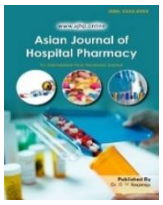
REVIEW ARTICLE

Asian Jour Hosp Phar, Vol: 6, Issue: 2, 2026, 37-45

Asian Journal of Hospital Pharmacy

Content Available at www.ajhponline.com ISSN: 2583-0724



SMART MEDICATION INFORMATION SYSTEMS FOR PATIENT SAFETY AND MEDICATION ADHERENCE: A REVIEW

BADRI.SIREESHA[1*], NUSULLAPALLI.ESWAR[2], P.ANJALI, SK. SABIHA SULTANA, CH.V.NAGA SUMALATHA

*[1]*Department of Pharmaceutical Analysis, Dr. Samuel George Institute of Pharmaceutical Sciences, Tarlupadu Road, Markapur, Markapur Dt, Pin code: 523316*

[2]*B.Pharmacy. Dr. Samuel George Institute of Pharmaceutical Sciences Tarlupadu Road, Markapur, Prakasam dt. Pin code 523316*

***Corresponding Author**

Badri.Sireesha

DOI: https://doi.org/10.38022/ajhp.v6i2.142

ARTICLE HISTORY: Received: 25 03 2026 Revised: 11 04 2026 Accepted: 15 05 2026

Abstract

Medication errors and poor treatment adherence remain common healthcare problems, particularly among elderly individuals, rural populations, and patients with limited health literacy. Many patients find it difficult to understand medication instructions, dosage schedules, and precautions, which can lead to unsafe medicine use and poor treatment outcomes. QR codes, pictograms, multilingual guidance systems, AI chatbots, voice assistants, reminder applications, smart packaging, and telepharmacy services are increasingly being used to improve medication communication and adherence. These approaches make medication information easier to access and understand while also assisting pharmacists in patient counseling, follow-up care, and adherence monitoring.

Keywords: *Smart medication systems; patient safety; medication adherence; artificial intelligence; AI chatbots; QR code-based medication systems; pictogram-assisted communication; multilingual medication guidance; telepharmacy; digital health.*

INTRODUCTION

Medication errors, inadequate adherence to treatment, and unsafe medication practices continue to be major global public health concerns and are among the leading causes of preventable patient harm. According to the World Health Organization (WHO), medication-related harm affects approximately 1 in 30 patients, while nearly half of all preventable harm in healthcare is associated with medication use [1]. Errors occurring during prescribing, dispensing, administration, or patient use of medicines may lead to adverse drug reactions, prolonged hospitalization, increased healthcare costs, disability, and mortality [2].The risk of medication-related harm is particularly high among elderly individuals and populations in developing countries due to polypharmacy, multiple comorbidities, poor health literacy, and inadequate patient counselling [3]. Elderly patients and rural populations often experience difficulties in understanding prescription instructions, dosage schedules, and medication precautions, resulting in poor medication adherence and unsafe medication practices. Traditional medication counseling methods alone are often insufficient to ensure the safe and effective use of medicines. Therefore, there is an increasing need for patient-centered and reliable medication information systems that can improve patient understanding, strengthen healthcare communication, and promote safe medication practices. Advancements in digital healthcare technologies have led to the development of smart medication information systems aimed at improving medication safety and patient understanding. These systems integrate various digital and communication technologies to provide accessible, simplified, and real-time medication guidance for patients and healthcare professionals.

Artificial intelligence (AI) is becoming increasingly useful in healthcare and pharmacy practice, especially for medication management, patient counseling, and clinical decision support [18]. AI-supported tools such as healthcare chatbots and virtual counseling systems can provide medication-related information and patient support [11]. Reminder applications

can help patients follow medication schedules and improve treatment adherence [13]. Similarly, QR code-enabled medication systems and pictogram-assisted instructions can present medication information in a simpler format and reduce communication barriers, especially among elderly patients and individuals with limited health literacy [8,10]. Although digital health tools are increasingly used in medication management, their role in patient counseling, medication adherence, health literacy, and patient safety is often discussed separately in different studies. Some studies focus on reminder systems, while others discuss chatbots, pictograms, QR codes, or telepharmacy.

