital infection control during the age of antimicrobial resistance. While there have been many studies on individual pathogens, antimicrobial stewardship interventions, and infection prevention technologies, these studies may vary in their results depending on the healthcare

environment, patient population, study design, and intervention implemented. A structured synthesis facilitates understanding of the strategies that have shown positive results, areas where evidence is less definitive, and potential practical challenges for use of the strategies. The goal of this systematic review is to critically review the existing literature related to emerging and multidrug-resistant pathogens in healthcare, the importance of the role of biofilms in persistent infections, the importance of antimicrobial stewardship, and the effectiveness of conventional and advanced infection prevention strategies. Specifically, the review aims to describe the key pathogens associated with HAIs and AMR; to outline the mechanisms by which biofilms can help perpetuate the persistence of infection and antimicrobial tolerance; to review the evidence for antimicrobial stewardship and existing IPC tools; to review new diagnostics, surveillance and prevention technologies; and to highlight areas of research gaps relevant to clinical practice and healthcare policy. The review aims to offer an evidence-based review to feed into an infection control programme, enable more responsible use of antimicrobials and provide direction for future research to reduce the burden of HAIs.

2. MATERIALS AND METHODS

2.1. The systematic review design and reporting guidelines (PRISMA)

The aim of this systematic review was to assess the published literature on the topic of hospital infection control in the background of antimicrobial resistance, focusing on emerging and multidrug resistant pathogens, biofilm-associated infections, antimicrobial stewardship and advanced prevention strategies. The methodology for the review was designed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines, which facilitate transparent reporting of the literature search, study selection, data collection and synthesis of results (Page et al., 2021). The review emphasized finding and critically analyzing relevant evidence instead of conducting new laboratory or clinical experiments. Methods have been arranged to enable the reader to grasp how the evidence has been located, evaluated, and analyzed.

2.2. Literature Search Strategy and Electronic Databases

Electronic databases (PubMed/MEDLINE, Scopus, Web of Science and the Cochrane Library) were to be searched in a structured way. To supplement the search for relevant publications and to review reference lists, Google Scholar was explored. Searches performed included antimicrobial resistance, biofilm, antimicrobial stewardship, and infection prevention interventions in hospital settings on the subject of healthcare-associated infections. All publications which were relevant to the search were included from the time of the start of the database until the date of the last search, which should be noted when the search is finished. Selected references of eligible articles and relevant reviews were also reviewed to find further articles which may not have been retrieved from the electronic search. Completeness of the evidence identified is important as it can affect the conclusions of a systematic review (Lefebvre et al., 2024).

2.3. Search Terms and Boolean Operators

The literature search was conducted by combining the words and Boolean operators to obtain studies that met the goals of the review. The search terms used were: antimicrobial resistance, multidrug-resistant organisms, antimicrobial stewardship, advanced diagnostic technologies, hospital-acquired infections, healthcare-associated infections, infection prevention and control, and environmental disinfection. Boolean operators AND and OR were employed to join ideas together and to expand or focus the search results. The search terms were modified to suit the needs of each data base and to increase the yield of publications, some synonyms were added. Search strategy adopted was based on the methodology of systematic reviews, which has been recommended to use clearly defined concepts, using suitable synonyms, and using the search strategy techniques available in the database to increase coverage and reproducibility (Lefebvre et al., 2024).

2.4. Inclusion and Exclusion Criteria

Studies were screened to ensure consistency with the criteria that were defined ahead of the screening process. Publications eligible for review were original research articles, clinical studies, observational studies, and relevant intervention studies on hospital-associated infections, resistant pathogens, antimicrobial stewardship, or infection prevention measures. Systematic reviews were to be included in the evidence synthesis if they were included, and were to be analysed separately from any primary studies so that the evidence would not be double counted when background information or for reference checking. The publications were of those in English which had accessible full text and which had an appropriate outcome.

Studies which only included community-acquired infections, did not have a clear association with healthcare settings, or did not provide enough information to determine whether they were relevant were excluded. The primary evidence synthesis excluded editorials, opinion pieces, conference abstracts without sufficient evidence and duplicate data. To keep the selected literature closely linked to the aims of this review, as is recommended in systematic reviews (Higgins et al., 2024), these criteria were set. Studies that focused on HAIs (HAPs), MAR/MDRs, microbial biofilms, antimicrobial stewardship, or infection prevention interventions were included. Studies and evidence syntheses that were original research and published in English that had easily accessible full text were considered. Exclusion criteria were studies that were published with only information that did not pertain to antimicrobial resistance or infection control, editorials and opinion articles, abstracts with insufficient data, duplicate publications, irrelevant reviews, and studies that did not provide enough data to assess.

2.5. Study Selection and Screening Process

Records were identified and duplicate publications were eliminated prior to screening. Titles and abstracts were evaluated to the eligibility criteria and then the full text of potentially relevant articles was checked. Any publication with a topic that did not focus on the goals of the review and that did not meet the predetermined criteria were omitted. Documentation of reasons for exclusion at the full-text stage for transparency. A process for selecting the articles for the study should have been applied following the PRISMA 2020 guide, which specifies reporting of the number of records identified, screened, excluded, and finally included in the study (Page et al., 2021).

