Review Article

Harnessing artificial intelligence for infection control and prevention in hospitals

A comprehensive review of current applications, challenges, and future directions

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ABSTRACT

تُشكّل العدوى المكتسبة من المستشفيات (HAIs) عبئًا كبيرًا على أنظمة الرعاية الصحية العالمية، وتتفاقم بسبب البكتيريا المقاومة للمضادات الحيوية. غالبًا ما تفتقر إجراءات مكافحة العدوى التقليدية إلى الاتساق بسبب تفاوت الامتثال البشري. تهدف هذه المراجعة الشاملة إلى استكشاف دور الذكاء الاصطناعي (AI) في تعزيز مكافحة العدوى والوقاية منها في المستشفيات. أُجري بحث منهجي في الأدبيات باستخدام قواعد بيانات مثل PubMed و Scopus وWeb of Science حتى أكتوبر 2024، مع التركيز على الدراسات التي تُطبّق الذكاء الاصطناعي على مكافحة العدوى. تُلخّص المراجعة التطبيقات الحالية للذكاء الاصطناعي، بما في ذلك التحليلات التنبؤية للكشف المبكر، وأنظمة المراقبة الآلية، وأساليب الطب الشخصي، وأنظمة دعم القرار، وأدوات إشراك المرضى. تُظهر النتائج أن الذكاء الاصطناعي يتنبأ بفعالية بالعدوى المكتسبة من المستشفيات، ويُحسّن استخدام مضادات الميكروبات، ويُحسّن الامتثال لبروتوكولات الوقاية من العدوى. ومع ذلك، فإن تحديات مثل مشكلات جودة البيانات، والتوافقية، والمخاوف الأخلاقية، والعقبات التنظيمية، والحاجة إلى استثمار كبير، تعيق التبني على نطاق واسع. تُعد معالجة هذه التحديات أمرًا بالغ الأهمية للاستفادة من إمكانات الذكاء الاصطناعي لتعزيز سلامة المرضى وتحسين جودة الرعاية الصحية بشكل عام.

Hospital-acquired infections (HAIs) significantly burden global healthcare systems, exacerbated by antibiotic-resistant bacteria. Traditional infection control measures often lack consistency due to variable human compliance. This comprehensive review aims to explore the role of artificial intelligence (AI) in enhancing infection control and prevention in hospitals. A systematic literature search was conducted using databases such as PubMed, Scopus, and Web of Science up to October 2024, focusing on studies applying AI to infection control. The review synthesizes current applications of AI, including predictive analytics for early detection, automated surveillance systems, personalized medicine approaches, decision support systems, and patient engagement tools. Findings demonstrate that AI effectively predicts HAIs, optimizes antimicrobial use, and improves compliance with infection prevention protocols. However, challenges such as data quality issues, interoperability, ethical concerns, regulatory hurdles, and the need for substantial investment impede widespread adoption. Addressing these challenges is crucial to leverage AI's potential to enhance patient safety and improve overall healthcare quality.

Keywords: artificial intelligence, infection control, cross infection, machine learning, health information technology

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Hospital-acquired infections (HAIs) remain a substantial concern worldwide, contributing to increased morbidity, mortality, and healthcare costs. The World Health Organization (WHO) estimates that hundreds of millions of patients are affected annually, leading to significant health and economic burdens. In the United States alone, approximately 687,000 HAIs were reported in acute care hospitals in 2015, resulting in 72,000 deaths.[1,2] Newer data underscore that both high- and low-resource regions continue to see concerning HAI prevalence, particularly in the context of emerging antibiotic resistance.[3] According to the WHO 2022

Global Progress Report on infection prevention and control, an average of 7–10% of hospitalized patients in developed countries and up to 15–20% in low- and middle-income countries are at risk of acquiring at least one HAI.[4] The financial implications are profound, with HAIs generating an estimated annual burden of $9.8 billion due to extended hospital stays and additional treatments.[3]

Traditional infection control measures such as hand hygiene, use of personal protective equipment, and environmental cleaning are fundamental but often rely heavily on human compliance, which can be inconsistent.[4] Studies have shown that hand hygiene compliance rates among healthcare workers can be as low as 40%4. This inconsistency highlights the need for more reliable and innovative approaches to effectively prevent the spread of infections.