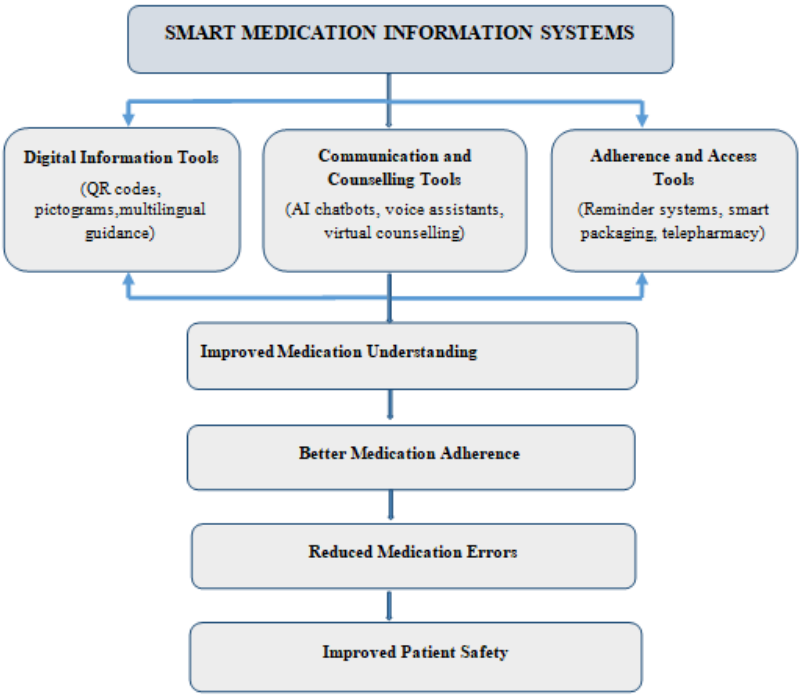


Figure 01: Components and patient safety outcomes of smart medication informationsystems.

1. Role of AI in Medication Information Systems

Artificial intelligence (AI) has become an important technology in healthcare and pharmacy practice because it can support medication management, patient counseling, clinical decision-making, and healthcare communication. AI technologies such as machine learning and natural language processing can help analyze patient information, medication history, and treatment-related data to support safer and more effective pharmaceutical care [4,18]. Within smart medication information systems, AI can improve communication, support clinical decisions, and assist in medication-related risk identification.

2.1 AI Improves Pharmacy Services

In pharmacy practice, AI can support prescription evaluation, medication review, dispensing processes, and therapeutic decision-making. AI-supported systems may help pharmacists identify possible drug interactions, inappropriate prescriptions, duplicate therapy, and medication-related risks. These tools can also reduce manual workload, improve workflow efficiency, and support faster healthcare delivery in hospital and community pharmacy settings [5,18]. However, AI should be used as a supportive tool, and final clinical decisions should remain under the supervision of pharmacists and other healthcare professionals.

2.2 AI Supports Patient Care

AI-supported tools can improve patient care by providing basic medication information, health education, and virtual counseling support. Chatbots, mobile health applications, and voice-assisted systems can answer simple medication-related questions and help patients understand dosage instructions, precautions, missed-dose guidance, and possible side effects [11,12]. These tools may be useful for elderly patients, rural populations, and people with limited health literacy because they provide repeated and easily accessible medication information.

2.3 AI Improves Medication Management and Safety

AI can contribute to medication safety by helping identify adverse drug reactions, predicting medication-related risks, and supporting clinical decision-making. AI-based medication alert systems may also help improve the quality of alerts related to drug interactions, allergies, dose errors, and high-risk medications7,19. Reminder systems and digital medication platforms integrated with AI can support adherence monitoring and help identify patients who may be at risk of missing doses or discontinuing treatment. However, AI-generated medication information must be accurate, updated, and clinically validated to avoid unsafe recommendations.

