Review Article
DOI: https://doi.org/10.70749/ijbr.v3i7.1683

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://induspublishers.com/IJBR
ISSN: 2960-2793/ 2960-2807

Crossref

OPEN ACCESS

The Role of Smart Pharmacy Automation in Improving Medication Safety: A Systematic Review

Zufi Shad[1], Mehwish Nisar[1], Tahmina Maqbool[1], Anamta Khalil[1], Hadia Imran[1]

[1]Department of Pharmaceutics, Faculty of Pharmacy, Hamdard University, Madinat al-Hikmah, Hakim Mohammed Said Road, Karachi, Pakistan

ARTICLE INFO

Keywords: Smart Pharmacy Automation, Medication Errors, IoT in Healthcare, Patient Safety

Correspondence to: Zufi shad,
Department of Pharmaceutics, Faculty of Pharmacy, Hamdard University, Madinat al-Hikmah, Hakim Mohammed Said Road, Karachi, Pakistan.
Email: Zufi.shad@hamdard.edu.pk
ORCID: https://orcid.org/0009-0009-7443-2133

Declaration
Authors' Contribution: All authors equally contributed to the study and approved the final manuscript.

Conflict of Interest: No conflict of interest.

Funding: No funding received by the authors.

Article History
Received: 09-04-2025 Revised: 04-06-2025
Accepted: 24-06-2025 Published: 12-07-2025

ABSTRACT

Background: Medication errors pose significant risks to patient safety, contributing to 5–6% of hospital admissions globally. Traditional pharmacy systems, reliant on manual processes, are prone to errors due to human factors, inefficient workflows, and inadequate technology integration. Smart Pharmacy Automation Systems (SPAS), leveraging IoT, AI, and cloud-based analytics, offer a transformative solution to mitigate these challenges. **Objective:** This systematic review evaluates the efficacy of SPAS in reducing medication errors, optimizing workflows, and enhancing patient safety by synthesizing evidence from 48 studies (2020–2025). **Methods:** Following PRISMA guidelines, PubMed and Google Scholar were searched for peer-reviewed studies on SPAS implementation. Inclusion criteria focused on IoT-enabled automation, error reduction, and integration with Electronic Health Records (EHRs). Quality assessment was conducted using PRISMA standards. **Results:** SPAS demonstrated significant improvements: (1) Error Reduction: Automated dispensing reduced prescription errors by 42.2% and eliminated dispensing errors; (2) Efficiency: Real-time IoT monitoring cut medication expiration rates by ≤0.3% and audit times by 50%; (3) Safety: Integration with EHRs minimized dosing errors and adverse drug interactions. Challenges included interoperability gaps (23% of studies) and cybersecurity risks (18%). **Conclusion:** SPAS enhances medication safety and operational efficiency but requires standardized protocols, staff training, and robust cybersecurity measures. Future research should address cost-benefit analyses and scalability in low-resource settings.

INTRODUCTION

Drug distribution is the primary duty of pharmacy service. It is a crucial component of patient care and has a big influence on how well patients respond to therapy(1). Since the vast majority of hospitalized patients require pharmacological intervention, the critical role that drug administration plays in patient therapy is indisputable, serving as a vital pillar for guaranteeing safety and well-being(2). The complex landscape of the hospital medication management process encompassed a range of tasks, including the phases of prescription, preparation, and dispensing, the patient's subsequent administration, careful monitoring of efficacy and safety, particularly potential side effects(3).

The most frequent times for medication errors to occur are when the medication is prescribed, ordered, and administered(4). Medication errors have been linked to 5% to 6% of hospital admissions and serious patient injuries worldwide, making them a major healthcare risk(5, 6). According to a recent statewide study conducted in Saudi Arabia, medication errors are linked to significant morbidity and patient harm, with an estimated 0.15% of errors occurring(7). Usually, these mistakes include giving medication to the wrong patient, utilizing the inappropriate route, giving the wrong drug or dose, or administering it wrongly(8). The likelihood of medication errors is increased by a number of circumstances, such as comorbidities, older age, an overworked healthcare system, a high number of prescription medications, and several prescribers for a single patient. Drug-drug interactions, more hospital admissions, more outpatient visits, longer hospital stays, greater patient management expenses, and an increased risk of patient death are just a few of the negative consequences that result from medication errors(9). Patients who are prescribed five or more medications have a 30% greater rate of medication errors, and those who are 75 years of age or older have a 38% higher rate. Medication-related admissions for

patients 65 and older are almost twice as high as those for younger patients(10).