Artificial intelligence (AI) has emerged as a transformative technology with the potential to enhance infection control and prevention practices. AI's wide-ranging applications, from predictive analytics to generative modeling, demonstrate a "dual nature" of empowering safer care while also raising concerns over data misuse.[5,6] The purpose of this review is to explore the current applications of AI in infection control, its advantages, implementation strategies, challenges, and future directions.

Current challenges in infection control. HAIs present significant challenges due to their prevalence and the complexities involved in their prevention. Variations in compliance with infection control protocols, the emergence of antibiotic-resistant bacteria, and resource limitations contribute to these challenges. The global impact of HAIs is underscored by higher prevalence rates in developing countries compared to developed nations. Traditional methods may fall short due to reliance on human factors and the increasing complexity of healthcare environments. Therefore, there is a pressing need for supplementary and more reliable approaches to infection control.

Bridging from these challenges, this review now discusses how AI-driven techniques can systematically address issues such as inconsistent human compliance, early detection of outbreaks, and optimization of antimicrobial therapy.

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Table 1 - Prevalence of hospital-acquired infections (HAIs) worldwide.

Region	Percentage of patients acquiring HAIs	Source
Developed countries	7–10%	WHO (2022)[4]
Developing countries	10–15%	WHO (2022)[4]

WHO: World Health Organization

Advantages of AI in infection control. AI offers several advantages that can address current challenges in infection control. Predictive analytics allow AI to analyze vast datasets to identify high-risk patients and predict the likelihood of infections. For instance, Henry et al[6] demonstrated that an AI model could predict sepsis up to 12 hours in advance, facilitating earlier interventions. Automated surveillance systems enable continuous monitoring of patient data and electronic health records (EHRs), detecting potential infection outbreaks and promptly alerting healthcare personnel. Wiemken and Carrico[7] reported that AI technologies accurately identified HAIs even in complex scenarios. Personalized medicine approaches allow AI to tailor infection control strategies to individual patients based on unique characteristics and medical history, optimizing resource allocation and patient care.[8] Decision support systems provide real-time guidance on best practices, including antimicrobial stewardship and adherence to protocols, reducing the misuse of antibiotics.[9] Enhanced patient safety is achieved by reducing medical errors and enabling early detection of infections, contributing to improved patient outcomes.[10] Improved efficiency results from the automation of routine tasks, allowing healthcare staff to focus on more complex activities, thereby increasing operational efficiency.[11] Furthermore, patient engagement is enhanced through AI tools such as chatbots and mobile applications, empowering patients to take an active role in their care and adherence to prevention measures.[12]

Building on these advantages, the next section underscores practical scenarios where AI is already deployed, followed by considerations for future implementation and personalization at the hospital level.

Applications of AI in infection control. AI's applications span various facets of infection control. Predictive modeling for HAIs allows AI models to forecast HAI likelihood based on patient data and risk factors, enabling proactive interventions.[13] Robotics and automation involve AI-equipped robots performing tasks like disinfection, which reduces human exposure to pathogens. For example, UV-C-emitting

Table 2 - Applications of artificial intelligence (AI) in infection control and their impacts.

AI application	Impact	Study reference
Predictive modeling	Improved prediction of HAIs	Baddal et al[13]
Robotics and automation	Reduced transmission of pathogens	Nerandzic et al[14]
Machine learning	Early detection of multidrug-resistant pathogens	Mora-Jiménez et al[15]
Natural language processing	Identification of HAI risk factors	Huang et al[16]
Computer vision	Enhanced hand hygiene compliance	Yang et al[17]
Antimicrobial stewardship analytics	Optimized antimicrobial use	Schuetz et al[9]
AI-assisted HAI surveillance	Accurate identification of HAIs	Wiemken & Carrico[7]