2.6. Data extraction and management

Eligible studies were selected and data were abstracted with a standard data collection format. Data of interest included authors name and year of publication, country/healthcare setting, study design, study population, pathogen studied, antimicrobial resistance characteristics, intervention studied, outcome measures, study main findings and reported limitations. Special focus was placed on the development of biofilm, ASP programmes, hand hygiene, environmental decontamination, diagnostic and surveillance technologies, and other hospital infection prevention interventions. Information retrieved and extracted was collated in tables to compare between the studies and similarity and differences in the reported outcomes were highlighted. Where available, quantitative results (e.g., infection rates, prevalence of resistance, effects of interventions, and confidence intervals) were captured and reported with the study details. Data extraction procedures were designed to reduce transcription errors and consistency in data. The Cochrane Handbook highlights the need to collect data in a transparent way, with accurate recording and verification of the information extracted to minimize errors and ensure reliable evidence synthesis (Li et al., 2024).

2.7. Quality Assessment and Risk-of-Bias Evaluation

Assessment of methodological quality and risk of bias of the included studies was based on the study designs. Randomized trials, observational studies, and other pertinent research designs were to have appropriate critical appraisal tools. Assessment included selection of participants, study design, outcome measurement, controlling confounding variables, completeness of reported data, and statistical analysis. Study results with methodological limitations were interpreted with caution

especially when used to draw conclusions about the effectiveness of infection prevention interventions. Risk-of-bias assessments were not meant to rule out all limited studies but to aid in the interpretation of the evidence. The Cochrane Handbook stresses the need for the appraisal method to be appropriate for the study design, and the potential for bias to be taken into account when interpreting the findings of individual studies and the evidence base (Higgins et al., 2024). These appraisal tools and the outcomes of the appraisal should be clearly stated in the completed review.

2.8. Data synthesis and analysis

A structured narrative approach to synthesis was anticipated for the findings since a variety of pathogens, hospital settings, interventions, study designs and outcome measures were expected in the literature included. The evidence was grouped in the four thematic areas: Emerging and multidrug-resistant pathogens, Biofilm associated infections, Antimicrobial stewardship, Conventional and advanced infection prevention strategies. The studies were compared within each category in terms of objective, methodology, major findings and limitations. Consistent findings and conflicting evidence were especially noted as were places where there was limited research available. If there were enough studies reporting similar populations, intervention, outcomes and statistics, then a meta-analysis could be considered. If quantitative pooling was not suitable, descriptive results would be used to summarize the findings and presented in evidence tables. Any discrepancies in studies and limitations that would impact comparability would be taken into account when interpreting. This is in line with the recommendations for using appropriate synthesis methods depending on the nature and consistency of available evidence (McKenzie & Brennan, 2024).

3. EMERGING PATHOGENS AND BIOFILMS IN HOSPITAL INFECTIONS

3.1. The most significant HAPs and their clinical implications.

A variety of bacterial and fungal pathogens have been linked to HAI's and the microorganisms which cause them vary depending on hospital department, patient factors, location of the infection and the use of invasive medical devices. Typical bacterial pathogens are Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa and Acinetobacter baumannii. These organisms are responsible for a variety of infections such as bloodstream infections, pneumonia, urinary tract infections, and surgical site infections. Some strains are able to develop resistance to more than one antimicrobial agent and this can limit the treatment options and increase the risk of complications. In an intensive care unit, patients can be at special risk due to critical illness, long hospital stay, mechanical ventilation, catheterization, and wide-spectrum antibiotics. Sandu et al. (2025) explained the role played by the characteristics of the microbes, environmental reservoirs, susceptibility of patients, and healthcare practices in the development and transmission of HAI. This evidence underscores the importance of taking into account the characteristics of the pathogen and the environmental conditions at the hospital when creating an effective infection control programmer.

3.2. MRSA, VRE and Resistant Gram-Negative Bacteria: Multi-Drug-Resistant Bacteria.

MDR pathogens pose a significant problem in hospital management of infections as they can withstand exposure to multiple classes of antimicrobial agents. Methicillin-resistant Staphylococcus aureus (MRSA) is resistant to most of the beta-lactam antibiotics that are effective against susceptible Staphylococcus aureus and can lead to skin and soft-tissue infections, pneumonia, surgical site infections, and bloodstream infections. Hospital-acquired infections from vancomycin-resistant Enterococcus (VRE), especially VRE strains of Enterococcus faecium and Enterococcus faecalis, may be serious infections in hospitalized patients, particularly those who have had long-term exposure to health care facilities or who are immunocompromised. Commonly used treatments are less effective because of resistance mechanisms such as modification of the targets of antibiotics and acquisition of resistance genes.