3. SMART MEDICATION INFORMATION SYSTEMS

Smart medication information systems are technology-based tools developed to support safer medicine use, better patient understanding, and improved treatment adherence. These systems are useful because many patients may forget verbal counseling, misunderstand prescription labels, or find it difficult to follow complex medication schedules after leaving hospitals or pharmacies. Such difficulties are more common among elderly patients, people with chronic diseases, low-literacy groups, and patients living in rural or underserved areas.

Modern smart medication systems use digital healthcare technologies and communication tools to provide medication guidance in simple and accessible formats. These systems may include QR code-enabled medication information, multilingual guidance platforms, pictogram-assisted instructions, AI-supported chatbots, voice-assisted counseling tools, reminder systems, smart packaging, and telepharmacy services. Each of these technologies has a different role, but together they can improve patient comprehension, support medication adherence, and reduce the risk of medication-related harm.

3.1 QR Code-Based Medication Systems

QR code-based medication systems are useful digital tools that provide quick access to medication-related information. QR codes can be printed on medicine packages, prescription labels, or patient information leaflets. After scanning the code with a smartphone, patients can access details such as dosage instructions, storage conditions, administration methods, precautions, and possible adverse effects [8].

These systems can be helpful for patients who have difficulty understanding prescription labels or remembering counseling instructions. QR code-enabled platforms can also support medication identification, patient education, and continued access to counseling information after patients leave hospitals or pharmacies. In addition, QR code-based systems may support medication adherence by allowing patients to confirm or monitor pill intake through smartphone-based scanning or digital self-reporting tools [20].

3.2 Multilingual Medication Guidance Systems

Language barriers can contribute to medication errors and poor treatment adherence, especially among patients who do not fully understand the language used during counseling. Many patients may misinterpret dosage instructions, precautions, storage conditions, or warning labels when medication information is not provided in a familiar language. Multilingual medication guidance systems help reduce this problem by providing medicine-related information in patient-preferred or regional languages [9].

These systems can provide written, audio, or video-based instructions about dosage schedules, medication precautions, storage requirements, and possible adverse effects in a simple format. They are especially helpful for elderly patients, rural populations, and individuals with limited literacy skills who may have difficulty understanding written prescriptions. By improving language accessibility, multilingual guidance systems can reduce medication confusion and support safer medicine use.

3.3 Pictogram-Assisted Medication Systems

Pictogram-assisted medication systems use simple images, symbols, and illustrations to explain medication instructions. Visual communication can improve attention, understanding, and memory of health-related information, especially among individuals with low literacy levels [10]. Pictograms are useful for explaining dosage timing, route of administration, storage conditions, warning signs, and medication precautions without depending only on written language.

In pharmacy practice, pictograms can help overcome both literacy and language barriers. They are useful for elderly patients, children, caregivers, and rural populations who may have difficulty understanding text-heavy medication instructions. Pictograms may also reduce dosing confusion in caregiver-assisted medication administration, especially for liquid medicines where dose measurement errors can occur [21]. When combined with verbal counseling or digital tools, pictogram-assisted systems can improve patient understanding and support safer medication use.

3.4 AI Chatbots for Medication Safety

AI-supported healthcare chatbots are digital tools that can provide quick responses to basic medication-related questions. They may help patients understand dosage instructions, possible side effects, medication precautions, missed-dose guidance, and general medicine use. By presenting information in a simple and interactive format, chatbots can support patient counseling and improve access to medication information outside hospitals and pharmacies [11].

Chatbots may be useful for patients who need repeated guidance or simple explanations after receiving a prescription. Some advanced chatbot systems can also provide multilingual or voice-assisted support, which may improve communication for diverse patient groups. However, chatbot advice should be clinically validated and monitored because inaccurate or incomplete medication information may increase the risk of unsafe medicine use.