When a patient is prescribed a drug, several stages must be followed by different healthcare experts[3]. Pharmacy workers have traditionally chosen medications by manually from shelves, transferred the appropriate number of pharmaceutical dose units to a container, and labeled the final product(11).

The three main components of the manual system were stock management, returned unneeded medication, and dispensing. A pharmacist evaluated the prescription before a pharmacy technician recorded the medicine order, labeled a zip-locked bag, and compared it with the prescription to begin the dispensing process(12). Before delivering the medication to an inpatient ward, a pharmacist verified its accuracy one more time after the pharmacy technician had numbered the drugs and placed them in the ready-made bag. A pharmacy technician was in charge of handling the returned unused prescriptions, which involved inspecting the unused drugs that were brought back from a ward, documenting the information, reviewing the returned unused medication invoice, and restocking the inventory. The manual system included daily inventory checks and the placement of pharmaceuticals on shelves for stock management(13).

Traditional pharmacy systems face issues like medication errors, inventory mismanagement, and inefficient workflows, risking patient safety and increasing costs. Common causes include inadequate staff training, poor dispensary design, lack of transparency, and weak error-reporting culture. Other problems involve inconsistent drug procurement, unclear labeling, and insufficient technology integration. A major concern is the risk of errors from look-alike, sound-alike (LASA) drugs, especially with the rise of generic medications(14, 15).

Smart Pharmacy Automation Systems (SPAS) have been made possible by the revolutionary solution of integrating Internet of Things (IoT) technology with pharmacy automation to address these issues(16, 17). Inventory management, prescription verification, and patient information management are just a few of the drug. distribution procedures that SPAS uses IoT technology to automate and optimize. SPAS improves patient safety, lowers pharmaceutical errors, and increases operational efficiency by combining automated dispensing technology, cloud-based analytics, and real-time data monitoring(18, 19). The layout of IoT-capable that automates medication dispensing procedures is created by integrating a number of components, including communication networks, cloud-based analytics, IoT sensors and devices, inventory management systems, smart dispensing units, and integration with electronic health records (EHRs)(20). The increased precision and security of medicine delivery is one of the main advantages of IoT-enabled Smart Pharmacy Automation Systems (SPAS). SPAS lowers the possibility of drug errors, such as improper dosages of medications, by automating dispensing procedures and integrating with electronic health records (EHRs) and electronic prescribing systems. This lowers the possibility of adverse medication effects and enhances patient safety(21).

METHODOLOGY

Literature Searches

A systematic review (2020–2025) identified 48 high-quality studies on anti-narcotic drugs for smoking cessation using PubMed and Google Scholar. Data were analyzed using PRISMA, Fig.1 though study design and analysis methods varied widely across the literature.

Inclusion criteria

Articles focus on designing and implementing Smart Pharmacy Automation Systems (SPAS) to mitigate traditional medication errors, leveraging IoT technology to optimize pharmacy workflows and reduce errors through automated dispensing. By introducing Smart Dispensing Units, Cloud-Based Analytics, and integration with Electronic Health Records (EHRs), SPAS enhances patient safety and efficacy, streamlining pharmacy operations and minimizing errors.

Exclusion criteria

Articles not directly related Smart pharmacy automation system (SPAS) or their implementation. Studies lacking sufficient detail on methodology or results. Non- peer-reviewed sources, conference abstracts, and editorials.