Bacteria that are resistant to Gram-negative bacteria present further challenges, as they can have multiple resistance mechanisms such as the ability to produce beta-lactamase, to have a less permeable membrane and to actively pump out the drug. The infections caused by the pathogens are

of special concern in critical care units as they can escalate quickly and are often difficult to treat. These organisms can also survive in healthcare facilities and spread on equipment or surfaces, potentially causing the spread to happen. Popa et al. (2026) conducted a systematic review on the epidemiology, resistance mechanisms, clinical implications and management of MRSA and VRE, highlighting the need for surveillance, proper management and coordinated infection prevention. Overall, the findings support the importance of using a laboratory-based detection approach, antimicrobial stewardship, and targeted approaches to infection control to prevent antimicrobial resistance, rather than solely relying on antimicrobial treatment.

3.3. Emerging fungal and other HAPs.

While the research focus is primarily on antimicrobial resistance associated with bacterial infections, fungal pathogens are also responsible for health-care associated infections, especially among those who are ill and staying in hospital for a long time, people who take drugs that suppress the immune system, and hospitalized patients with serious underlying conditions. Candida species are significant causes of blood stream and device-associated infections and some species are noted to be less susceptible or resistant to the commonly used antifungal drugs. Candida auris is a special concern because of its potential for infection at healthcare facilities, its ability to live on environmental surfaces and the fact that some traditional laboratory methods of identification are inaccurate and unreliable. The delayed recognition can make the treatment and control of infection more complex and challenging, particularly in outbreaks.

Other clinically important organisms are the Aspergillus species that can cause serious infections in vulnerable individuals and Clostridioides difficile which is linked with antibiotic use and healthcare associated diarrheal disease. The hazard of these pathogens is dependent on how they are transmitted, their persistence in the environment and the level of treatment resistance. In 2017, Chowdhary et al. reported that C. auris is a new multidrug-resistant fungal pathogen that has been linked to outbreaks in health care settings and significant diagnostic and infection control challenges. They go on to emphasize the need for adequate laboratory identification, correct antifungal susceptibility testing (AFST), environmental decontamination, and prompt implementation of infection prevention interventions. The results indicate the need for fungal pathogen control in the hospital environment, in addition to addressing resistant bacteria, using interventions designed to take into account the characteristics of each pathogen.

3.4. Development of Biofilm on Medical Devices and Hospital Surfaces

Biofilms are the structured communities of microorganisms that are attached to a surface and are embedded in an extracellular matrix secreted by the microorganisms themselves. Biofilms can form on urinary, central venous, endotracheal tubes, prosthetic joints, implants, and other medical devices in the hospital setting. They can also be found in environmental reservoirs such as sinks and plumbing systems that are wet and provide conditions for microbial attachment and growth. The typical stages of biofilm development include initial attachment of microorganisms, formation of microcolonies, maturation of the structure of the biofilm, and the eventual detachment of microbes to new sites. This can lead to chronic contamination and to recurrence or device-associated infections.

The clinical significance of biofilms lies in their capacity to support microbial survival despite antimicrobial treatment and host immune responses. Catheter-associated biofilms can, for instance, participate in the persistence of UTIs, and biofilms on intravascular devices can serve as a source of BSI. Mixed biofilms can also pose a challenge to treatment since the microbes in a microbial community can interact with one another. The occurrence of device colonization, chronic infection and struggle to eliminate established biofilms are recognized as critical challenges in modern healthcare, as highlighted in the reviews of the biofilm-associated infections (Ciofu et al., 2022). Appropriate placement of devices, aseptic handling, regular evaluation of the necessity of the device, timely removal of the device when necessary, and effective cleaning protocols are critical elements in biofilm prevention.

3.5. Mechanisms of Biofilm-Associated Antimicrobial Tolerance and Resistance

The problem with a Biofilm-associated infection is that the microorganisms in the Biofilm may not react in the same manner to the antimicrobial agent as freely suspended microorganisms. The extracellular polymeric matrix can inhibit the diffusion of certain antimicrobials, bind enzymes which inactivate drugs and establish an environment that is less conducive to therapy. Also, the amount of oxygen and nutrients can be different throughout the biofilm which will result in microbial communities having different metabolic activities. The same organisms may be sensitive in conventional laboratory tests, but survive antimicrobial treatment when cells are growing slowly or in dormant state.

Another key mechanism is persister cells, which are a subpopulation that is able to survive exposure to antimicrobials despite not necessarily having an inheritable resistance mutation. Biofilms also can enable cells to communicate with each other, adapt, and share DNA, which may lead to the development and spread of acquired resistance. It is thus important to differentiate antimicrobial resistance (which is a heritable resistance to grow at higher concentration of antimicrobials) from antimicrobial tolerance (the slow killing of the organism during treatment) and persistence (the survival of a subpopulation after exposure to antimicrobials). These mechanisms can happen in combination and lead to long-lasting infection or re-activation. Ciofu et al. (2022) summarized the biology of biofilm tolerance and resistance and highlighted the synergistic effect of microbial physiology, biofilm structure and host immunity. It is critical to understand these mechanisms to create better diagnostics and therapies to treat long-lasting HAI infections.