HAIs: hospital-acquired infections, AI: artificial intelligence

devices have demonstrated over 90% reduction in Clostridioides difficile spores.[14] Machine learning for pattern recognition enables AI to identify patterns in infection spread, aiding in targeted interventions.[15] Natural language processing (NLP) analyzes clinical notes to uncover infection-related information, enhancing detection accuracy.[16] Computer vision allows AI systems to monitor hand hygiene practices through video surveillance, improving compliance.[17] Antimicrobial stewardship is assisted by AI in optimizing antimicrobial use by predicting resistance patterns.[18] Additionally, AI algorithms detect infection outbreaks earlier than traditional methods, as seen with platforms like BlueDot during the COVID-19 pandemic.[17]

As illustrated above, AI can significantly reinforce daily infection control operations. However, harnessing AI efficiently requires careful system integration, workforce training, and a supportive organizational culture topics explored in the next section.

Implementation of AI in infection control. Successful AI implementation requires a multidisciplinary approach. It begins with data collection and integration, involving high-quality data aggregation from EHRs, laboratory systems, and monitoring devices. Consistency and standardization are crucial in this process to ensure data reliability and usability.[13] Following data collection, advanced machine learning algorithms are employed to analyze the data, identifying significant patterns and infection predictors. Rigorous model development and validation are essential to ensure accuracy and reliability, which is critical for clinical applications. Seamless integration of AI tools into clinical workflows is also paramount, as highlighted by new insights on "generative" AI approaches.[5] For instance, generative models can process complex, multimodal data. Combining surveillance videos, laboratory findings, and patient comorbidities, yet must be carefully constrained by ethical guidelines.[5,6] By embedding these solutions into practitioners' normal routines (such as routine clinical decision support), operational efficiency and acceptance can be maximized.

Performance monitoring and evaluation are necessary through continuous monitoring and adjustments to improve effectiveness over time. Training and education for healthcare staff are also vital to ensure the effective use of AI tools and to foster acceptance among users. Finally, ethical and regulatory compliance necessitates adherence to data privacy regulations and ethical guidelines, underscoring the importance of responsible AI deployment in healthcare settings.[17]

Moreover, adopting certain advanced frameworks from other medical fields, such as the synergy of AI and 3D-printing (Elbadawi et al[6]), illustrates how innovation can expand to personalized care devices or targeted infection prevention products, bridging AI's potential from theoretical analytics to tangible hospital interventions.

Challenges and limitations of AI in infection control. Several challenges hinder the integration of AI in infection control. Data quality and availability issues arise from fragmented or incomplete data, which can affect AI performance and outcomes.[13,19] thereby necessitating efforts toward standardization. Interoperability issues present technical challenges in integrating AI systems with existing healthcare infrastructures, which can be both costly and complex.[20] Ethical and safety concerns, including data privacy, bias, and the potential misuse of medical data, make patient confidentiality a critical consideration.[17] Regulatory and ethical considerations require the development of clear frameworks to guide AI development and use in healthcare, ensuring compliance with laws and ethical standards.[21] Bias and fairness are significant concerns because AI algorithms may inherit biases from training data, leading to unequal treatment among patients; thus, vigilance is required to ensure fairness and equity.[22] Building acceptance and trust among healthcare providers and patients is essential, as misunderstandings

Figure 1 - Artificial intelligence implementation framework for infection control.

about AI capabilities may hinder adoption and effective utilization.[23] Liability and accountability issues involve clarifying responsibility when AI contributes to clinical decisions, which is necessary for legal and ethical reasons.[24] Finally, resource constraints affect significant investment requirements for technology and expertise, posing barriers for under-resourced facilities that may lack the financial means to adopt AI solutions.[25]

These hurdles mirror those seen in broader AI applications, as described by Albahri et al,[5] who highlight that as AI's power grows, so do the risks of malicious usage. A balanced approach—maximizing the benefits for infection control while minimizing AI's downsides—remains central to its responsible deployment.

In conclusion, AI holds significant promise in revolutionizing infection control and prevention within hospitals. By leveraging predictive analytics, automated surveillance, personalized interventions, and decision support systems, AI can enhance patient safety and improve the overall quality of healthcare. Addressing challenges related to data quality, interoperability, ethical considerations, and stakeholder acceptance is essential for effective implementation and widespread adoption.