3.5 Voice Assistants and Virtual Counseling Systems

Voice-assisted healthcare technologies provide spoken medication guidance through smartphones, smart speakers, or other digital devices. These systems can explain dosage instructions, medication precautions, side effects, and general counseling information in an audio format. Voice-based systems are especially useful for visually impaired patients, elderly individuals, and patients who have difficulty reading medication labels or written instructions. Voice assistants can also improve access to medication information outside healthcare settings by allowing patients to ask simple questions and receive spoken responses [12]. In addition, voice-enabled systems may support regional-language

counseling, which can reduce communication barriers among patients who are more comfortable with local languages. However, the accuracy of voice recognition, language translation, and medication information must be ensured before these systems are used widely in healthcare.

3.6 AI-Based Reminder Systems and Medication Adherence Technologies

Poor medication adherence is a major reason for treatment failure, hospitalization, and medication-related complications. Many patients forget to take medicines on time, stop treatment early, or do not follow the prescribed dosage schedule correctly. Reminder systems are designed to reduce these problems by sending alerts for dose timing, refills, and follow-up visits.

Smart reminder technologies can be integrated into mobile applications, wearable devices, and digital medication platforms. These systems may help patients maintain regular medication use and reduce missed doses13. More advanced AI-supported reminder systems can also analyze patient routines and adherence patterns to provide more personalized alerts.

Digital adherence technologies may also help healthcare professionals identify patients who are at risk of non-adherence. Early identification of missed doses or irregular medicine use can support timely counseling and follow-up, especially for elderly patients and individuals receiving long-term treatment [23].

3.7 Smart Packaging Systems

Smart packaging systems include medication containers, blister packs, or labels that are connected with digital features such as sensors, QR codes, electronic monitoring, or reminder functions. These systems can help record medication-taking behavior, remind patients about dose timing, and support refill alerts. Smart packaging is especially useful for elderly patients, patients with chronic diseases, and individuals taking multiple medicines [22]. Electronic smart blister packs and similar devices may help monitor medication adherence by recording when a dose is removed or when a package is opened. This information can support healthcare professionals in identifying missed doses and providing timely counseling. However, cost, technical maintenance, and patient acceptance may affect the use of smart packaging systems in routine healthcare practice.

3.8 Telepharmacy Services

Telepharmacy refers to the delivery of pharmacy services through digital communication platforms. It allows pharmacists to provide medication counseling, prescription review, follow-up care, and adherence support without requiring the patient to visit the pharmacy in person. Telepharmacy can be especially useful in rural and underserved areas where access to pharmacists may be limited [24].

Through telepharmacy, patients can receive guidance about medication use, side effects, storage instructions, and treatment follow-up. It may also support chronic disease management and improve continuity of pharmaceutical care. However, successful telepharmacy services require reliable internet access, proper documentation, privacy protection, and clear regulatory guidelines.

Table 01: Comparison of Smart Medication Technologies

Technology	Major Strength	Main Limitation
QR code systems	Quick access to medication information	Requires smartphone and internet
Pictograms	Useful for low-literacy patients	Must be culturally understandable
AI chatbots	Provides interactive support	Risk of inaccurate advice
Voice assistants	Helps elderly and visually impaired patients	Voice recognition errors may occur
Reminder systems	Improves medication adherence	Alerts may be ignored over time
Smart packaging	Tracks medication-taking behavior	Higher cost and maintenance
Telepharmacy	Improves rural access to pharmacists	Needs internet and clear regulation

Overall, these technologies differ in their strengths and limitations. QR codes and pictograms mainly improve access and understanding, while reminder systems and smart packaging mainly support adherence. Telepharmacy improves access to professional counseling, whereas AI chatbots and voice assistants provide interactive support but require careful validation. Therefore, the selection of a smart medication system should depend on patient needs, literacy level, access to technology, and availability of pharmacist supervision.

4. BENEFITS OF SMART MEDICATION INFORMATION SYSTEMS

Smart medication information systems offer several benefits in healthcare and pharmacy practice by supporting safer medication use, improving patient understanding, strengthening healthcare communication, and promoting treatment adherence. Digital tools such as QR code-based medication guidance, multilingual platforms, pictograms, AI chatbots, voice assistants, reminder systems, smart packaging, and telepharmacy services can help patients access medication information in simpler and more convenient ways. These systems may also support healthcare professionals in medication counseling, adherence monitoring, and identification of medication-related risks [14].