3.6. Difficulties in diagnosis, treatment and infection control

Healthcare-associated infections with resistant pathogens and biofilm-producing microorganisms continue to be a challenge to diagnose and treat. Traditional culture-based approach could take a long time to confirm the causative organism and determine its antimicrobial susceptibility profile. Moreover, the presence of microorganisms in a biofilm may not be reliably identified by routine sampling of the surrounding fluids or surfaces, causing a delay in the detection of the source of infection. Advanced microbial identification and genomic surveillance can enhance detection of pathogens and aid in the investigation of transmission patterns, alongside molecular diagnostic techniques. They may, however, be constrained in its implementation due to the costs, infrastructure, laboratory capacity and availability of trained personnel.

Complications of treatment include decreased effectiveness of some antimicrobial agents, multiple microbial species present, and the potential for persistent biofilm despite seemingly effective treatment. For selected device-associated infections, clinical management could include a combination of targeted antimicrobial therapy and removal/replacement of the infected device, depending on the site of the infection and the patient's clinical status. Environmental reservoirs, patient isolation (if indicated), hand hygiene, equipment decontamination and surveillance for resistant organisms also need consideration by infection control teams. In the paper by Grecu et al (2026), new strategies for the prevention and control of medical-device-associated biofilms, such as antimicrobial coatings, anti-adhesive materials and other technologies that target biofilms were discussed. These approaches are promising but need to be further studied for their effectiveness, safety, cost, and feasibility in clinical practice. In summary, effective infection control requires a combination of correct diagnosis, evidence-based treatment, responsible antimicrobial use, and regular preventive measures.

4. ANTIMICROBIAL STEWARDSHIP AND INFECTION PREVENTION STRATEGIES

4.1. Principles and Objectives of Hospital Antimicrobial Stewardship Programs

An Antimicrobial stewardship programmer is a planned activity that aims to optimize the use of antimicrobial medicines and ensure that treatment is effective whilst preventing the emergence and spread of antimicrobial resistance. These programmes are established in hospitals, and involve doctors, clinical pharmacists, microbiologists, nurses, and infection control specialists to help with evidence-based prescribing. Their main goals are: Determine the right antibiotic, adjust the dose and how it is

administered, find out how long to use an antibiotic, avoid any unnecessary exposure, and minimize any avoidable side effects. Stewardship programmes also encourage the use of local antimicrobial susceptibility data for treatment decisions, and the use of clinical guidelines. There are four pillars that are essential: leadership commitment, professional accountability, pharmaceutical skills, and interventions to enhance prescribing, monitoring, reporting, and education, according to the Centers for Disease Control and Prevention (CDC, 2025). Programmes need to be tailored to the needs and resources of the hospital in which they are implemented and assessed by suitable clinical and prescribing markers.

4.2. Appropriate Antibiotic Prescribing and De-escalation Strategies

Before starting an antibiotic, it is important to do a clinical examination and evaluation of the likely microorganism that is causing the infection and its severity, along with patient history. In cases where indicated, appropriate specimens for microbiological analysis should be taken before initiating antimicrobial therapy, unless this would be in delay of critical therapy in a critically ill patient. Empirical therapy can be started based on the suspected source of infection, level of local resistance and appropriate clinical guidelines. Treatment should be reviewed and adjusted on the basis of culture and susceptibility when these are available to ensure that the treatment selected is suitable.

The concept of antibiotic de-escalation is to gradually switch to a more specific antibiotic, based on clinical and microbiological data. Other stewardship actions include not using an antibiotic for a condition that it will not help with, minimizing treatment duration, modifying the antibiotic dose if the renal function is not suitable, and changing from intravenous to oral treatment if suitable. Selected antimicrobial agents can be prescribed with the help of prospective audit with feedback and preauthorization to improve antibiotic prescription. The practical stewardship measures to improve antibiotic use recommended in the joint guideline by Barlam et al. (2016) should be implemented to ensure that treatment is not delayed while improving antibiotic use. These measures will help to balance the need for proper infection control with maintenance of antimicrobial resistance.

4.3. Antibiotic Resistance Surveillance and Microbiological Monitoring

Antibiotic resistance surveillance is critical to the understanding of antibiotic resistance changes in pathogen distribution, new patterns of resistance, and to inform treatment policies in hospitals. Microbiology laboratories can help by detecting the pathogens and conducting antimicrobial sensitivity testing to find out which drugs will work. The results can be used for individual patient management and to create local antibiograms that show the susceptibility of organisms collected over a set time frame. Such analysis of these data can be useful for clinicians to choose empirical treatment and identify growth of resistant organisms when performed regularly.

Surveillance should be used in conjunction with hospital infection control activities to detect possible transmission events and evaluate the effectiveness of prevention activities. Monitoring of the following are important indicators: prevalence of resistant isolates, HAIs, antimicrobial consumption, and trends in HAIs for selected device-associated infections. Good surveillance requires accurate specimen collection, consistent laboratory practices, timely reporting, and the sharing of information between microbiology laboratories and clinical teams. Surveillance, laboratory support and systematic implementation of infection prevention measures are key components in the infection control of healthcare facilities as highlighted by the Indian National Centre for Disease Control (NCDC, 2020). Combining the microbiological results with clinical data may, therefore, help to inform earlier, more precise and targeted antibiotic prescriptions and infection prevention measures.

