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ETIOLOGICAL STRUCTURE, CLINICAL SIGNIFICANCE, DIAGNOSIS, AND PREVENTION MEASURES OF NOSOCOMIAL INFECTIONS IN MODERN MEDICINE

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Abstract
This article provides a systematic analysis of the current problems, etiological structure, and management strategies of nosocomial infections in modern medical institutions. Based on data from international healthcare organizations, the multidrug-resistant characteristics of opportunistic pathogens belonging to the ESKAPE group and their direct impact on patient mortality rates are revealed. Furthermore, the scientific advantages of modern molecular genetic technologies, such as PCR and MALDI-TOF, over traditional methods in the early diagnosis of the disease are substantiated. In conclusion, it is emphasized that the comprehensive implementation of strict sanitary and epidemiological control, hand hygiene among medical personnel, and multi-component "bundle" prevention protocols is a critical necessity in the healthcare system to prevent the spread of hospital-acquired infections.

Keywords: Nosocomial infections, antimicrobial resistance, hospital-acquired infections, opportunistic microorganisms, infection control, hand hygiene.

Introduction

Hospital-acquired infections (HAIs), also referred to as nosocomial infections (NIs), remain among the most acute, complex, and socioeconomically burdensome global challenges facing contemporary healthcare systems. According to the World Health Organization (WHO), tens of millions of patients worldwide develop infections directly associated with the provision of inpatient medical care each year. Epidemiological analyses indicate that nosocomial infections occur in approximately

7 out of every 100 hospitalized patients in high-income countries, whereas in low- and middle-income countries this figure rises to nearly 15 per 100 hospitalized patients [1,9,6]. The risk increases particularly sharply in intensive care units (ICUs). Although ICU beds constitute only approximately 10% of total hospital capacity, these departments account for 20% to 50% of all hospital-acquired infections. This observation demonstrates that NIs represent not only a serious medical issue but also a substantial economic burden. According to estimates from the Centers for Disease Control and Prevention (CDC) and independent epidemiological centers, more than 99,000 deaths annually are attributable to hospital-acquired infections, while the associated additional medical and rehabilitation expenditures reach approximately 4.5 billion US dollars per year [2,14,17,31]. Recent prevalence screening studies conducted across the European Union during 2022–2023 similarly documented persistently high prevalence rates, further confirming the critical relevance of this problem [3,16].

In modern hospitals, the etiological structure of nosocomial infections is becoming increasingly complex. Over recent decades, considerable attention within the medical community has focused on the group collectively designated by the acronym “ESKAPE,” which comprises the predominant causative agents of hospital-acquired infections worldwide. The ESKAPE group includes six major pathogens: Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa, and Enterobacter species [4,27,29]. These microorganisms are characterized by pronounced opportunistic properties and by their remarkable capacity for rapid adaptation to environmental conditions and therapeutic pressure, thereby “escaping” antimicrobial action. Epidemiological investigations indicate that patients undergoing surgical interventions or transplantation procedures, as well as individuals with severe chronic disorders associated with immune suppression—such as hepatic diseases and chronic hepatitis—constitute the principal target population for these pathogens [15,21,36]. Numerous studies have demonstrated that, particularly in intensive care settings, Staphylococcus aureus (predominantly methicillin-resistant S. aureus [MRSA]), Acinetobacter baumannii, and Pseudomonas aeruginosa are the dominant pathogens responsible for severe acute infections. Among the major clinical manifestations, ventilator-associated pneumonia (VAP), bloodstream infections including catheter-associated sepsis, and surgical site infections remain the leading nosological entities.

From the perspective of clinical practice, the greatest significance and danger of nosocomial infections lie in the rapidly escalating global prevalence of multidrug

resistance (MDR) to modern antibacterial agents. Mechanisms of antibiotic resistance are biologically diverse and include reduced permeability of the bacterial cell membrane, production of antibiotic-destructive enzymes such as extended-spectrum beta-lactamases (ESBLs) and carbapenemases, as well as modifications of the protein synthesis apparatus [24,32]. One of the most critical resistance mechanisms is the ability of bacteria to form biofilms. Bacterial colonies embedded within biofilms formed on the surfaces of medical devices, venous catheters, or endoprosthetic materials may tolerate antibiotic concentrations up to one hundred times higher than standard therapeutic doses. Consequently, treatment regimens recommended in international clinical protocols frequently lose their effectiveness, forcing clinicians to prescribe last-reserve antibiotics such as vancomycin, linezolid, and colistin. This, in turn, contributes to increased hepatotoxic and nephrotoxic adverse effects and significantly prolongs the duration of hospitalization.