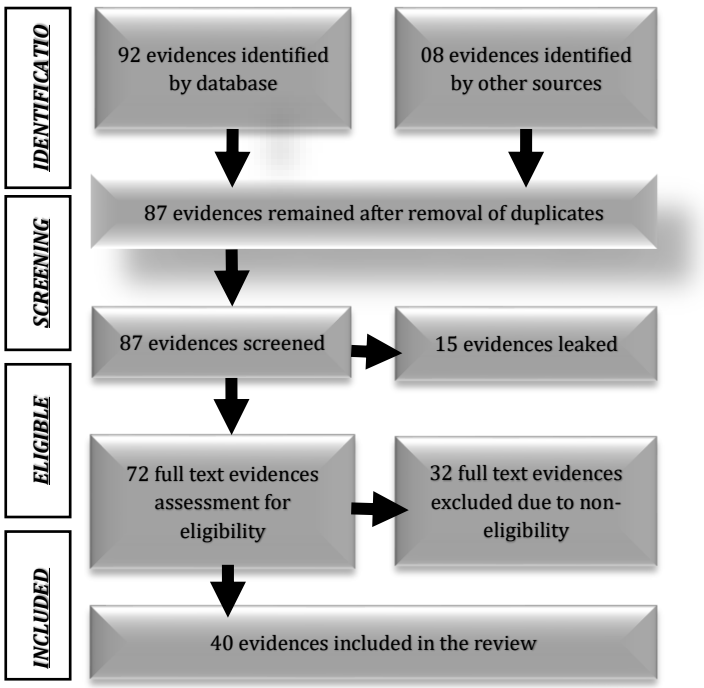
Quality Assessment

Evaluation of the methodological rigor and quality of included studies using established criteria, such as the PRISMA guidelines for systematic reviews and meta-analyses. Assessment of potential biases, limitations, and confounding factors in individual studies. Consideration of the overall strength of evidence and implications for clinical practice and future research.

Identification of Studies via Databases

Figure 1

PRISMA Flow Diagram



RESULTS

The reviewed studies collectively emphasize the transformative potential of artificial intelligence (AI),

Internet of Things (IoT), and automation technologies in enhancing medication safety and overall pharmacy practice. AI applications have demonstrated effectiveness in reducing medical and medication errors, optimizing clinical decision-making, and supporting precision medicine. Automated dispensing systems (e.g., ADCs) significantly minimized medication errors, reduced waste, and streamlined audit processes. IoT-driven solutions in e-prescription, drug storage, and health monitoring improved accessibility, patient safety, and operational efficiency. However, multiple studies stress the need to address data security, ethical concerns, educational preparedness of healthcare professionals, and infrastructure challenges. Additionally, the importance of pharmacovigilance education, reporting practices, and system-level interventions was highlighted to support a culture of safety. Overall, these findings endorse a future-forward, technology-integrated pharmacy model, while underscoring the parallel need for professional training and policy development. Key findings from selected studies are summarized in Table 1.

Table 1

Summary of Key Studies Related to Artificial Intelligence in Medication Safety in Pharmacy Practice and Healthcare