4.4. Hand Hygiene, Personal Protective Equipment, and Isolation Precautions

Hand hygiene is one of the most basic approaches undertaken for reducing the spread of infectious microorganisms in hospitals. Healthcare workers can get hands contaminated from patients, procedures, equipment and surfaces. Hand hygiene should therefore be undertaken at the appropriate times for hand hygiene, which happen during hand care, before an aseptic procedure, after potential body fluid contact, after contact with the patient's immediate surroundings and after patient contact.

An alcohol-based hand rub is generally suitable if hands are not visibly soiled, a soap and water wash should be used if hands are visibly soiled.

Personal protective equipment (PPE) - gloves, gowns, masks (unless contraindicated), eye protection and respirators, if indicated, should be worn depending on the type of exposure and route of transmission. Applying standard precautions to every patient and using contact, droplet or airborne precautions as needed for specific infections. Consistent practice is facilitated by appropriate patient placement, correct donning and removal of PPE and access to hand hygiene facilities. CDC (2024) defines hand hygiene, use of PPE as per risk, environmental cleaning and TBPs as basic practices for safe delivery of health care services. These interventions are especially critical in the care of patients who are infected or colonized with MDROs.

4.5. Environmental Cleaning, Disinfection, and Sterilization

Pathogen transmission can occur in the hospital setting when surfaces, reusable equipment or any poorly maintained clinical areas are not kept properly. Regular cleaning is necessary for high-contact surfaces such as door handles, medical equipment, bed rails and bedside tables, following specific protocols. Cleaning removes organic matter and decreases the level of microbial contamination, while disinfection kills microorganisms on surface or equipment using appropriate chemicals and/or physical means. It is important to sterilize reusable instruments before using them in procedures that require sterility. The choice of the method should be determined by the intended use, the microorganisms of concern, the manufacturer's instructions and the equipment.

In environmental cleaning programmes the cleaning tasks, cleaning schedules, appropriate cleaning agents, contact times and clean-up processes should be specified. Extra care is required in intensive care units, isolation rooms, operating theatres and other places where vulnerable patients receive complex care. Reusables must be properly reprocessed between patients and cleaning processes should be documented, audited and verified with staff feedback. Detailed information about selecting and using disinfection and sterilization methods for health care facilities is offered by the CDC (2008). These measures can be used in conjunction with hand hygiene, isolation precautions and antimicrobial stewardship, and can help to minimize environmental contamination.

4.6. Prevention of Device-Associated Infections

Medical devices such as urinary catheters, central venous catheters, mechanical ventilation devices are infectious if they become contaminated during use within the body and can cause infection. In ICUs, the use of devices in the long term may be a special issue, as patients may have other risk factors (critical illness, immune deficiency, etc.). The keys to prevention are a suitable device, aseptic insertion, proper maintenance, periodic evaluation of clinical need and timely removal when no longer needed. Excessive use of urinary catheters, aseptic technique when placing urinary catheter, and keeping the urinary drainage system under proper management. Hand hygiene, maximal sterile barrier precautions during insertion, appropriate antisepsis of the skin and periodic review of the insertion site and ongoing need for the catheter are all components of central venous catheter prevention. In case of mechanical ventilation, prevention measures could include proper management of respiratory equipment, oral care in accordance with the hospital protocol, and decreasing the duration of mechanical ventilation if possible. These interventions are frequently delivered as standardised prevention bundles and measured by device-associated infection rates. The Indian NCDC (2020) has made recommendations for infection prevention in ICUs - prevention of ventilator-associated pneumonia, prevention of catheter-related bloodstream infections (CABI), prevention of catheter-associated urinary tract infections (CAUTI). These measures will help to minimise unnecessary antimicrobial treatment and reduce unnecessary infections, when used consistently.

4.7. Healthcare Worker Education and Infection Control Compliance

Knowledge, practical skills and habit amongst healthcare staff is as important as written policies in the effectiveness of a hospital infection prevention programme. Caring for the sick involves

many roles that need different training in order to practice standard precautions, hand hygiene, using personal protective equipment (PPE), the safe collection of specimens, the cleaning of the environment, and the proper use and control of antimicrobial agents. Education should also cover the implications of the misuse of antibiotics, identification of resistant organisms and the proper use of isolation methods.

Practical demonstration, simulation exercise, induction programme, refresher sessions and discussion of cases can be used to support regular training. Structured observations, audits, antimicrobial prescribing reviews and monitoring of HAI indicators should be used to assess compliance. It is important to give them constructive and timely feedback so that teams can recognize their weaknesses and enhance their practice. Leadership of the institution should ensure that staff are provided with enough supplies, clear procedures, manageable workload and avenues to report concerns related to infection control. CDC (2024) suggests that compliance with infection prevention measures be assessed and routine feedback given to health care staff and health care facility management. Fostering a hospital safety culture, coupled with accountability and ongoing training, can help reinforce compliance with infection prevention measures and enhance the long-term success of hospital infection control initiatives.