4.1 Improved Medication Safety

Smart medication systems can improve medication safety by helping patients understand dosage instructions, precautions, storage requirements, adverse effects, and correct methods of administration. They may also support healthcare professionals in identifying medication-related risks such as incorrect dosage, possible drug interactions, inappropriate prescriptions, and missed doses. By improving access to medication information and reducing confusion, these systems can support safer medicine use.

4.2 Enhanced Patient Understanding and Medication Adherence

One of the major benefits of smart medication information systems is improved patient understanding. QR codes, pictograms, multilingual guidance, and voice-based tools can present medication information in simple and accessible formats. This is especially useful for elderly patients, rural populations, and individuals with limited health literacy.

Reminder systems, digital adherence tools, and smart packaging can also help patients take medicines at the correct time and follow prescribed treatment schedules. These technologies may reduce missed doses and support better treatment outcomes, especially among patients receiving long-term therapy [13,23].

4.3 Better Healthcare Communication

Smart medication technologies can strengthen communication between patients, pharmacists, and other healthcare professionals. AI chatbots, voice assistants, virtual counseling platforms, and telepharmacy services can provide repeated medication guidance even after the patient leaves the hospital or pharmacy. These tools may reduce misunderstanding of prescriptions and help patients clarify basic medication-related doubts. However, pharmacist counseling remains important for complex conditions, high-risk medicines, and patient-specific medication decisions.

Although AI chatbots and virtual counseling systems improve access to medication information, their effectiveness depends on the accuracy of the information provided. Incorrect or outdated responses may lead to inappropriate medication use if professional supervision is absent.

4.4 Increased Healthcare Accessibility

Digital medication systems and telepharmacy services can improve access to pharmaceutical care, especially in remote and underserved regions. Patients who cannot frequently visit hospitals or pharmacies may still receive medication counseling, follow-up support, and adherence guidance through mobile applications or remote pharmacy platforms. Such technologies may reduce healthcare gaps and improve continuity of care among patients requiring long-term treatment [24]. Telepharmacy has considerable potential to improve pharmaceutical care in rural and underserved regions.

4.5 Support for Elderly and Low-Literacy Populations

Smart medication systems are especially helpful for elderly individuals, rural populations, and patients with limited health literacy. Pictogram-assisted communication can simplify medication information for low-literacy patients10.Voice-guided technologies may support elderly and visually impaired patients [12]. Reminder systems can help patients follow medication schedules more consistently [13]. These tools may reduce medication confusion, improve confidence in medicine use, and support safer medication practices among vulnerable patient groups.

4.6 Support for Pharmacists and Healthcare Professionals

Smart medication information systems can also support pharmacists and healthcare professionals by improving access to patient medication history, adherence data, drug information, and counseling records [18, 23]. These tools may assist in medication review, identification of drug interactions, monitoring of adverse drug reactions, and follow-up of patients with chronic diseases. However, digital systems should support professional judgment rather than replace pharmacist-patient interaction.

Table 02: Major Smart Medication Information Systems and Their Patient Safety Benefits

Technology	Main Function	Target Population	Patient Safety Benefit
QRcode-based systems	Provides digital medication information	Smartphone users and chronic disease patients	Improves access to dosage, storage, precautions, and adverse-effect information
Multilingual guidance systems	Provides medication instructions in preferred language	Rural, migrant, and regional-language patients	Reduces language-related misunderstanding
Pictogram-assisted systems	Uses visual symbols for medication instructions	Elderly and low-literacy patients	Improves comprehension and memory retention

AI chatbots	Provides interactive medication counseling	Patients needing quick medication guidance	Supports real-time answers and adherence education
Voice assistants	Provides audio-based medication support	Visually impaired and elderly patients	Improves accessibility for patients unable to read labels
Reminder systems	Sends alerts for dose timing and refills	Chronic disease and long-term therapy patients	Reduces missed doses and improves adherence
Smart packaging	Tracks medication use and refill needs	Elderly and polypharmacy patients	Supports adherence monitoring
Telepharmacy	Provides remote pharmacist counseling	Rural and underserved patients	Improves access to professional medication advice

5. Challenges and Limitations of Smart Medication Information Systems

Despite their benefits, smart medication information systems also have several challenges that may affect their use in healthcare and pharmacy practice. Problems related to cost, infrastructure, privacy, digital literacy, technical reliability, and regulation can limit their implementation, especially in rural and low-resource settings.

