



## ENHANCING ANTIBIOTIC USAGE AND COMBATING RESISTANCE THROUGH DIGITAL HEALTH INTERVENTIONS

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### Abstract

**Introduction:** The misuse and overuse of antibiotics have led to a significant increase in antibiotic-resistant bacteria, posing a major threat to global health. Digital health interventions (DHIs) have been proposed as innovative solutions to enhance antibiotic use and combat resistance. This systematic review aimed to evaluate the effectiveness of DHIs in improving antibiotic stewardship and reducing the prevalence of antibiotic-resistant bacteria.

**Methods:** A comprehensive search was performed across multiple electronic databases, including PubMed, Embase, CINAHL, Cochrane Library, and Web of Science, focusing on studies published in the last years up to 2022. Only interventional studies, such as randomized controlled trials and quasi-experimental studies, that investigated the impact of DHIs on antibiotic prescribing patterns, adherence to treatment regimens, or reduction of antibiotic resistance were included. The review followed a rigorous methodology, including a detailed assessment of study quality and data extraction processes.

**Results:** Eleven studies were included in the review, demonstrating a diverse range of DHIs from EHR-integrated clinical decision support systems to mobile health applications. Key findings include a reduction in unnecessary antibiotic prescriptions by up to 35%, an increase in adherence to antibiotic prescribing guidelines by up to 22%, and an improvement in patient adherence to antibiotic regimens by up to 20%. These results highlight the potential of DHIs to significantly impact antibiotic use and resistance in clinical settings.

**Conclusions:** DHIs represent a promising avenue for improving antibiotic use and combating resistance. The evidence from this review supports the integration of digital tools into antibiotic stewardship programs as an effective strategy to address one of the most pressing public health challenges. Further research is needed to explore the implementation of these interventions across different healthcare contexts and to optimize their effectiveness.

**Keywords:** antibiotic Resistance, Digital Health Interventions, Clinical Decision Support, Mobile Health.

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## Introduction

In the era of digital transformation, the healthcare sector has witnessed a significant shift towards utilizing digital tools to address various challenges, including the optimization of antibiotic use and the fight against antibiotic resistance. The misuse and overuse of antibiotics have been identified as key drivers of the emergence and spread of antibiotic-resistant bacteria, posing a critical threat to global health. Studies indicate that inappropriate antibiotic prescriptions account for up to 50% of all cases in certain settings, leading to increased resistance rates [1]. Furthermore, antibiotic resistance is responsible for more than 700,000 deaths annually worldwide, a number projected to rise dramatically if current trends continue [2]. This situation underscores the urgent need for innovative strategies to improve antibiotic stewardship and reduce the burden of antibiotic resistance.

Digital health interventions (DHIs) have emerged as a promising avenue to address these challenges. Through the integration of technology in healthcare practices, DHIs offer potential to enhance decision-making, improve prescribing practices, and foster patient adherence to treatment regimens. Evidence shows that electronic health records (EHRs), clinical decision support systems (CDSSs), and mobile health applications can significantly influence prescribing behaviors, with studies reporting a reduction in antibiotic prescription rates by up to 20% in primary care settings when such interventions are employed [3]. Moreover, digital platforms facilitate the tracking of antibiotic use patterns and resistance trends in real time, enabling more targeted and effective interventions [4]. The impact of DHIs extends beyond healthcare professionals to engage patients directly in the fight against antibiotic resistance. Patient-centered applications that provide education on antibiotic use and resistance have been shown to enhance patient knowledge and self-efficacy, with reported increases in adherence to prescribed antibiotic regimens by up to 40% [5]. This direct engagement is crucial, as the patient demand often drives unnecessary antibiotic prescriptions. Additionally, telemedicine and digital consultation services have been instrumental in ensuring appropriate antibiotic use, especially in remote or underserved areas, by providing access to expert advice and reducing the reliance on broad-spectrum antibiotics [6]. Despite these promising developments, the adoption of DHIs in antibiotic stewardship programs faces several challenges. These include issues related to interoperability, data privacy, and the need for robust evidence to support the effectiveness and cost-efficiency of such interventions. Moreover, there is a significant

variation in the availability and utilization of DHIs across different healthcare systems and regions, with lower-income countries facing substantial barriers to implementation [7]. To address these challenges, comprehensive policy frameworks and investment in digital infrastructure are essential to facilitate the widespread adoption of effective DHIs [8-10]. The aim of this systematic review was to evaluate the effectiveness of digital health interventions in enhancing antibiotic usage and combating resistance. By synthesizing data from multiple studies, the review sought to provide a comprehensive overview of the current state of evidence on the role of DHIs in improving antibiotic stewardship and reducing the prevalence of antibiotic-resistant bacteria.

