Science Archives (2026) Vol. 7 (2), 143-153

Science Archives (ISSN:2582-6697)

Journal homepage: www.sciencearchives.org

DOI: https://doi.org/10.47587/SA.2026.7213

Research Article

Approaches to Infection Prevention and Control in Healthcare Facilities: Current Practices, Barriers, and Emerging Innovations: A Review Article

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Received: Apr 21, 2026/ Revised: May 29 2026/Accepted: June 7, 2026

Abstract

Healthcare-associated infections (HAIs) remain among the most prevalent adverse events in global health service delivery, placing an enormous burden on patients, healthcare workers, and health systems worldwide. Despite evidence-based interventions, implementation of infection prevention and control (IPC) remains inconsistent, particularly in low- and middle-income countries (LMICs). This narrative review examines current IPC practices in healthcare facilities, analyses the structural, behavioural, and resource barriers that impede effective implementation, and explores emerging technological and programmatic innovations. A comprehensive literature search was conducted across PubMed/MEDLINE, Scopus, and CINAHL for peer-reviewed articles and authoritative reports published between 2020 and 2025 using the terms 'infection prevention and control', 'healthcare-associated infections', 'hand hygiene', 'antimicrobial stewardship', 'UV-C disinfection', and 'AI surveillance'. Multimodal IPC strategies incorporating standard precautions, contact precautions, environmental cleaning, and chlorhexidine bathing demonstrate the greatest efficacy (RR 0.04, 95% CI 0.02–0.08). Key barriers include infrastructural deficits, HCW compliance gaps, inadequate training, and resource limitations in LMICs. Emerging innovations, including UV-C disinfection robots, AI-assisted surveillance, whole-genome sequencing, and IoT-enabled smart environments, offer promising complements to conventional IPC measures. Achieving sustainable reduction in HAIs requires integration of evidence-based multimodal strategies, context-specific implementation support, and investment in emerging technologies, particularly in resource-limited settings.

Keywords: *Infection prevention and control; Healthcare-associated infections; Hand hygiene; Antimicrobial stewardship; UV-C disinfection; Artificial intelligence; Multimodal strategies; low- and middle-income countries*

1. Introduction

Healthcare-associated infections (HAIs) represent one of the most significant threats to patient safety worldwide. On any given day, approximately one in ten hospitalised patients in high-income countries is affected by an HAI; in low- and middle-income countries (LMICs), this proportion can rise to 20% or higher, particularly among patients in intensive care units (ICUs).[14,15] In Europe alone, an estimated nine million HAIs occur annually in acute and long-term care facilities, generating 25 million extra hospital-days and costing between €13 and €24 billion.[15] In the United States, approximately 687,000 HAIs were reported in acute care hospitals in 2015, resulting in 72,000 deaths.[16]

The global burden of hospital-associated infections resistant to antibiotics is staggering. Balasubramanian et al. estimated 136 million (95% CI: 26–246 million) healthcare-associated antibiotic-resistant infections per year globally, with the highest burden in China, Pakistan, and India. [17,18] Importantly, 63.5% of antibiotic-resistant bacterial infections are healthcare-associated, and antimicrobial resistance (AMR) is projected to contribute to nearly five million deaths annually. [15,18]

Despite the availability of evidence-based IPC interventions, WHO surveys conducted in 2019 and 2021–22 demonstrate that the majority of countries and healthcare facilities fail to meet minimum IPC requirements.[14,15] Only 3.8% of assessed countries met all national minimum requirements for IPC in 2022, and only 15.2% of healthcare facilities met facility-level IPC minimums.[14,15] The COVID-19 pandemic further exposed IPC weaknesses, with data from multiple countries showing alarming increases in HAIs and AMR during 2020–2021.[11,14]
This review synthesises the current evidence on IPC practices across healthcare settings, identifies the multifaceted barriers to sustained implementation, and critically evaluates emerging innovations, from autonomous UV-C disinfection robots to AI-powered surveillance systems, that are reshaping the IPC landscape. The review is structured to serve as a practical and evidence-based resource for healthcare administrators, infection control practitioners, and policymakers.