Against such a complex and critical background, the early and etiopathogenetically accurate diagnosis of nosocomial infections has become a pivotal task in clinical microbiology and diagnostic medicine. Although conventional phenotypic methods based on pure culture isolation and disk diffusion antimicrobial susceptibility testing continue to retain their status as the “gold standard,” the prolonged turnaround time of these approaches (typically 48–96 hours) may result in the loss of critically important time in severely ill patients and may contribute to inappropriate empirical antimicrobial therapy [5,19,30]. Under current clinical conditions, revolutionary approaches to diagnostics are increasingly required. Innovative molecular-genetic technologies, including genomic sequencing, multiplex polymerase chain reaction (PCR), and MALDI-TOF mass spectrometry, enable the identification of both the causative pathogen and its antimicrobial resistance genes within only a few hours [15,23]. These advances in diagnostic methodology provide a robust foundation for the implementation of Antimicrobial Stewardship strategies aimed at the rational use of antimicrobial agents.

The necessity of fundamentally improving systems for the prevention of nosocomial infections, in addition to their treatment, has also become critically important. Contemporary international standards recommended by the World Health Organization (WHO) emphasize the implementation of multifactorial and non-pharmacological preventive interventions [6,30]. These measures primarily include strict adherence to hand hygiene protocols, continuous education and awareness among healthcare personnel, and maintenance of sanitary-epidemiological cleanliness through advanced technologies such as hydrogen peroxide vapor generators and high-efficiency particulate air (HEPA) filtration systems. In current

clinical practice, the concept of "bundles," defined as targeted and interrelated packages of preventive interventions, has demonstrated particularly high effectiveness.

Research objective

To systematically evaluate, on the basis of contemporary scientific literature, the etiological structure of nosocomial infections in modern healthcare institutions, their antimicrobial resistance characteristics, innovative diagnostic approaches, and the effectiveness of preventive strategies.

Materials and methods

During the study, scientific publications published in recent years were analyzed using international electronic databases including PubMed, Scopus, Web of Science, and Google Scholar, as well as reports issued by the World Health Organization and the Centers for Disease Control and Prevention. The literature search utilized key terms including "nosocomial infections," "ESKAPE pathogens," "antimicrobial resistance," "diagnostic methods," and "prevention bundles." For the systematic review, more than 50 randomized studies and epidemiological meta-analyses with high levels of evidence were selected, and a comparative-analytical methodological approach was applied.

Results

The analysis of scientific literature and epidemiological databases demonstrated the following evidence-based findings regarding the current status of nosocomial infections in modern clinical practice, the evolution of pathogenic microorganisms, and strategies for their management.

Etiological structure and epidemiology of nosocomial infections. According to the large-scale Point Prevalence Survey conducted by the European Centre for Disease Prevention and Control (ECDC) during 2022–2023 in acute care hospitals, at least one hospital-acquired infection was identified in an average of 7.1% of hospitalized patients across countries of the European Union [2,18]. The analyses indicate that the etiological structure of contemporary inpatient healthcare settings is distributed between Gram-negative and Gram-positive opportunistic bacteria, while approximately 60% of all infections are attributable to pathogens belonging to the ESKAPE group [7].

Table 1 below presents the prevalence of the most common microorganisms responsible for hospital-acquired infections according to the ECDC report. The

values are expressed as percentages relative to the total number of confirmed NI cases.

Table 1. Prevalence structure of leading pathogens causing nosocomial infections in acute care hospitals [2].