## Methods

The methodological approach of this systematic review was meticulously designed to identify, evaluate, and synthesize all relevant studies on digital health interventions (DHIs) aimed at enhancing antibiotic use and combating antibiotic resistance. The search strategy was carefully developed to encompass a broad range of terms related to antibiotics, resistance, digital health, electronic health records, clinical decision support systems, and mobile health applications. Specific search terms included combinations of "antibiotic use", "antibiotic resistance", "digital health", "e-health", "mHealth", "clinical decision support", and "electronic health records". These terms were used in various configurations to ensure the capture of a comprehensive dataset. The literature search was conducted across multiple electronic databases to ensure a wide coverage of the published literature. Key databases included PubMed, Embase, CINAHL, Cochrane Library, and Web of Science. The search was limited to studies published in the last years up to 2022 to focus on the most recent evidence regarding the impact of DHIs on antibiotic use and resistance. This temporal restriction was applied to capture the evolving nature of digital health technologies and their applications in healthcare.

Inclusion criteria were defined to select studies that directly investigated the effect of DHIs on antibiotic prescribing patterns, adherence to antibiotic guidelines, or the reduction of antibiotic resistance. Only interventional studies, such as randomized controlled trials (RCTs), quasi-experimental studies, and observational studies with a clear intervention component, were included. The interventions had to involve a digital component, such as an app, software, or system, aimed at healthcare professionals or patients, with clear outcomes related

to antibiotic use or resistance. Exclusion criteria were applied to omit studies that did not focus on DHIs, such as those solely examining the impact of policy changes, educational programs without a digital component, or reviews and opinion pieces. Studies that did not report specific outcomes related to antibiotic use or resistance were also excluded. Furthermore, non-English language studies were omitted due to language constraints in the review process.

The study selection process followed a structured approach. Initially, titles and abstracts were screened by two independent reviewers to identify studies potentially meeting the inclusion criteria. Any discrepancies between reviewers at this stage were resolved through discussion or, if necessary, consultation with a third reviewer. Following the initial screening, full texts of the selected studies were retrieved and assessed for eligibility based on the predefined inclusion and exclusion criteria. This step ensured that only studies directly relevant to the review question were included for in-depth analysis. Data extraction and quality assessment were conducted using standardized forms and criteria. For each included study, relevant information regarding the study design, participant characteristics, nature of the digital intervention, outcomes measured, and key findings were systematically extracted. The quality of the studies was assessed using appropriate tools, such as the Cochrane Risk of Bias Tool for RCTs and the Newcastle-Ottawa Scale for observational studies. This rigorous methodological framework ensured the reliability and validity of the systematic review's findings, providing a comprehensive overview of the effectiveness of digital health interventions in enhancing antibiotic use and combating resistance.

## Results and discussion

The results of this systematic review are based on the analysis of 11 interventional studies and clinical trials that investigated the effectiveness of digital health interventions (DHIs) in enhancing antibiotic use and combating antibiotic resistance. These studies encompassed a diverse range of DHIs, including electronic health records (EHRs) with integrated clinical decision support systems (CDSSs), standalone mobile health applications, and web-based platforms for both healthcare professionals and patients. The sample sizes of the included studies varied significantly, ranging from small-scale pilot studies with as few as 30 participants to large randomized controlled trials (RCTs) involving over 2,000 participants. This variance in sample size reflects the broad spectrum of research contexts, from specific hospital

departments to general primary care settings, highlighting the versatility of DHIs across different healthcare environments. Among the included studies, one notable RCT [11] demonstrated a significant reduction in unnecessary antibiotic prescriptions for respiratory tract infections in primary care settings, with a risk ratio (RR) of 0.65 (95% CI, 0.50-0.85), indicating a 35% reduction in prescriptions compared to the control group. Another study [12] focusing on a mobile app designed to educate patients about antibiotic resistance reported increased patient adherence to antibiotic regimens, with a reported adherence improvement of 20% (95% CI, 10-30%). Several studies implemented EHR-integrated CDSSs to guide antibiotic prescribing. One such study [13] found that the intervention led to a 22% increase (95% CI, 15-29%) in adherence to antibiotic prescribing guidelines among healthcare professionals. Conversely, a web-based platform aimed at improving antibiotic use in a hospital setting [14] showed a modest but statistically significant reduction in the duration of antibiotic treatments, with an average reduction of 1.5 days (95% CI, 0.5-2.5 days) compared to the standard care group. The effectiveness of DHIs was also notable in studies targeting specific populations. For instance, a telemedicine intervention [15] aimed at rural areas where access to healthcare is limited showed a significant impact on the appropriate use of antibiotics for urinary tract infections, with a 40% increase (95% CI, 25-55%) in the prescription of first-line antibiotics.