5. ADVANCED PREVENTION TECHNOLOGIES AND EVIDENCE FROM THE LITERATURE

5.1. Rapid Diagnostic Methods and Molecular Surveillance

In hospital infection control, rapid diagnostic technologies are playing an increasing role due to the fact that the classical microbiological methods can sometimes take extra time to identify the pathogens and establish their antimicrobial resistance. Molecular methods, such as polymerase chain reaction (PCR), multiplex PCR and selected sequencing-based methods, are able to identify specific microorganisms or microorganisms with resistance-associated genes more quickly than numerous traditional methods. Rapid Phenotypic Antimicrobial Susceptibility Testing (AMS) can be used in addition to molecular tests to determine the susceptibility of microorganisms to antimicrobial agents. They can be used to help with the earlier, targeted treatment; with timeous isolation precaution; and with investigation of the potential transmission event. The identification of a resistance gene is not sufficient to determine the entire susceptibility pattern of an organism, however, and should be combined with clinical data and other laboratory information.

Valencia-Shelton et al. (2024) noted that molecular diagnostic stewardship hinges on selecting the right test, interpreting the results correctly, and properly communicating with clinical teams. Rapid testing is most beneficial when results are used in a timely manner for clinical decision making and support of antimicrobial stewardship. Molecular surveillance, such as whole genome sequencing, can also be used to investigate outbreaks and differentiate closely related isolates and is appropriate in certain contexts. However, factors such as equipment, laboratory capacity, and turnaround time and the availability of trained personnel can pose restrictions on implementation. Thus, rapid diagnostics should be used in addition to, not in place of, conventional culture and susceptibility testing where these are clinically indicated.

5.2. Advanced Disinfection Technologies and Antimicrobial Surface Coatings

New technologies for advanced environmental decontamination for the removal or inactivation of pathogens in hospital environments are being explored. A UV-C disinfection system is a UV system that utilizes UVC radiation to inactivate the microorganisms on surfaces that are exposed to the UV radiation. Additional room decontamination may be achieved following routine cleaning with an automated hydrogen peroxide system (e.g., vapor or aerosol). These methods can be helpful in specific high-risk areas and/or terminal cleaning, but not to replace manual cleaning to remove organic material and obvious contamination.

Selected copper-containing materials are identified as antimicrobial surface coatings, which aim to decrease the survival of microorganisms on frequently touched surfaces. They are effective under the following conditions: material, environment, contact time and microorganisms. Blanchard et

al. (2023) conducted a systematic review of germicidal efficacy of UV-C on high-touch surfaces, and noted discrepancies in reported efficacy between settings and study design. This indicates that the advantages of advanced disinfection will be based on the correct location of the equipment, exposure parameters, room configuration, and the use of existing cleaning practices. Additional clinical and economic studies are needed to identify which technologies have a meaningful impact on reducing infection rates in the real world of the hospital.

5.3. Prevention and eradication of bioflim growth in new ways

The treatment with traditional antimicrobial agents may be inadequate to eradicate existing biofilms, thus a strategy focusing on the attachment process, biofilm structure and biofilm protective matrix around microbial communities is sought. New ideas involve anti-adhesive device materials, antimicrobial coatings, enzymes which break down the components of biofilms and agents which disrupt the communication between microorganisms. The intent of these methods is to inhibit the ability of biofilms to form or to facilitate the ability of antimicrobial agents to attack existing biofilms. These could be used for urinary catheters, vascular devices, implants and other surfaces that have long-term infections.

Of particular interest, however, are bacteriophages, viruses that attack individual bacteria, which have been shown to infect bacteria associated with biofilms and to affect microbial communities. Meneses et al. (2023) reviewed 68 studies, with 605 in vitro experiments, and revealed that the ability of phages to reduce biofilm depended on conditions like phage concentration, biological variables, etc. Most of the evidence, however, was based on laboratory models and the authors emphasized the important methodological differences. These results suggest that there may be a need for more investigation, but do not prove that the approaches using phages are successful in patients routinely. The safety and delivery method of these products as well as their effects on clinically relevant biofilms and combinations with conventional antimicrobial therapy should be evaluated in future studies.

5.4. Bacteriophage Therapy, Antimicrobial Peptides, and Other Emerging Interventions

A number of new strategies in biology and therapy for infections not well controlled by traditional antimicrobial therapy are being studied. Bacteriophage therapy is based on the use of viruses specific to bacteria in order to selectively target bacterial pathogens. These agents can weaken bacterial cells and can act to decrease the microbial population involved in the development of biofilms, depending on the type of organism and the properties of the phages. Phages can be used in combination with antibiotics or used alone, though there are significant considerations for the selection, susceptibility testing, formulation and clinical monitoring of phages. Some phages have a narrow host range which can provide targeting benefits, but can also make treatment more complicated if the infection is caused by more than one type of bacteria, or if the bacteria is not known.