2. The Epidemiology and Burden of HAIS

The principal categories of HAIs include surgical site infections (SSIs), central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), ventilator-associated pneumonia (VAP), and Clostridioides difficile infections (CDI). These infections disproportionately affect the most vulnerable patient populations, the immunocompromised, the elderly, and those in critical care settings. [9,12,20]

A retrospective study from Saudi Arabia documented CLABSI rates of 2.6 per 1,000 central-line days and CAUTI rates of 0.76 per 1,000 catheter-days, with SSIs constituting approximately 15–20% of device-related HAIs.[12,20] In sub-Saharan Africa, a systematic review and meta-analysis found a pooled HAI prevalence of 12.9% (95% CI: 8.9–17.4%), with East Africa recording the highest sub-regional burden at 19.7%. [19] This underscores the pronounced disparity between high-income and lower-resource contexts.
The four key antimicrobial-resistant pathogens most frequently implicated in healthcare settings, Escherichia coli and Klebsiella pneumoniae resistant to third-generation cephalosporins, methicillin-resistant Staphylococcus aureus (MRSA), and carbapenem-resistant Pseudomonas aeruginosa, account for 68% of the total AMR burden.[11] These organisms are also strongly linked to healthcare transmission and excess mortality. Table 1 presents Common HAI Types, Causative Organisms, Reported Frequencies, and Key Risk Factors in Healthcare Facilities.

Table 1. Common HAI Types, Causative Organisms, Reported Frequencies, and Key Risk Factors in Healthcare Facilities. [1,9,11,12,16,17,20]

HAI Type	Common Causative Organisms	Frequency (%)	Associated Risk Factors	Key References
Surgical Site Infection (SSI)	S. aureus, E. coli, Pseudomonas spp.	15–20% of device-related HAIs	Prolonged surgery, obesity, diabetes	[3,12,20]
CLABSI	CoNS, S. aureus, Candida spp.	~2.6/1000 central-line days	Immunocompromised, long-term catheter	[12,20]
CAUTI	E. coli, Klebsiella, Enterococcus	~0.76/1000 catheter days	Female sex, prolonged catheterization	[12,20]
VAP	P. aeruginosa, Acinetobacter, MRSA	5–40% of ventilated patients	Duration of MV, supine positioning	[9,12]
C. difficile Infection (CDI)	Clostridioides difficile	Significant in post-antibiotic patients	Antibiotic use, advanced age	[16]
MRSA Bacteraemia	Methicillin-resistant S. aureus	68% AMR burden from 4 key organisms	ICU stay, skin breaks, prior antibiotics	[1,11]

Recent data from the US Centers for Disease Control and Prevention (CDC) for 2024 show significant declines from 2023 baselines: CDI decreased by 11%, CAUTI by 10%, CLABSI by 9%, and MRSA by 7% in acute care hospitals, suggesting that sustained, evidence-based IPC programmes can drive measurable progress.[16]

3. Current IPC Practices: A Structured Overview

3.1 Standard and Transmission-Based Precautions

Standard precautions (SPs) form the cornerstone of IPC in every patient care encounter, irrespective of diagnosis or infection status. They encompass hand hygiene, use of personal protective equipment (PPE), safe injection practices, respiratory hygiene, environmental cleaning, and proper waste management.[13] Transmission-based precautions—contact, droplet, and airborne—are layered atop SPs when specific pathogens are identified or suspected.[8]

A network meta-analysis of 97 studies examining IPC measures against multidrug-resistant organisms (MDROs) demonstrated that SP + CP + ENV (contact precautions plus environmental cleaning) was the most effective combination for reducing MDRO acquisition (RR 0.04; 95% CI 0.02, 0.08), while the CP + CHG combination was most effective for reducing MDRO infection (RR 0.38; 95% CI 0.18, 0.79).[1,7]

3.2 Hand Hygiene

Hand hygiene (HH) with alcohol-based handrub (ABHR) or soap and water at the WHO's five moments for hand hygiene represents the single most cost-effective IPC

intervention.[28] Studies consistently link HH improvements to reductions in HAI rates and healthcare costs.[10] Yet compliance rates remain alarmingly low across settings, often below 40% in LMICs and ranging from 40–80% in high-income countries.[10,25,26,28]
A quality improvement initiative in six Ugandan hospitals using the WHO HH improvement strategy and continuous quality improvement (CQI) approach demonstrated meaningful, measurable gains in HH compliance rates, indicating that structured, context-specific interventions can bridge compliance gaps in resource-limited settings.[29]

3.3 Environmental Cleaning and Decontamination

Environmental surfaces serve as reservoirs for HAI pathogens, including MRSA, vancomycin-resistant enterococci (VRE), and C. difficile spores. Rigorous terminal cleaning protocols, combined with validated disinfectants and enhanced procedures, form a critical layer of HAI prevention. A multimodal review commissioned by the WHO identified nine studies reporting a positive effect of bundled strategies, including enhanced environmental cleaning, on reducing device-associated HAIs and SSIs.[2]

3.4 Antimicrobial Stewardship

Antimicrobial stewardship programmes (ASPs) aim to optimise antimicrobial use, reduce selective pressure for AMR, and minimise CDI and other collateral harms. In high-income countries, multidisciplinary ASPs led by infectious disease physicians, clinical microbiologists, and pharmacists have been shown to reduce inappropriate antibiotic prescribing and hospital-acquired resistance. [30,31,32].