Microorganism	Proportion among hospital-acquired infections (%)	Primary site of infection / Nosology
Escherichia coli	13.2%	Urinary tract infections (UTIs), sepsis
Klebsiella pneumoniae	10.1%	Pneumonia, including ventilator-associated pneumonia (VAP), bloodstream infections
Enterococcus faecalis/faecium	9.8%	Surgical site infections (SSIs), UTIs
Staphylococcus aureus	9.2%	SSIs, bloodstream infections
Pseudomonas aeruginosa	8.5%	Ventilator-associated pneumonia (VAP)
Clostridioides difficile	6.8%	Gastrointestinal tract infections, particularly antibiotic-associated diarrhea

Clinical significance and dynamics of antimicrobial resistance (AMR). Numerous studies have demonstrated that the principal clinical significance of nosocomial infections is associated with the rapid increase in multidrug-resistant (MDR) pathogens that are difficult to treat. According to systematic literature reviews, approximately 70–80% of Acinetobacter baumannii strains isolated from intensive care units exhibit resistance to carbapenem-class antibiotics [7,24]. Furthermore, statistical analyses have confirmed that mortality rates associated with infections caused by methicillin-resistant Staphylococcus aureus (MRSA) are approximately 2.5 times higher than those caused by methicillin-susceptible strains.

Development and comparative effectiveness of diagnostic methods. Analysis of the scientific literature indicates that the transition from conventional phenotypic methods toward genotypic and mass spectrometric approaches substantially improves patient survival outcomes in the management of nosocomial infections. The implementation of syndromic panel testing based on multiplex polymerase chain reaction (PCR) and MALDI-TOF mass spectrometry technologies significantly shortens pathogen identification time, thereby accelerating the transition from empirical to targeted antimicrobial therapy [8].

Table 2. Comparative analysis of conventional and modern microbiological diagnostic methods for the detection of hospital-acquired infections [8].

Diagnostic method	**Technological basis**	**Time-to-result**	**Capability for detection of resistance genes**
Culture-based method ("gold standard")	Pure culture isolation and phenotypic disk diffusion susceptibility testing	48–96 hours	Absent (only phenotypic antimicrobial susceptibility is determined)
MALDI-TOF MS	Protein profile–based mass spectrometry	10–30 minutes after pure culture isolation	Partial (special modifications enable carbapenemase detection)
Multiplex PCR / Syndromic panels	Amplification of pathogen DNA/RNA and resistance genes using PCR	1–6 hours (directly from clinical specimens)	Available (e.g., mecA, vanA/B, KPC, NDM genes)

Prevention measures and prophylactic strategies. Analysis of the global report on Infection Prevention and Control (IPC) issued by the World Health Organization demonstrated that the proper implementation of comprehensive preventive measures can reduce the risk of nosocomial infections by up to 70%. Evidence presented in the WHO report further indicates that strict adherence by healthcare personnel to hand hygiene protocols alone may reduce inpatient mortality rates and associated economic expenditures by approximately 50% [9,25]. In addition, international randomized studies have confirmed that implementation of the "bundle" approach in intensive care units—consisting of standardized algorithms for catheter insertion and maintenance—reduced the incidence of central line-associated bloodstream infections (CLABSI) from 5.0 to 1.2 cases per 1,000 catheter-days [11,12,16].

Discussion

This literature review was aimed at the systematic evaluation of the global epidemiological situation of hospital-acquired infections (HAIs), also referred to as nosocomial infections (NIs), including their etiological structure, diagnostic innovations, and preventive strategies. The obtained findings demonstrate that, despite continuous advances in medical technologies and sanitary practices, nosocomial infections remain an unprecedented clinical and economic burden for healthcare systems worldwide. Our results are fully consistent with the conclusions

reported by authoritative international scientific institutions, particularly the World Health Organization and the European Centre for Disease Prevention and Control.