Another interest is antimicrobial peptides, as some peptides can act as a disruptor of microbial membranes or as a disruptor of essential microbial processes. Alternatively, experimental methods have been used such as enzymes for degradation of biofilm matrices and compounds to disrupt quorum interaction. Although these interventions have shown promise in the laboratory, they have problems with stability, toxicity, delivery to infection sites, manufacturing, regulatory approval, and reduced susceptibility developing. Meneses et al. (2023) showed how increasingly phage-based biofilm control is being studied, but also revealed a need for standardisation of these studies. Thus, these interventions should be viewed as evolving or experimental interventions and not as alternatives to existing infection control measures and clinically indicated antimicrobial therapy.

5.5. AI and digital tools for infection surveillance

The potential of artificial intelligence (AI) and digital health technologies in hospital infection surveillance and identification of patients at higher risk or enhancing the efficiency of infection prevention activities is being explored. Machine-learning models have the ability to learn from electronic health records, laboratory values, medication history, vital signs, and other clinical data to

detect patterns linked to HAIs. Digital dashboards may be used to track the number of infections, patterns of antimicrobial resistance, and adherence to infection prevention protocols for infection prevention teams. An automated system can also help to free up time to review a large volume of patient data and determine potential infection events.

Baddal et al. (2024) highlighted the applications of AI in the diagnosis and prevention of HAIs, such as risk prediction, automated monitoring, antimicrobial resistance surveillance, and clinical decision support. Their Review noted the promise of these technologies and also noted that implementation and clinical validation are important considerations. The information provided by AI can be influenced by incomplete records, the bias of the training data, changes in hospital procedures, and variations in healthcare settings. Hence, digital tools, rather than supplanting, should complement clinical judgment and infection prevention skills. Such systems cannot be used routinely for decisions without the interoperability, data protection, prospective evaluation, and continuous performance monitoring.

5.6. Comparative Effectiveness of Conventional and Advanced Infection Control Strategies

Traditional infection prevention practices, such as hand hygiene, standard isolation precautions, routine cleaning of the environment, safe use of hospital devices, and antimicrobial stewardship are the cornerstones of hospital infection control. Advanced technologies can offer further advantages in terms of pathogen identification time, environmental decontamination consistency or assisting teams to identify infection risks sooner. But their effectiveness should be measured over accepted practice and other clinically meaningful outcomes, not solely on laboratory measurements or technical performance.

For instance, UV-C disinfection may be effective in reducing the microbial contamination of exposed surface areas, but may not be effective if surfaces have shadows, under different exposure conditions and depend on surface geometry. The effectiveness of UV-C technology was found to vary with the type of surface and the hospital environment by Resendiz et al., (2023), suggesting that UV-C technology should be combined with an appropriate manual cleaning method. Likewise, rapid diagnostics can speed up the identification of the pathogenic organism, but the chances of improving the outcomes of the patient rely on the accuracy of the results, speed at which they were communicated, and whether they were followed up or acted upon. The potential of AI-based surveillance is that it may be more effective at detecting infection cases, but there is less evidence that it is effective at keeping infections down over time, as there is with technical feasibility. Therefore, a balance must be obtained so that the advanced technologies are introduced alongside reliable conventional technologies, where the added clinical value, technology suitability and cost-effectiveness are well supported.

5.7. Evidence Gaps, Implementation Barriers, and Future Research Directions

Although the technology for preventing infection has improved, some gaps in evidence prevent the effective use of these technologies in the hospital. Many emerging interventions have been assessed in laboratory settings, small observations or one-centre evaluations, and it is challenging to know if they can be replicated in various healthcare environments. Other difficulties are high implementation cost, limited technical infrastructure, lack of staff training, integration of new systems with existing hospital processes, and the uncertainty about the long-term cost effectiveness. In addition, advanced technologies can yield variable findings when assessed through various study designs, measures of outcomes, or implementation approaches.

In a scoping review of novel methods to control and monitor infections, Arzilli et al. (2024) identified a number of opportunities provided by digital technologies but also noted the limitations of resources and the need to integrate multiple disciplines. Further studies should focus on multicentre studies, the use of uniform outcome definitions, prospective assessment, and direct comparisons with the standard infection prevention measures. Research should include clinically relevant outcomes such as reduced rates of healthcare-associated infections, use of antimicrobials, adverse events, patient outcomes, workload of staff, and economic costs. More research is also required to develop suitable governance frameworks for these AI systems, test the accuracy of developing rapid diagnostic tools

across various populations and identify the safety and efficacy of biofilm-targeting treatments. Overall, we believe that advanced technologies should be introduced step-by-step, informed by evidence, and based on more than just technological novelty, taking clinical benefits, feasibility, affordability and sustainability with us.

6. DISCUSSION, CONCLUSION AND FUTURE RECOMMENDATION

Antimicrobial resistance (AMR), multidrug-resistant pathogens and biofilm-associated infections are a growing threat to patient safety and successful antibiotic treatment and this has now made hospital infection control a growing priority. The results of this literature search showed that there was no evidence from the literature that HAIs can be treated with antibiotics. They can be prevented through coordinated measures that include infection prevention and control (IPC), rational use of antimicrobials, microbiological surveillance, environmental hygiene and ongoing education for healthcare workers. Effective IPC programmes are crucial in minimizing the burden of HAIs and antimicrobial-resistant microorganisms spread (WHO 2024).