In LMICs, however, ASP implementation faces severe barriers including the absence of structural frameworks, insufficient diagnostics, language barriers in adopting international guidelines, trained personnel shortages, and weak supply chains. [24,31,32] A qualitative study within the Global-PPS network found that LMIC hospitals require tailored AMS strategies that integrate into existing workflows rather than creating parallel 'project silos'.[32] Table 2 shows the WHO Core Components of IPC, Current Practices, and Evidence of Effectiveness.

4. Barriers To Effective IPC Implementation

4.1 Infrastructural and Resource Barriers

In many LMICs and even some high-income settings, HAI prevention is undermined by physical infrastructure deficits, inadequate water, sanitation and hygiene (WASH) services, unreliable supply of ABHR and PPE, insufficient numbers of sinks, and poor ward design that inhibits effective isolation.[11,14] A WHO/UNICEF 2024 WASH report estimated that in 2022, 1.7 billion people used healthcare facilities lacking basic water services.[14]

A systematic review of barriers to HH compliance found that unavailability, shortage, or poor placement of hand hygiene products was the most commonly reported barrier to HH adherence, documented in 22 of the included studies.[28] This structural barrier transcends individual behaviour and demands systems-level intervention.

Table 2. WHO Core Components of IPC, Current Practices, and Evidence of Effectiveness. [1,2,8,9,14,15,20,23,25,26,27]

WHO Core Component	Current Practice/Intervention	Evidence of Effectiveness	References
1. IPC Programmes	Dedicated IPC teams with annual workplan and budget	Functioning programme exists in only 54.7% of countries	[14,15]
2. IPC Guidelines	Evidence-based national and facility-level guidelines (e.g., WHO, CDC, SHEA/IDSA)	Guidelines adherence reduces HAI rates by 35–70%	[8,15]
3. Education & Training	Multimodal HCW training; simulation-based learning	Weakest component globally; only 20% met training minimums in 2021	[14,15]
4. HAI Surveillance	Electronic surveillance systems; real-time dashboards; AI-assisted detection	AI improves early detection accuracy by identifying patterns earlier than traditional methods	[23]
5. Multimodal Strategies	Bundles of SP + CP + ENV + CHG decolonisation	SP+CP+ENV combination: RR 0.04 [0.02, 0.08] for MDRO acquisition	[1,2]
6. Monitoring & Audit	Direct observation; electronic hand hygiene monitoring; CCTV-assisted audits	Continuous feedback improves HH compliance in ICU settings	[25,26]
7. Workload & Staffing	Safe nurse-to-patient ratios; IPC link nurse systems	ICT with ICLN system did not significantly reduce HAI incidence rate in RCTs (low quality evidence)	[9]
8. Environ. Cleaning	UV-C disinfection robots; automated H_2O_2 systems; enhanced terminal cleaning	UV-C robots achieve >90% reduction in C. difficile spores	[23,27]

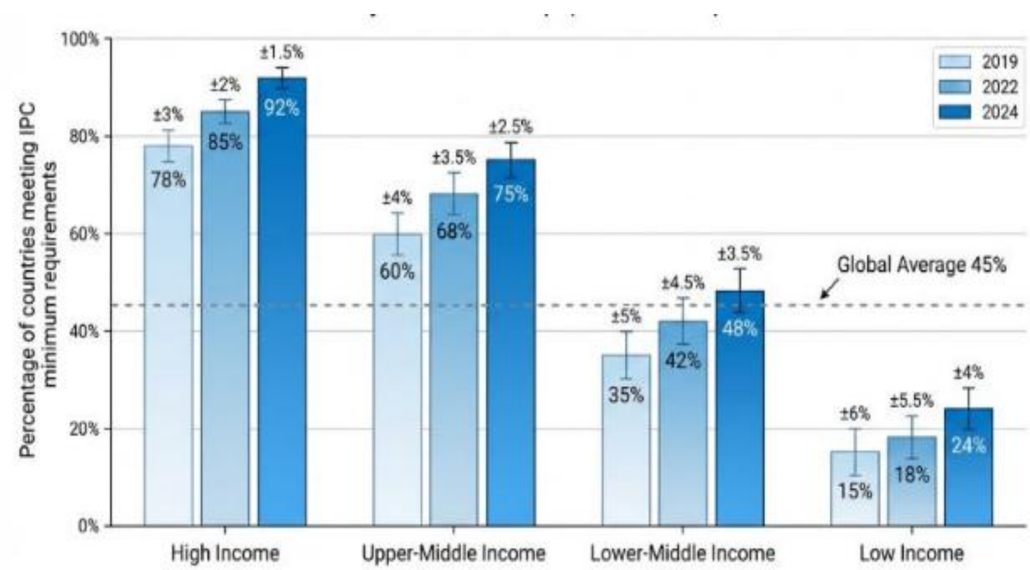

Figure 1. Global compliance with WHO IPC minimum requirements by income group (2019–2024). [14,15] *Caption: A grouped bar chart with four income groups (High, Upper-Middle, Lower-Middle, Low Income) on the x-axis and percentage of countries meeting IPC minimum requirements on the y-axis, with three bars per group representing years 2019, 2022, and 2024.*