Etiological shifts and the global burden of antimicrobial resistance. The structure of leading pathogens identified in the present study, particularly representatives of the ESKAPE group, corresponds closely with current international epidemiological data. As highlighted in our findings, the exceptionally high level of carbapenem resistance among Acinetobacter baumannii and Klebsiella pneumoniae strains (70–80%) represents an alarming global trend. These observations are supported by the systematic analysis conducted by the "Antimicrobial Resistance Collaborators" group and published in The Lancet [11,18]. That study demonstrated that approximately 1.27 million deaths worldwide in 2019 were directly attributable to bacterial antimicrobial resistance, including infections associated with hospital settings, with lower respiratory tract infections and bloodstream infections identified as the principal contributors. Furthermore, the prioritization framework proposed for the WHO by Tacconelli et al. [12], in which carbapenem-resistant Gram-negative bacteria were classified within the "Critical Priority" category for new antibiotic development, objectively confirms our conclusion regarding the extreme epidemiological and clinical threat posed by ESKAPE pathogens.

Possibilities and barriers to the implementation of diagnostic innovations in clinical practice. In the Results section, the substantial superiority of MALDI-TOF MS and multiplex PCR technologies over conventional culture-based methods in terms of time-to-result was demonstrated. An important issue requiring further discussion is that rapid molecular diagnostics not only reduce diagnostic delays but also facilitate the early transition from empirical antibiotic therapy to targeted antimicrobial treatment within the framework of Antimicrobial Stewardship programs. Existing analyses indicate that the direct detection of resistance genes from patient blood samples or clinical swabs using PCR-based approaches significantly reduces mortality rates [8,21]. Nevertheless, the literature also demonstrates that the high cost of equipment and the continuous requirement for specialized reagents remain major barriers to the widespread implementation of these technologies in low- and middle-income countries (LMICs). Consequently, the development of cost-effective and rapid point-of-care diagnostic tools remains one of the most urgent priorities in contemporary clinical microbiology.

Effectiveness of prevention and infection prevention and control (IPC) strategies: the role of the human factor. Based on the WHO report published in 2022, we concluded that comprehensive bundle-based preventive approaches and strict adherence to hand hygiene protocols may reduce the risk of nosocomial infections by up to 70%

[9]. However, a critical issue requiring discussion is that healthcare personnel compliance with these protocols remains insufficient on a global scale. As demonstrated by Didier Pittet and colleagues [10], the principal route of transmission for nosocomial pathogens is the transient microflora present on the hands of healthcare workers. Therefore, effective control of hospital-acquired infections requires not only the implementation of advanced technologies such as HEPA filtration systems and ultraviolet disinfection devices, but also continuous psychological, educational, and administrative interventions aimed at strengthening infection prevention and control culture among medical personnel.

Conclusion

In contemporary medicine, nosocomial infections remain among the most complex and hazardous challenges facing healthcare systems due to several interrelated factors, including the continuous evolution of opportunistic pathogens, the rapid emergence of antimicrobial resistance, and diagnostic delays associated with conventional microbiological methods. The conducted analysis demonstrated that effective control of this problem requires a comprehensive and multidisciplinary approach:

1. Microorganisms belonging to the ESKAPE group, particularly carbapenem-resistant Acinetobacter baumannii and Klebsiella pneumoniae, as well as methicillin-resistant Staphylococcus aureus (MRSA), represent the leading etiological agents of hospital-acquired infections and pose the highest clinical risk due to their pronounced biofilm-forming capacity and extensive antimicrobial resistance profiles.
2. The global increase in multidrug resistance among pathogenic microorganisms substantially aggravates disease pathogenesis, leading to markedly increased mortality rates, prolonged hospitalization, and a multiple-fold escalation in the economic burden imposed on healthcare systems.
3. The transition from conventional culture-based diagnostic approaches to rapid molecular-genetic technologies, including multiplex polymerase chain reaction (PCR) and MALDI-TOF mass spectrometry, represents a revolutionary advancement in the early and accurate diagnosis of infectious diseases. These methods enable the identification of infectious agents and their resistance-associated genes within a matter of hours, thereby facilitating the rapid transition from ineffective empirical therapy to targeted antimicrobial treatment.
4. Preventive strategies, particularly strict implementation of Infection Prevention and Control (IPC) protocols recommended by the World Health Organization,

rigorous adherence to hand hygiene standards, and systematic application of multicomponent bundle-based interventions, constitute the most effective approach for reducing infection risk by up to 70%, frequently demonstrating greater effectiveness than pharmacological interventions alone.

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