5.1 Technical and Infrastructure Limitations

The development and maintenance of smart medication systems require proper digital infrastructure, internet access, devices, software support, and trained personnel. Many healthcare settings, especially in rural or developing regions, may not have stable internet connectivity or enough technical resources. Limited access to smartphones and digital devices can also reduce the usefulness of these systems among economically disadvantaged patients.

Another challenge is integration with existing pharmacy workflows, electronic health records, and hospital information systems. Software errors, poor data entry, system failures, or outdated medication information may affect the reliability of digital medication guidance. Therefore, regular updates, technical support, and system monitoring are necessary.

5.2 Privacy and Data Security Concerns

Smart medication systems may collect and store patient information such as medication history, adherence data, disease conditions, and personal details. This creates concerns about privacy, confidentiality, and cybersecurity. Unauthorized access, data leakage, or misuse of patient information can reduce trust in digital healthcare systems [15]. Strong data protection, secure storage, patient consent, and proper access control are needed to protect patient information.

5.3 Digital Literacy and Accessibility Barriers

Limited digital literacy is a major barrier to the use of smart medication technologies. Elderly patients, low-literacy populations, and people unfamiliar with smartphones or mobile applications may find it difficult to use digital medication systems properly. Even when multilingual or voice-based tools are available, patients may still need guidance to understand and use these systems effectively. Digital health literacy is important for improving patient confidence and access to digital healthcare tools25.

5.4 Ethical and Regulatory Challenges

The use of AI-supported medication systems and digital health platforms raises ethical and regulatory concerns. Issues such as patient consent, accountability, transparency, and responsibility for errors must be clearly addressed. In many regions, guidelines for AI-based healthcare tools and telepharmacy services are still developing. Lack of clear regulations may create uncertainty about how these systems should be used safely in routine pharmacy practice.

5.5 Overdependence on Technology

Although smart medication systems are useful, excessive dependence on technology may reduce direct interaction between patients and healthcare professionals. Pharmacist counseling and professional judgment remain important, especially for complex diseases, high-risk medicines, elderly patients, pregnant women, and patients taking multiple medications. Smart medication systems should support healthcare professionals rather than replace them.

5.6 Risk of Inaccurate AI-Generated Medication Information

AI-supported systems, especially chatbots and virtual counseling tools, may sometimes provide inaccurate, incomplete, or non-patient-specific medication information. This can be risky if patients ask about dosage changes, drug interactions, missed doses, adverse effects, or high-risk medicines. AI-based medication alert systems also require proper validation before routine use [19]. Therefore, AI-supported medication tools should be trained using reliable drug information sources, regularly updated, clinically validated, and supervised by pharmacists or qualified healthcare professionals.

Clear guidelines are needed to define responsibility when digital or AI-supported tools provide incorrect medication information.

Table 03: Challenges and Possible Solutions in Smart Medication Information Systems

Challenge	Impact	Possible Solution
High implementation cost	Limited adoption in low-resource healthcare settings	Use low-cost mobile platforms and public health funding
Poor internet connectivity	Reduced effectiveness in rural and	Provide offline features, SMS

	remote areas	reminders, or telephone-based support
Limited digital literacy	Difficulty using smart medication technologies	Use simple interfaces and provide patient education
Limited smartphone accessibility	Reduced access among elderly and economically disadvantaged patients	Provide community pharmacy support and alternative non-smartphone options
Data privacy concerns	Risk of patient information misuse or data leakage	Use encryption, patient consent, secure storage, and controlled access
AI misinformation	Unsafe or incomplete medication advice	Use pharmacist supervision and verified drug information databases
Technical failures	Interruption of medication guidance services	Perform regular updates, maintenance, and technical monitoring
Lack of standardized regulations	Ethical and legal uncertainty in implementation	Develop clear digital health, telepharmacy, and AI guidelines
Overdependence on technology	Reduced direct pharmacist-patient interaction	Use technology as a support tool, not as a replacement for healthcare professionals