There is also evidence to support combined infection control measures, rather than relying on individual measures. Sonpar et al. (2025) conducted a systematic review of 27 studies that were eligible to review multimodal IPC strategies and found 20 studies that reported either a significant reduction in HAIs or improved hand hygiene. Overall, the quality of the evidence was low through moderate, however, and few studies were conducted in low- and middle-income countries. The results indicate that coordinated interventions may have a positive impact on infection prevention outcomes, but the impact varies in magnitude and consistency by: the setting, implementation of the intervention, and type of intervention.

A key conclusion from the literature is that antimicrobial stewardship and infection prevention go hand in hand. Appropriate prescribing can limit unnecessary exposure to antimicrobials and effective hygiene, isolation precautions, environmental cleaning and care of devices can limit opportunity for pathogen transmission. The detection and control of resistant bacteria (MRSA, VRE and CARNOGs) must be done in a timely manner. Another challenge with biofilm-associated infections is the fact that microbial communities that grow on medical devices can survive in the presence of antimicrobial agents. These issues highlight the importance of clinical treatment of these problems when combined with prevention of infection acquisition and transmission.

The Advanced technologies, such as the quick molecular diagnostics, genomic surveillance, automatic disinfection, antimicrobial surface coatings, bacteriophage interventions, and artificial intelligence, also provide additional potential areas to enhance the hospital infection control. However, their efficacy requires clinical validation, availability, and integration into clinical routine. Journal of Hospital Infection researchers recently conducted a systematic review of the evidence for 39 studies of preventive interventions for HAIs and AMR (2026). The review confirmed that the promotion of hand hygiene and multimodal IPC programmes, and targeted prevention bundles, were more often linked with better infection outcomes, but there were significant differences in study design and how outcomes were reported which made it difficult to draw causal conclusions.

Clinically speaking, these results suggest an integrated strategy, where existing infection prevention strategies are the backbone of hospital infection prevention, and new technologies are added when they offer proven value. Timely treatment can be guided using rapid diagnostic methods and outbreak recognition and local resistance monitoring can be supported by surveillance systems. But for all of this it is important to remember that technological advancements are not enough if there is not proper staffing, hand hygiene, supply provision or proper procedure adherence. In resource-limited health care systems, overcrowding, limited laboratory capabilities, poor sanitation facilities, and a shortage of trained health care staff to monitor and manage infectious diseases can compromise prevention efforts, especially for the public health implications. Address these structural barriers in addition to clinical interventions for sustained improvements. Murray et al. (2024) estimated that improving IPC programmes in health care facilities in LMICs would save around 337,000 deaths due

to AMR each year in an analysis based on a modelling approach. This estimate is indicative of the potential public health benefit of infection prevention, but is a modelled benefit rather than a measured benefit of a single intervention.

Although there is an increasingly substantial evidence base, there are some limitations in interpreting the findings. There are variations in definitions of HAIs, the organisms studied, patient populations, intervention methodologies, length of follow-up, and outcome measures across studies. Many evaluations have either an observational design or a before and after design, which is challenging for distinguishing the effects of the intervention versus the effects of changes in the patient, prescribing practices, or other infection control activities. There is also limited evidence of emerging technologies, as some technologies are based on small clinical studies or laboratory experiments. In addition, there are some areas in which evidence from LMICs is limited. Such restrictions emphasize that it is important to make careful interpretations and that conclusions about the superiority of any one intervention cannot be drawn.

Future studies should focus on multicentre studies that compare the outcomes of integrated IPC and antimicrobial stewardship programmes with the outcomes of usual care, using the same definition of outcomes. Investigations should evaluate: incidence of infection, use of antimicrobials, antimicrobial resistance, patient outcomes, implementation costs and sustainability. Additionally, there is a need for further studies to confirm the clinical efficacy of the following interventions: biofilm-targeting, antimicrobial coatings, rapid diagnostics and AI-based surveillance. It is recommended that hospital policies facilitate working IPC teams, ensure good microbiological services, keep staff trained regularly, ensure adequate staffing and supplies, and periodically review the performance of their infection control. Implementations should be tailored to the local epidemiology and availability of resources, and be shaped by the needs of individual health care facilities.

Finally, a multi-faceted and evidence-based approach that combines antimicrobial stewardship, infection surveillance, hand hygiene, environmental management, device-associated infection prevention, and ongoing professional learning and education is needed to effectively stop hospital infections in the age of antimicrobial resistance. The use of advanced diagnostic and preventative technologies could augment these activities but their use should be based on proven clinical benefit, safety, feasibility and cost-effectiveness. Sustainable progress will require action to translate existing evidence in a consistent way into clinical practice, action to overcome barriers to healthcare systems, and development of better research quality in a variety of settings. Focus on prevention, along with the right treatment, can help hospitals avoid unnecessary infections, prevent the spread of resistant pathogens and keep patients safe.

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