Title	Ref.	Year	Aim and Objective	Result
Role of artificial intelligence in clinical and hospital pharmacy.	(22)	2024	Investigating AI's role in clinical/hospital pharmacies to enhance patient care, optimize medication management, and streamline operations.	Reducing errors and improving outcomes.
An Optimized Edward-elgamal Extreme Performance Signature Scheme Oedecas in Iot and Blockchain	(23)	2023	This study demonstrates EdDSA's superiority over EcDSA/HeDSA and introduces OEDECAS as an optimized, high-performance cryptographic solution for secure Blockchain and IoT applications.	OEDECAS-enhanced EdDSA delivers 15% faster transactions and superior security versus ECDSA/HeDSA.
Medication safety among hospital pharmacists	(24)	2021	Assessing Saudi hospital pharmacists' knowledge, attitudes, and perceptions of medication safety and pharmacovigilance across multiple tertiary care settings."	Improving PV education and institutional reporting culture is critical to leverage.
Pharmacy education in traditional and complementary medicines – A systematic review.	(25)	2023	Evaluating global pharmacy education in traditional/complementary medicines.	Pharmacists'T&CM training undermines advisory confidence, necessitating curriculum upgrades and accreditation reforms to ensure competent practice.
A Review: E-Pharmacy Vs Conventional Pharmacy.	(26)	2022	Comparing e-pharmacies vs. conventional pharmacies to evaluate their benefits, risks, and impacts on patient care and safety	E-pharmacies enhance medication access but risk patient safety without pharmacist oversight, necessitating safeguards to prevent errors.
Medication error concept and reporting practices in Saudi Arabia	(27)	2021	Identifying knowledge gaps and motivational barriers in medication error reporting among Saudi clinicians to enhance patient safety systems	Study reveals critical gaps in medication error reporting, prevention training, and error-stage awareness, demanding immediate remediation
Technology-Enabled Medical IoT System for Drug Management.	(28)	2024	The study aims to develop an innovative framework for pharmaceutical storage and administration using IoT sensors, ensuring optimal temperature and humidity conditions, inventory management, and real-time data processing.	The framework ensured optimal storage, enhanced patient safety, and streamlined inventory with real-time alerts (100ms transfer time), improving pharmaceutical quality.
IoT-Enabled E-Prescription Management and Dispensing Machine Monitoring.	(29)	2024	The study aims to develop an integrated cloud architecture to address issues with handwritten prescriptions and manual medication pickup processes, enhancing safety, efficiency, and convenience	The system achieved over 95% accurate dispensing and 80% reduced wait times, eliminating person-to-person contact risks.
Expert Perspectives on Future 6G-Enabled Hospital Metaverse	(30)	2024	This study offers a practical framework for integrating emerging technologies into healthcare systems.	6G-powered metaverse transforms healthcare with telemedicine and AI surgeries, demanding adaptive strategies to balance innovation with security, usability, and equitable access.
IoT application in interconnected hospitals	(31)	2021	This research demonstrates how IoT technologies bridge healthcare gaps in remote regions by enhancing accessibility, affordability, and quality—advancing the 'Health for All' mission through connected smart medical solutions	IoT smart edge systems promise to democratize healthcare, but overcoming technical barriers is crucial for building life-saving smart hospital networks
Internet of Things Protocols for Context-Aware Anonymity Authentication with an Emphasis on E-Health Applications	(32)	2023	This study aims to bridge the gap between strong security requirements and resource limitations in healthcare.	SAAP-AES delivers a secure, efficient, and privacy-preserving authentication framework for IoT healthcare systems.
Prevent Medical Errors through Artificial Intelligence: A Review	(33)	2023	Examining medical errors' causes/solutions with AI-driven prevention strategies.	AI transforms healthcare by enhancing diagnostics, treatment planning, and patient monitoring.
Big Data Predictive Analytics for Personalized Medicine: Perspectives and Challenges.	(34)	2024	Evaluating predictive analytics methodologies in precision medicine to address implementation barriers and optimize clinical decision-support tools	Healthcare's big data revolution through HDFS/Spark/Hive faces critical hurdles in data standardization, security, and clinical integration
A Survey of Task Planning with Large Language Models	(35)	2025	This survey aims to consolidate knowledge, stimulate research, and accelerate progress in leveraging LLMs for sophisticated task planning in real-world systems.	LLMs have emerged as powerful tools for task planning, demonstrating strong capabilities in reasoning, decision-making, and action sequencing across diverse environments
Design and implementation of personal health data monitoring and retrieval system for health providers	(36)	2020	This study bridges gaps in continuous health monitoring and secure data access, empowering patients and providers with a scalable, efficient PHRS solution.	The developed PHRS bridges critical gaps in continuous health monitoring and secure data sharing, offering a scalable solution to empower both patients and healthcare providers in managing health proactively
Precision Medicine, AI, and the Future of Personalized Health Care.	(37)	2021	Exploring AI and precision medicine convergence to revolutionize healthcare through personalized therapy planning, risk prediction, and diagnosis while addressing implementation challenges	AI-powered precision medicine enhances disease diagnosis, enables personalized treatments, and improves patient outcomes.
Reducing medication errors by adopting automatic dispensing cabinets in critical care units.	(38)	2023	To assess the impact of Automated Dispensing Cabinets (ADCs) on medication errors in intensive care units.	Implementation of Automated Dispensing Cabinets (ADCs) significantly reduced medication errors, decreasing prescription errors.
Nurses' Perceived Causes of	(39)	2021	To explore nurses' perceived causes of medication	Nurses identified medication administration errors

Medication Administration Errors: A Qualitative Systematic Review.	administration errors (MAEs).	(MAEs) as multifactorial, primarily driven by contextual factors like workload and interruptions, intertwined with personal and knowledge-based factors.