6. IMPLEMENTATION RECOMMENDATIONS

For successful implementation, smart medication information systems should be simple, affordable, secure, and easy to use. Healthcare institutions should provide patient education, pharmacist training, regular software updates, and data privacy protection. These systems should also be available in regional languages and designed for elderly and low-literacy patients. Before routine use, AI-based tools should be clinically validated and monitored by healthcare professionals to ensure patient safety [19,25].

7. FUTURE PERSPECTIVES OF SMART MEDICATION INFORMATION SYSTEMS

Smart medication information systems are expected to become more important in future healthcare and pharmacy practice. As digital health technologies continue to improve, medication management may become more personalized, accessible, and patient-centered. Future systems may combine AI chatbots, reminder applications, smart packaging, telepharmacy, wearable devices, and electronic health records to provide more complete medication support.

In the future, smart medication systems may help monitor medication adherence, detect missed doses, provide refill alerts, and support early identification of medication-related risks. Wearable devices and smart packaging may help track patient medication-taking behavior, while AI-based platforms may assist healthcare professionals in identifying patients who need additional counseling or follow-up [22,23].

Telepharmacy services are also likely to expand, especially in rural and underserved areas. Through telepharmacy platforms, patients may receive medication counseling, prescription review, treatment follow-up, and adherence support without frequent hospital or pharmacy visits. This may improve access to pharmaceutical care and support continuity of treatment for patients with chronic diseases [24].

Future systems may also provide more personalized medication guidance based on patient age, language preference, literacy level, disease condition, and medication history. Interactive QR code platforms may include videos, audio instructions, regional-language explanations, adverse-effect reporting, and direct pharmacist consultation.

Such features can make medication information easier to understand and more useful for different patient groups. While emerging technologies offer significant opportunities for improving medication management, their long-term effectiveness should be supported by clinical evidence, cost-effectiveness studies, and patient acceptance research before large-scale implementation.

However, successful future implementation will require proper infrastructure, digital literacy, patient education, pharmacist involvement, clinical validation, data security, and clear regulatory guidelines. Future research should focus on real-world studies, usability testing, cost-effectiveness, and long-term impact on medication adherence and patient safety.

Table 04: Future Technologies and Their Applications in Smart Medication Information Systems

Future Technology	Application
Wearable devices	Real-time medication adherence monitoring
Smart packaging systems	Medication tracking and dosage monitoring

Telepharmacy platforms	Remote patient counseling and follow-up
Predictive analytics	Early identification of medication-related risks
Personalized medication systems	Customized therapy and adherence support
Interactive QR platforms	Digital medication guidance and pharmacist consultation
Electronic health record integration	Medication history review and clinical decision support

8. CONCLUSION

Medication errors and poor adherence remain common problems in healthcare and often affect treatment outcomes. Many patients still face difficulties in understanding medication instructions, dosage schedules, and precautions, which can lead to inappropriate medicine use.Digital medication guidance tools have made medication information easier for patients to access and understand. QR codes, pictograms, multilingual guidance systems, reminder applications, telepharmacy services, smart packaging, and AI-supported tools provide different ways of improving medication communication and patient support.Digital literacy, cost, privacy, and infrastructure remain important challenges. Clear and accessible medication information remains important for helping patients understand and use their medicines correctly.

FUNDING

Nil

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

ACKNOWLEDGMENT

We also thank the patients who consented to participate in this research.

AUTHOR CONTRIBUTIONS

All are contributed equally.

ETHICAL STATEMENT

Not Applicable

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