4.2 Behavioural and Cultural Barriers

Individual HCW behaviour is shaped by a complex interplay of knowledge, attitudes, risk perception, peer norms, and organisational culture. High workload, cognitive overload, and forgetfulness were cited as key barriers to HH compliance in studies from intensive care settings across multiple continents. [10,28] A qualitative study exploring compliance determinants among ICU nurses in the West Bank found that insufficient supply levels, low supervision frequency, and limited education contributed significantly to IPC non-compliance.[10]

4.3 Organisational and Policy Barriers

The absence of institutional mandates, weak IPC leadership, inadequate budget allocation, and a culture that does not prioritise IPC at the management level are widely documented impediments to sustained programme implementation. [24,31] In a survey of AMS programmes across 90 countries in the Global-PPS network, lack of trained personnel and funding was the most commonly cited barrier to AMS activities globally.[32]

4.4 Training and Knowledge Gaps

Globally, education and training are the weakest component of IPC programmes, with only 20% of countries having a training programme meeting minimum requirements in 2021. [14,15] Healthcare workers who lack up-to-date, contextually relevant training are less likely to adhere to IPC protocols, particularly when guidelines are complex or perceived as inapplicable to their specific care environment.[3] Table 3 gives the Summary of Key Barriers to IPC Implementation by Category, with Supporting Evidence, while Figure 2 shows the Fishbone diagram of barriers to infection prevention and control implementation.

Table 3. Summary of Key Barriers to IPC Implementation by Category, with Supporting Evidence. [10,14,15,24,25,28,29,31,32]

Barrier Category	Specific Barrier	Evidence/Context	References
Structural/Infrastructural	Shortage of ABHR, sinks, PPE	22 of the studies reported unavailability of HH products as the main barrier	[28,29]
Human/Behavioural	Forgetfulness, high workload, low risk perception	Forgetfulness due to busy schedules reported in 8 included studies	[28]
Organisational	Absence of IPC mandates, poor leadership buy-in	Socioeconomic instability and absence of mandates aggravate HAI/AMR burden	[24,31]
Resource Constraints (LMICs)	Insufficient funding, lack of trained personnel, supply chain gaps	Only 15.2% of healthcare facilities globally met all IPC minimum requirements in 2019	[14,24]
Educational Gaps	Lack of structured training programmes	Only 20% of countries had IPC training programmes fulfilling minimum requirements in 2021	[14,15]
Antimicrobial Stewardship Gaps	No structural AMS framework, inadequate diagnostics, language/cultural barriers	Only 12% of hospitals in Africa reported having an AMS committee in global survey	[30,31]