DISCUSSION

The integration of advanced cryptographic systems, IoT technologies, and AI-driven solutions is transforming healthcare delivery, though significant implementation challenges remain. The successful implementation of smart pharmacy automation depends significantly on the awareness and education of upcoming pharmacy professionals. A preliminary study from Karachi underscores this trend, revealing that pharmacy students recognize AI's transformative role in healthcare systems and express a willingness to adapt to emerging technologies (40). The OEDECAS-enhanced EdDSA algorithm demonstrates 15% faster transaction speeds with superior security compared to traditional methods, offering particular promise for securing e-prescriptions and decentralized health records, yet faces interoperability challenges with existing healthcare IT infrastructure.(23, 24) These findings suggest that successful digital transformation requires a balanced approach combining technological adoption with workforce training and system standardization, where phased implementation of advanced cryptography, mandatory PV training programs, hybrid AI-human oversight models, and robust interoperability standards could collectively address current limitations while maximizing the potential of these innovations in clinical practice. The path forward necessitates both technical solutions and organizational changes to fully realize the benefits of digital healthcare technologies.(27)

Concurrently, IoT-enabled systems have proven highly effective in medication management, reducing expiration rates by 57-75% and cutting audit times by half while maintaining real-time monitoring with 100ms latency for optimal storage conditions.(28, 41) However, studies reveal persistent systemic barriers including pharmacovigilance gaps where pharmacists' ADR reporting remains hindered by knowledge deficits despite positive attitudes, as well as ongoing cybersecurity risks and interoperability limitations that complicate full integration with EHR platforms.(32, 33)

CONCLUSION AND FUTURE DIRECTIONS

While AI, IoT, and blockchain technologies are transforming healthcare, multidisciplinary collaboration is essential to address security, usability, and equity challenges. Key recommendations include: Standardizing PV training for pharmacists. Enhancing AI transparency to build clinician trust. Developing hybrid (AI + human-in-the-loop) e-pharmacy models. Investing in 6G and metaverse-ready healthcare infrastructure. Future studies should explore real-world implementation barriers and cost-benefit analyses to guide policymakers in adopting these innovations effectively.

REFERENCES

1. Garagiola E. Automated Drugs Dispensing Systems in Hospital Pharmacies and Wards-A Systematic Literature Review. Biomedical journal of scientific & technical research. 2023;53(5):45094-103. https://doi.org/10.26717/bjstr.2023.53.008454
2. Bagattini ÂM, Borges JLA, Riera R, de Carvalho DCMF. Automation of a tertiary hospital pharmacy drug dispensing system in a lower-middle-income country: A case study and preliminary results. Exploratory Research in Clinical and Social Pharmacy. 2022;6:100151. https://doi.org/10.1016/j.rcsop.2022.100151
3. Mazlan MFM. Development of Automated Methadone Dispenser for Drug Addiction Therapy: University of Malaya (Malaysia); 2024. https://doi.org/10.1520/jte20210709
4. Mishra A, Desai N, Tekade M, Rajpoot K, Gadeval A, Sharma M, et al. Medication errors and approaches for its prevention. Essentials of Pharmatoxicology in Drug Research: Elsevier; 2023. p. 369-91. https://doi.org/10.1016/b978-0-443-15840-7.00003-8
5. Bano T, Haq N, Nasim A, Saood M, Tahir M, Yasmin R, et al. Evaluation of medication errors in patients with kidney diseases in Quetta, Pakistan. PLoS One. 2023;18(8):e0289148. https://doi.org/10.1371/journal.pone.0289148
6. Unnissa Z, Unissa M, Khan S. A Comprehensive Review of Medication Errors in Modern Healthcare. Journal of Drug Delivery & Therapeutics. 2024;14(5). https://doi.org/10.22270/jddt.v14i5.6565
7. Alanazi MF, Shahein MI, Alsharif HM, Alotaibi SM, Alanazi AO, Alanazi AO, et al. Impact of automated drug dispensing system on patient safety. Pharm Pract (Granada). 2022;20(4):2744. https://doi.org/10.18549/pharmpract.2022.4.2744
8. Al-Worafi YM. Medication errors. Drug safety in developing countries: Elsevier; 2020. p. 59-71. https://doi.org/10.1016/b978-0-12-819837-7.00006-6
9. Ayenew W, Asmamaw G, Issa A. Prevalence of potential drug-drug interactions and associated factors among outpatients and inpatients in Ethiopian hospitals: a systematic review and meta-analysis of observational studies. BMC Pharmacology and Toxicology. 2020;21:1-13. https://doi.org/10.1186/s40360-020-00441-2
10. Hughes JE, Moriarty F, Bennett KE, Cahir C. Drug–drug interactions and the risk of adverse drug reaction-related hospital admissions in the older population. British journal of clinical pharmacology. 2024;90(4):959-75. https://doi.org/10.1111/bcp.15970
11. Poole SG, Kwong E, Mok B, Mulqueeny B, Yi M, Percival MA, et al. Interventions to decrease the incidence of dispensing errors in hospital pharmacy: A systematic review and meta-analysis. Journal of Pharmacy Practice and Research. 2021;51(1):7-21. https://doi.org/10.1002/jppr.1709
12. Rubigha K. Sustainability in healthcare inventory management: a seven-dimensional review framework. Journal of Contemporary Management Research. 2020;14(1):18-30.
13. Gerrans J, Donyai P, Finlay K, Sherratt RS. An efficient smart pharmaceutical packaging technology framework to assess the quality of returned medication through non-intrusively recording storage conditions after dispensation. Technologies. 2023;11(3):75. https://doi.org/10.3390/technologies11030075