Moreover, future AI tools, ranging from advanced machine learning models to generative algorithms, must be backed by robust ethical guidelines, regulatory policies, and interdisciplinary collaboration.[5,6] As AI technologies continue to evolve, their integration into infection control practices can lead to significant advancements in reducing HAIs and improving patient outcomes.

Recommendations. To harness AI effectively in infection control, several recommendations are proposed. Enhancing data infrastructure is paramount, involving improvements in data collection, integration, and standardization to enable effective AI applications.[13] Developing regulatory frameworks requires collaboration with policymakers to establish guidelines that ensure the safe and ethical use of AI in healthcare settings.[17] Promoting education and training by providing comprehensive education on AI technologies can facilitate acceptance and utilization among healthcare professionals. Addressing ethical and safety concerns involves implementing measures to prevent biases, protect data privacy, and ensure transparency in AI applications.[17] Encouraging multidisciplinary collaboration fosters partnerships among technologists, clinicians, and ethicists to develop clinically relevant and ethically sound AI solutions. Securing funding and resources is also crucial, necessitating investment in AI

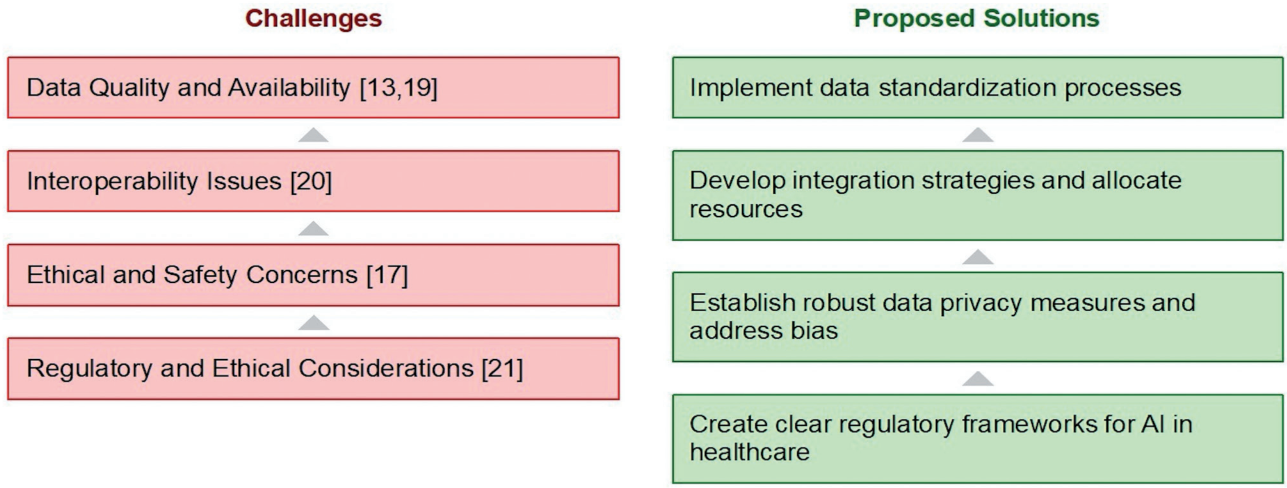

Figure 2 - Challenges and solutions in artificial intelligence integration for infection control.

technologies, particularly in resource-limited settings where financial constraints may hinder adoption.

Future directions. The future of AI in infection control includes integration with emerging technologies, suggesting that combining AI with the Internet of Things (IoT), advanced EHRs, and blockchain could provide comprehensive infection control solutions.[13] Advancements in AI algorithms require the development of sophisticated methods capable of handling complex data and providing accurate predictions. Expanding the application of AI beyond hospitals involves applying AI-driven strategies to community health settings and public health emergencies, thereby broadening the impact of AI in healthcare. Personalized infection control may utilize genomics and AI to create individualized prevention plans based on genetic susceptibility, enhancing the effectiveness of interventions. Furthermore, global collaboration, including sharing data and AI models internationally, can enhance global infection control efforts by fostering collective learning and resource sharing.[17]

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