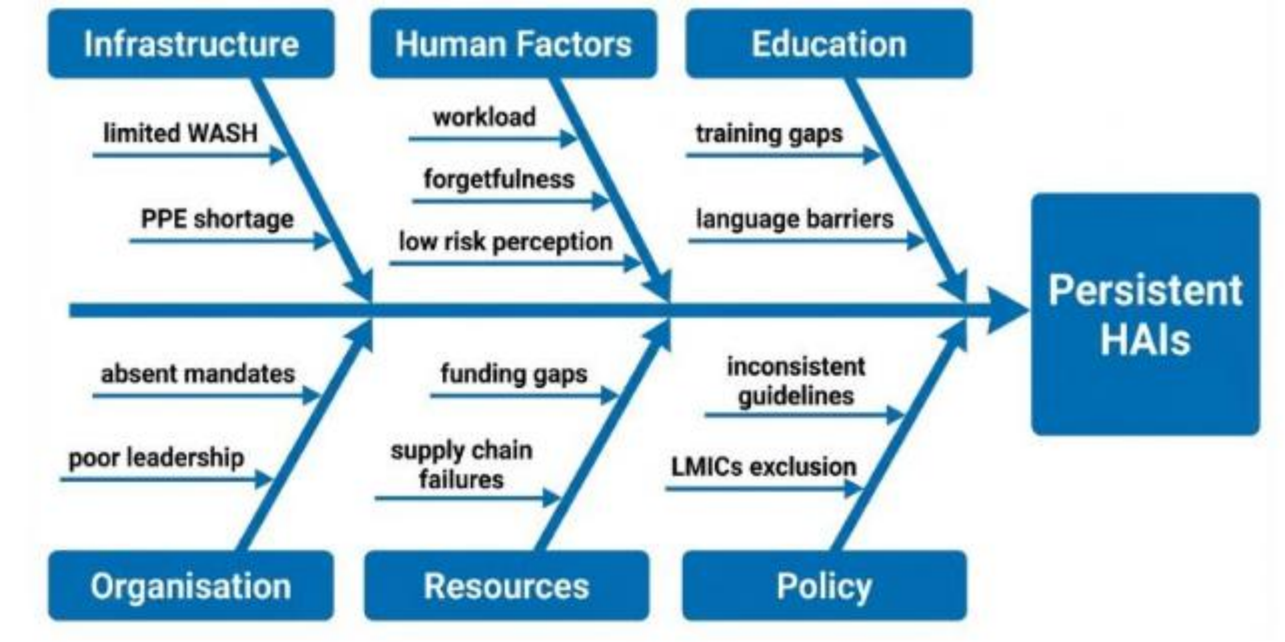

Figure 2. Fishbone diagram of barriers to infection prevention and control implementation. [10,14,15,24,28,31] *Caption: Ishikawa (fishbone/cause-and-effect) diagram with 'Persistent HAIs' as the head. The main 'bones' represents: (1) Infrastructure – limited WASH, PPE shortage; (2) Human Factors – workload, forgetfulness, low risk perception; (3) Education – training gaps, language barriers; (4) Organisation – absent mandates, poor leadership; (5) Resources – funding gaps, supply chain failures; (6) Policy – inconsistent guidelines, LMICs exclusion*

5. Emerging Innovations in Infection Prevention and Control

5.1 Automated UV-C Disinfection Technology

Ultraviolet C (UV-C) radiation at wavelengths of 200–280 nm disrupts the nucleic acids of microorganisms, preventing replication. Autonomous UV-C disinfection robots have emerged as a significant adjunct to manual environmental decontamination, particularly for high-touch surfaces in ICUs, operating theatres, and terminal room cleaning. [21,22,27]

Mehta et al. conducted a comprehensive review of commercially available UV-C disinfection robots and catalogued key technical challenges including dosage modelling, navigation in complex environments, and safety during occupancy.[22] A combination disinfection system integrating UV-C radiation with hydrogen peroxide aerosol achieved a 92.95% reduction of natural airborne bacteria in controlled trials.[27] UV-C-emitting devices have demonstrated more than 90% reduction in C. difficile spores, making them particularly relevant for the prevention of CDI in acute care settings.[23]

Despite their promise, UV-C robots present limitations: high acquisition and maintenance costs, shadow areas where irradiation cannot reach, the requirement for room clearance during operation, and variability in dosage delivery across surface geometries. [22,27] A systematic review by Pfleger et al. highlighted ongoing challenges in environmental mapping accuracy and dose verification as priority research areas.[22]

5.2 Artificial Intelligence and Digital Surveillance

AI is revolutionising IPC surveillance through predictive analytics, natural language processing (NLP) of clinical notes, and computer vision for real-time HH monitoring. A comprehensive review by Arzilli et al. and subsequent analyses confirmed that AI-powered systems identify HAI outbreak patterns earlier than conventional threshold-based surveillance, enabling proactive rather than reactive intervention. [23,26]

Machine learning models trained on electronic health record (EHR) data have been deployed to predict patients at high risk of developing HAIs, enabling targeted preventive measures such as enhanced isolation, decolonisation, or intensified monitoring.[23] AI-assisted antimicrobial stewardship tools help predict antibiotic resistance patterns and support prescribing decisions, improving ASP outcomes in settings where specialist personnel are scarce.[23]

5.3 Whole-Genome Sequencing (WGS) in IPC

Pathogen whole-genome sequencing has transformed the investigation of healthcare outbreaks by enabling highresolution transmission mapping, identification of acquisition routes, and detection of AMR genes with unprecedented precision. Eyre et al. reported that a decade of WGS use in hospital settings has fundamentally enhanced understanding of pathogen transmission dynamics, supplanting conventional epidemiological methods in outbreak investigations.[26]

5.4 Internet of Things (IoT) and Smart Healthcare Environments

IoT-integrated systems, encompassing smart sensor networks, automated hand hygiene dispensers linked to RFID technology, real-time air quality monitors, and connected environmental cleaning systems, are enabling a shift from reactive to proactive IPC.[26] These technologies generate continuous environmental and behavioural data streams that support real-time audit and feedback, a critical enabler of HH compliance improvement.[26]

5.5 Whole-Room and Hydrogen Peroxide Vapour Disinfection

Aerosolised hydrogen peroxide (aHP) and gaseous ozone systems provide no-touch, automated whole-room disinfection following patient discharge. Clinical studies have confirmed high-level activity of automated room disinfection (ARD) systems against a range of HAI pathogens including C. difficile, VRE, and MRSA, serving as an effective complement to manual terminal cleaning.[21] Table 4 presents the Emerging Innovations in Infection Prevention and Control: Technology, Mechanism, and Evidence.