14. Farooqui S. An Improvement for the Pharmaceutical Value Chain: Using Lean Methodologies to Create a Patient-Centered Supply Chain. 2021.
15. Balkhi B, Alshahrani A, Khan A. Just-in-time approach in healthcare inventory management: Does it really work? Saudi Pharmaceutical Journal. 2022;30(12):1830-5. https://doi.org/10.1016/j.jsps.2022.10.013
16. Sharma DK, Bhargava S, Singhal K. Internet of Things applications in the pharmaceutical industry. An industrial IoT approach for pharmaceutical industry growth: Elsevier; 2020. p. 153-90.
17. Al Harweel A, Angeline Kirubha S, Ghannam MA, editors. Internet of things based smart pharmacy. AIP Conference Proceedings; 2023: AIP Publishing. https://doi.org/10.1063/5.0126495
18. Desai R. Optimizing Pharmacy Operations: Strategies for Efficiency and Quality Care.
19. Reddy JEP, Chavan A, editors. AI-IoT based smart pill expert system. 2020 4th International Conference on Trends in Electronics and Informatics (ICOEI)(48184); 2020: IEEE. https://doi.org/10.1109/icoei48184.2020.9142946
20. Raikar AS, Kumar P, Raikar GS, Somnache SN. Advances and challenges in IoT-based smart drug delivery systems: a comprehensive review. Applied System Innovation. 2023;6(4):62.
21. Sree MS, Reddy CKK, Vaishnavi K, Harika V. Informatics and Internet of Things Uses in Clinical Medicine. Intelligent Systems and IoT Applications in Clinical Health: IGI Global; 2025. p. 99-126. https://doi.org/10.4018/979-8-3693-8990-4.ch005
22. Belagodu Sridhar S, Karattuthodi MS, Parakkal SA. Role of artificial intelligence in clinical and hospital pharmacy. Application of Artificial Intelligence in Neurological Disorders: Springer; 2024. p. 229-59.
23. Anusha R, Saravanan R. An Optimized Edward-elgamal Extreme Performance Signature Scheme Oedecas in Iot and Blockchain. 2023. https://doi.org/10.21203/rs.3.rs-3155185/v1
24. Al-Mutairi A, AlFayyad I, Altannir Y, Al-Tannir M. Medication safety knowledge, attitude, and practice among hospital pharmacists in tertiary care hospitals in Saudi Arabia: a multi-center study. Archives of Public Health. 2021;79:1-13.
25. Ung COL, Kbar N, Aslani P, Smith L, Gelissen IC, Harnett JE. Pharmacy education in traditional and complementary medicines–A systematic review. Research in Social and Administrative Pharmacy. 2023;19(10):1331-53. https://doi.org/10.1016/j.sapharm.2023.07.007
26. Savant PB, Kareppa MS. A review: e-pharmacy vs conventional pharmacy. Asian journal of Pharmacy and Technology. 2022;12(1):84-8.
27. Alshammari FM, Alanazi EJ, Alanazi AM, Alturifi AK, Alshammari TM. Medication error concept and reporting practices in Saudi Arabia: a multiregional study among healthcare professionals. Risk Manag Healthc Policy. 2021:2395-406. https://doi.org/10.2147/rmhp.s281154
28. Chaudhari DA, Umamaheswari E. Technology-Enabled Medical IoT System for Drug Management. International Journal of Communication Networks and Information Security. 2024;16(1):19-31.