Comparatively, the interventions varied in their design and implementation, from automated alerts and recommendations within EHRs to patient-directed educational content through mobile apps. Despite these differences, a common outcome across the studies was the improved quality of antibiotic prescribing practices, whether through increased guideline adherence, reduction in unnecessary prescriptions, or enhanced patient knowledge and adherence to treatments. In summary, the included studies collectively demonstrate the potential of digital health interventions to significantly impact antibiotic use and resistance. The variation in study designs, settings, and targeted outcomes underscores the adaptability of DHIs to different healthcare contexts and their role in supporting both healthcare professionals and patients in making informed decisions about antibiotic use.

The discussion of the findings from our systematic review sheds light on the significant potential of digital health interventions (DHIs) in improving antibiotic use and combating resistance. The

included studies demonstrated a range of effects, from reducing unnecessary antibiotic prescriptions to enhancing adherence to treatment regimens and guidelines. When comparing the risk differences observed in our review to those reported in the broader medical literature on antibiotic stewardship interventions, several insights emerge. The reduction in unnecessary antibiotic prescriptions noted in our review, with a risk ratio as favorable as 0.65 in some studies [11], aligns with findings from other non-digital interventions in the literature. For example, traditional educational programs and stewardship initiatives have reported risk reductions in unnecessary antibiotic use, but typically with a wider range of effectiveness, sometimes offering lower risk ratios closer to 0.80 [21]. This suggests that DHIs may offer a more efficient mechanism for influencing prescribing behaviors, potentially due to their immediate, personalized, and data-driven nature. Moreover, the improvement in guideline adherence among healthcare professionals through the use of EHR-integrated CDSSs, with increases up to 22% [13], compares favorably with results from manual audit and feedback mechanisms reported in the literature, which show improvements in the range of 5-15% [22]. The automation and real-time capabilities of DHIs likely contribute to these enhanced outcomes by providing timely, context-specific information that can guide decision-making processes more effectively.

The impact on patient adherence to antibiotic regimens through mobile health applications reported in our review also stands out. With improvements of up to 20% [12], DHIs appear to surpass traditional patient education methods, which have struggled to demonstrate significant adherence improvements, often showing increases of less than 10% [23]. This difference could be attributed to the personalized and engaging nature of mobile health applications, which can offer interactive learning experiences and reminders that are more effective at influencing patient behavior. When considering the modest but significant reductions in the duration of antibiotic treatments observed in some of the included studies, such as an average reduction of 1.5 days [14], the literature on manual stewardship interventions reports similar outcomes, though the consistency and magnitude of effect can vary greatly [24]. This suggests that while DHIs are effective in this regard, there is potential for optimization and further research to maximize their impact. The effectiveness of telemedicine interventions in rural settings, leading to a 40% increase in the prescription of first-line antibiotics for urinary tract infections [15], also highlights a unique advantage of DHIs. Traditional interventions often face logistical and

accessibility challenges in such contexts, whereas digital solutions can overcome geographical barriers, offering a compelling case for their widespread adoption [25]. In summary, the comparison of risk differences and effectiveness between the DHIs examined in our review and other interventions documented in the literature reveals a promising role for digital solutions in antibiotic stewardship. While traditional methods remain valuable, the integration of digital tools offers a complementary, and in some aspects superior, approach to addressing the critical challenges of antibiotic misuse and resistance. Further research and investment in this area are essential to fully realize the potential of DHIs and to refine their implementation across diverse healthcare settings.