Table 4. Emerging Innovations in Infection Prevention and Control: Technology, Mechanism, and Evidence. [21,22,23,25,26,27]

Innovation	Mechanism/Application	Key Findings	References
UV-C Disinfection Robots	Autonomous mobile platforms emitting UV-C irradiation for room decontamination	Combination disinfection robot achieved 92.95% reduction of natural airborne bacteria	[21,22,27]
Artificial Intelligence (AI) Surveillance	Predictive analytics, NLP, computer vision for hand hygiene monitoring and outbreak detection	AI predicts HAIs, optimises antimicrobial use, and monitors HH compliance via video surveillance	[23]
Whole-Room Disinfection (H_2O_2/Ozone)	Automated aerosolised hydrogen peroxide or ozone systems for terminal decontamination	Ozone system highly active against SARS-CoV-2 surrogates; broadened to HAI pathogens	[21]
Whole-Genome Sequencing (WGS)	Pathogen WGS for outbreak investigation, transmission tracking, and AMR gene identification	A decade of WGS use has transformed IPC insights into pathogen transmission routes in healthcare	[26]
IoT-Enabled Smart Environments	Sensor networks for real-time air filtration, environmental monitoring, and automated disinfection triggers	IoT integration creates safer healthcare facilities through continuous environmental data collection	[26]
Digital Hand Hygiene Monitoring	Electronic counters, wearable sensors, and automated dispensers linked to real-time compliance dashboards	Continuous CCTV-assisted feedback showed long-term HH improvement in ICU settings	[25,26]

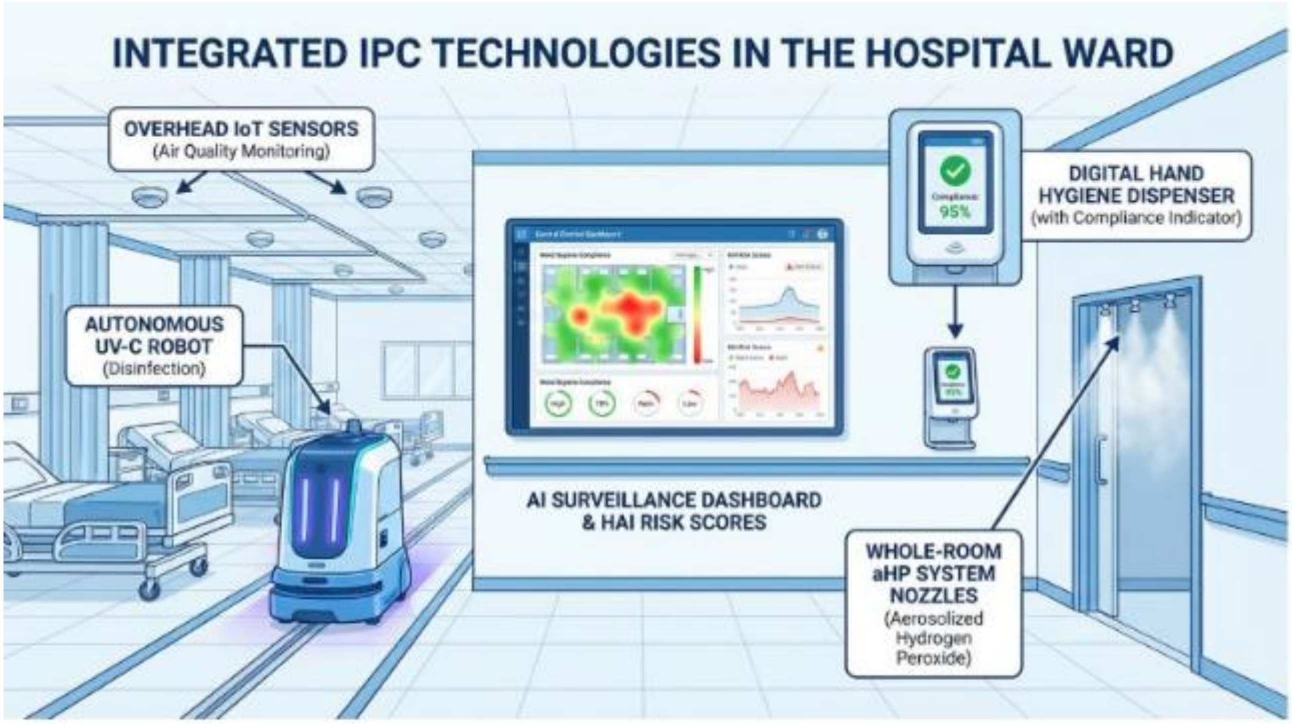

Figure 3. Integrated smart hospital IPC ecosystem [23, 26, 27]