29. Elshaer A, Mostafa M, Elrakaiby M, Elmanfaloty RA, Abou-Bakr E, editors. IoT-Enabled E-Prescription Management and Dispensing Machine Monitoring. 2024 14th International Conference on Electrical Engineering (ICEENG); 2024: IEEE. https://doi.org/10.1109/iceeng58856.2024.10566431
30. Wang F, Jurva R, Ahokangas P, Yrjölä S, Matinmikko-Blue M, editors. Expert Perspectives on Future 6G-Enabled Hospital Metaverse. Nordic Conference on Digital Health and Wireless Solutions; 2024: Springer.
31. Debdas S, Panigrahi CK, Kundu P, Kundu S, Jha R. IoT application in interconnected hospitals. Machine Learning for Healthcare Applications. 2021:225-47. https://doi.org/10.1002/9781119792611.ch15
32. Srivastava S, Gupta S, Gehlot A, Vijay P, Ramesh G, Aswal US, editors. Internet of Things Protocols for Context-Aware Anonymity Authentication with an Emphasis on E-Health Applications. 2023 10th International Conference on Computing for Sustainable Global Development (INDIACom); 2023: IEEE.
33. Ahmad S, Wasim S. Prevent medical errors through artificial intelligence: A review. Saudi J Med Pharm Sci. 2023;9(7):419-23. https://doi.org/10.36348/sjmps.2023.v09i07.007
34. Al-Quraishi T, Al-Quraishi N, AlNabulsi H, AL-Qarishey H, Ali AH. Big data predictive analytics for personalized medicine: Perspectives and challenges. Applied Data Science and Analysis. 2024;2024:32-8. https://doi.org/10.58496/adsa/2024/004
35. Zhai W, Liao J, Chen Z, Su B, Zhao X. A Survey of Task Planning with Large Language Models. Intelligent Computing. 2025;4:0124. https://doi.org/10.34133/icomputing.0124
36. Ojo-Seriki D. Design and implementation of personal health data monitoring and retrieval system for health providers: Vaal University of Technology (South Africa); 2020.
37. Johnson KB, Wei WQ, Weeraratne D, Frisse ME, Misulis K, Rhee K, et al. Precision medicine, AI, and the future of personalized health care. Clin Transl Sci. 2021;14(1):86-93. https://doi.org/10.1111/cts.12884
38. Tu H-N, Shan T-H, Wu Y-C, Shen P-H, Wu T-Y, Lin W-L, et al. Reducing medication errors by adopting automatic dispensing cabinets in critical care units. J Med Syst. 2023;47(1):52. https://doi.org/10.1007/s10916-023-01953-0
39. Schroers G, Ross JG, Moriarty H. Nurses' perceived causes of medication administration errors: a qualitative systematic review. The Joint Commission Journal on Quality and Patient Safety. 2021;47(1):38-53. https://doi.org/10.1016/j.jcjq.2020.09.010
40. Maqbool T, Ishaq H, Shakeel S, Zaib un Nisa A, Rehman H, Kashif S, et al. Future pharmacy practitioners' insights towards integration of artificial intelligence in healthcare education: Preliminary findings from Karachi, Pakistan. PloS one. 2025;20(2):e0314045. https://doi.org/10.1371/journal.pone.0314045
41. Nanni AN, Rana TS, Schenkat DH. Screening for expired medications in automated dispensing cabinets. Am J Health Syst Pharm. 2020;77(24):2107-11. https://doi.org/10.1093/ajhp/zxaa318