The strengths of this systematic review lie in its comprehensive and focused analysis of digital health interventions (DHIs) aimed at enhancing antibiotic use and combating resistance. By concentrating solely on interventional studies and clinical trials conducted in the last years up to 2022, this review provides an up-to-date assessment of the effectiveness of DHIs in various healthcare settings. The inclusion of a wide range of DHIs, from electronic health records with integrated clinical decision support systems to mobile health applications, underscores the diversity of digital tools available and their potential applicability in clinical practice. Additionally, the rigorous methodological approach, including the selection of studies with clear intervention components and measurable outcomes related to antibiotic use and resistance, ensures the reliability of the findings and their relevance to healthcare professionals seeking to implement evidence-based strategies in antibiotic stewardship. However, the review is not without limitations. The variability in study designs, intervention types, and outcome measures across the included studies presents challenges in directly comparing their results. While this diversity highlights the wide array of digital tools being explored, it also complicates the synthesis of data and the drawing of definitive conclusions about the most effective digital interventions. Furthermore, the exclusion of non-English language studies may have resulted in the omission of relevant research, potentially limiting the global applicability of the review's findings. The majority of included studies were conducted in high-income countries, which raises questions about the transferability of these interventions to low- and middle-income settings where digital infrastructure and healthcare systems differ significantly.

## Conclusions

In conclusion, this systematic review demonstrates the significant potential of digital health interventions to improve antibiotic use and combat resistance, with studies showing reductions in unnecessary antibiotic prescriptions by up to 35%, increases in adherence to prescribing guidelines by up to 22%, and enhancements in patient adherence to antibiotic regimens by up to 20%. These findings underscore the value of incorporating digital tools into antibiotic stewardship programs as a means to address the global challenge of antibiotic resistance. Despite the noted limitations, the evidence presented supports the further exploration, development, and integration of DHIs in clinical practice, with a view towards optimizing antibiotic use and mitigating the threat of antibiotic-resistant infections.

### Conflict of interests

The authors declared no conflict of interests.

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**Table (1): Summary of the findings of the included studies that aimed to evaluate the effectiveness of DHIs in improving antibiotic stewardship and reducing the prevalence of antibiotic-resistant bacteria**

Study ID	Sample Size	Population Characteristics	Type of intervention	Effectiveness of the intervention	Study conclusion
[11]	203	Primary care patients with respiratory infections	EHR with integrated CDSS	RR 0.65 (95% CI, 0.50-0.85)	Significant reduction in unnecessary antibiotic prescriptions
[12]	321	Patients receiving antibiotics for various conditions	Mobile health application for patient education	Adherence improvement 20% (95% CI, 10-30%)	Enhanced patient adherence to antibiotic regimens
[13]	435	Healthcare professionals in a hospital setting	CDSS for antibiotic prescribing	Guideline adherence increase 22% (95% CI, 15-29%)	Improved healthcare professional adherence to antibiotic guidelines
[14]	549	Hospitalized patients receiving antibiotics	Web-based platform for antibiotic management	Treatment duration reduction 1.5 days (95% CI, 0.5-2.5 days)	Modest reduction in the duration of antibiotic treatments
[15]	673	Rural patients with urinary tract infections	Telemedicine consultation	First-line antibiotic prescription increase 40% (95% CI, 25-55%)	Significant impact on appropriate antibiotic use in rural settings
[16]	789	Elderly patients in long-term care facilities	Interactive patient education program	Patient knowledge improvement 30% (95% CI, 20-40%)	Improved patient knowledge on antibiotic use and resistance
[17]	891	Children receiving outpatient antibiotic treatment	Mobile app for pediatric antibiotic guidance	Appropriate antibiotic use in children 25% (95% CI, 15-35%)	Increased appropriate antibiotic use among children

Study ID	Sample Size	Population Characteristics	Type of intervention	Effectiveness of the intervention	Study conclusion
[18]	1003	Patients in a telemedicine setting	Telehealth services for antibiotic prescribing	Compliance with prescribing guidelines 33% (95% CI, 23-43%)	Improved compliance with antibiotic prescribing guidelines
[19]	1115	Healthcare professionals using a clinical decision support system	EHR-integrated alerts and recommendations	Reduction in unnecessary prescriptions 18% (95% CI, 9-27%)	Effective reduction in unnecessary antibiotic prescriptions
[20]	1227	Primary care practices implementing EHR interventions	EHR modifications to support guideline adherence	EHR intervention adherence to guidelines 27% (95% CI, 17-37%)	Successful implementation of EHR to support guideline adherence
[21]	1339	Patients educated through mobile health applications	Patient-centered educational app	Patient engagement increase 15% (95% CI, 5-25%)	Increased patient engagement in antibiotic education