Caption: A detailed 2D schematic/infographic of a hospital ward showing integrated IPC technologies: (a) an autonomous UV-C robot navigating between patient beds; (b) overhead IoT sensors monitoring air quality; (c) a digital hand hygiene dispenser at a point-of-care station with a compliance indicator display; (d) a central control screen showing AI surveillance dashboard with HAI risk scores and hand hygiene heat maps; (e) whole-room aHP system nozzles above the doorway.

6. Strategies For Strengthening IPC In Diverse Healthcare Settings

The WHO multimodal IPC improvement strategy, encompassing system change, training and education, monitoring with feedback, reminders/communications, and safety climate, remains the most robustly evidence-based framework for improving IPC compliance at scale.[2,14,15] An updated systematic review of 27 eligible studies found that multimodal strategies effectively reduced device-associated HAIs, SSIs, and MDROs in both high- and low-resource settings.[2]

For LMICs, context-sensitive adaptations are essential. These include the adoption of low-cost, high-impact measures such as soap-and-water handwashing where ABHR is inaccessible, nurse-led IPC champion networks, integration of AMS into existing clinical workflows, and engagement of community health workers in IPC education.[24,29,31,32] The USAID MTaPS programme demonstrated that a CQI-based HH

intervention in Uganda produced significant compliance improvements across six hospitals, illustrating the scalability of structured quality improvement approaches in resource-limited settings.[29]

At the national level, governments must ensure dedicated IPC budgets, incorporate IPC into national health plans, mandate HAI surveillance, and enforce minimum facility requirements as outlined in the WHO global action plan for IPC (adopted in 2023). [14,15] International partnerships and capacity-building initiatives are critical for bridging the implementation gap between high- and low-resource settings.

7. Discussion

This review demonstrates that HAIs remain a pervasive, preventable, and costly burden that demands sustained, multifaceted responses. The weight of evidence strongly supports multimodal IPC strategies, particularly the combination of standard precautions, contact precautions, environmental cleaning, and decolonisation, as the most effective approach to reducing MDRO-associated infections. [1,2,7]

However, translating evidence into practice is hampered by a convergence of structural, behavioural, and resource barriers that vary substantially by setting. In LMICs, where the burden is highest, implementation is simultaneously most urgent and most challenging. [14,19,24,31] Structural deficits in WASH infrastructure, endemic shortages of ABHR and PPE, and a paucity of trained IPC personnel create conditions in which even basic standard precautions cannot be reliably implemented.

Emerging technologies offer exciting new pathways. UV-C disinfection robots, AI-powered surveillance, WGS, and IoT-enabled environments represent a new frontier in IPC. Yet their deployment must be calibrated to context; these innovations are most valuable as adjuncts to, rather than replacements for, the human-centred practices of hand hygiene, appropriate precautions, and antimicrobial stewardship.[23,26,27] Furthermore, the high cost of these technologies currently limits their accessibility in resource-constrained settings, where investment in training, infrastructure, and supply chains may yield greater immediate gains.

This review has several limitations. As a narrative review, it is subject to selection bias. The heterogeneity of study designs, settings, and outcome measures across included sources limits direct comparisons. Furthermore, the rapidly evolving nature of the field, particularly with respect to AI applications, means that some emerging findings may not yet be fully represented in the peer-reviewed literature.

8. Conclusion

Infection prevention and control in healthcare facilities demands a comprehensive, sustained, and adaptive strategy. Current best evidence supports multimodal approaches underpinned by the WHO IPC core components, with particular emphasis on hand hygiene, environmental cleaning, contact precautions, and antimicrobial stewardship. Barriers at structural, behavioural, and systemic levels must be explicitly addressed through context-tailored interventions, robust training programmes, and institutional leadership.

Emerging innovations, including UV-C disinfection robotics, AI-powered surveillance and prediction, whole-genome sequencing, and IoT-integrated smart environments, hold transformative potential to augment conventional IPC practices and address persistent compliance gaps. Their equitable deployment, particularly in LMICs, will require international collaboration, investment, and innovative implementation strategies. Ultimately, protecting patients and healthcare workers from HAIs is a fundamental obligation of health systems globally, and achieving this goal demands nothing less than a sustained, system-wide commitment to IPC excellence. Figure 4 illustrates the Conceptual framework: The IPC continuum from current practices to emerging innovations.

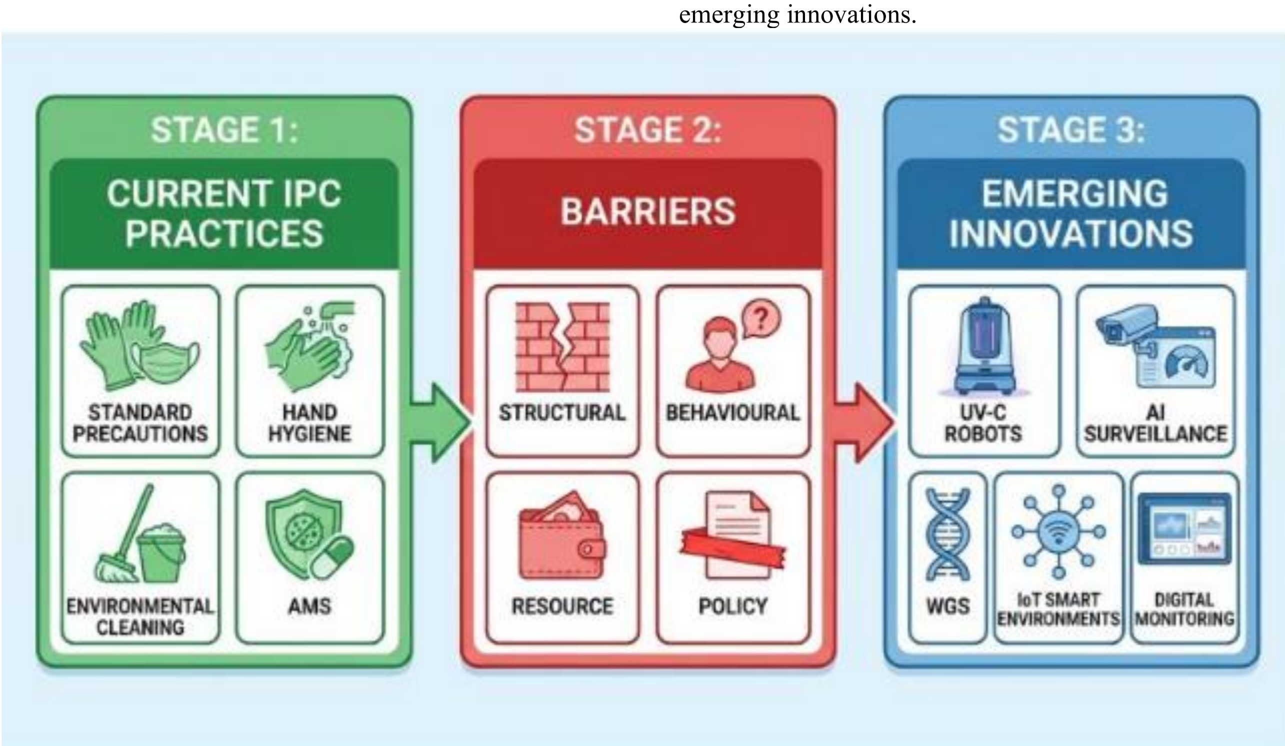

Figure 4. Conceptual framework: The IPC continuum from current practices to emerging innovations [1, 2, 14, 23, 26]

Caption: A horizontal flow diagram or funnel infographic with three stages: Stage 1 – 'Current IPC Practices' (standard precautions, hand hygiene, environmental cleaning, AMS) feeding into Stage 2 – 'Barriers' (structural, behavioural, resource, policy) which are addressed by Stage

3 – 'Emerging Innovations' (UV-C robots, AI surveillance, WGS, IoT smart environments, digital monitoring).

Author Contributions

The author has significantly contributed to the study's conception, design, data collection, analysis, and interpretation. All authors were involved in writing the manuscript or critically reviewing it for its intellectual value. They have reviewed and approved the final version for submission and publication and accept full responsibility for the content and integrity of the work.

Financial Support

The authors declare that no external funding was received for this study.

Conflicts of Interest

The authors state that there are no financial, personal, or professional conflicts of interest associated with this research.

Ethical Approvals

This research did not involve the use of human participants or animal subjects and therefore did not require ethical clearance

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How to cite this article

Etsu, P. C., Oladosu, M. A., Abah, M. A., Agbo, O. S., Olufosoye, B. O., & Udeh, C. C. (2026). *Approaches to infection prevention and control in healthcare facilities: Current practices, barriers, and emerging innovations: A review article*. *Science Archives, 7*(2), 143–153. https://doi.org/10.47587/SA.2026.7213