The Effect of Digital Technologies and Artificial Intelligence on Pharmacy Operations and Workflow Efficiency

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***Abstract*—Digital technologies and artificial intelligence (AI) are transforming traditional manual pharmacy work into highly efficient, patient-oriented systems. In the past, pharmacies relied on handwritten prescriptions and face-to-face interactions, which resulted in frequent errors and inefficient processes. The first steps toward safer and more reliable practice were the adoption of electronic health records, e-prescribing, barcode verification, and automated dispensing cabinets. Today, machine learning and AI-based clinical decision support and predictive analytics allow pharmacists to predict drug interactions, personalize treatment, and better manage medication regimens. Telepharmacy platforms, mobile health applications, and wearable devices are enhancing access to pharmaceutical care, especially in under-served or remote communities, while enabling pharmacists to assume a broader clinical role such as disease management and patient education. In the future, improved AI tools, robotics, and precision medicine can continue to transform pharmacy practice to be more automated and efficient in drug discovery, and to provide more customized treatment. Even though challenges remain around data privacy, interoperability, and ethical use, the future of pharmacy will be characterized by a balance between technological innovation and human expertise, providing safer, more efficient, and more patient-focused care.**

***Index Terms*—Digital pharmacy, Artificial intelligence in pharmacy, Electronic health records (EHRs), Clinical decision support systems (CDSS), Telepharmacy, Mobile health (mHealth) applications, Wearable devices, Automated dispensing cabinets (ADC), Medication management technologies, Precision medicine.**

I. INTRODUCTION

There are different aspects of AI and digital technologies in the functioning of pharmacies which have been revealed through historical perspectives. Conventional drug delivery, inventory control, and direct patient-guiding practices were always the main focus of pharmacy practice. Face-to-face interactions and manual record-keeping were the main methods of the pre-digital era, likely to cause problems associated with scale, human error, and inefficiency. The handwritten prescription process was usually prone to errors due to illegibility and misinterpretation [1]. The implementation of electronic health records (EHRs) and electronic prescribing (e-prescribing) in the early 2000s was a major step forward. Through e-prescribing, prescriptions were sent electronically to pharmacies directly by medical professionals, which improved dispensing efficiency and minimized errors caused by handwritten prescriptions [1],[2]. This integration reduced the occurrence of adverse drug events and made available to pharmacists more detailed and accurate patient medication histories, which enhanced patient safety and made it easier to track inventory [1]. Automated dispensing cabinets further improved the accuracy and reliability of medicine delivery in hospitals and other large healthcare facilities, even though early digital interventions were largely limited to elementary automation and record keeping. These initial developments began to shift the pharmacist's role toward a more clinical one in drug management rather than a purely dispensing-based role, through technologies that enhanced data access and workflow efficiency [1].

II. CURRENT SITUATION OF DIGITAL AND AI IN PHARMACY

Digital technology and artificial intelligence are incorporated into pharmacy practice today, impacting operational processes and enhancing patient outcomes in ways not previously possible. The extensive use of clinical decision support systems (CDSS) and comprehensive pharmacy management systems (CPMS) involves AI algorithms that analyse large volumes of data to improve pharmaceutical efficacy and safety [3],[5]. Pharmacists using AI-powered solutions can predict adverse interactions, detect potential drug-drug interactions, and adjust dosing according to patient-specific factors. Predictive analytics offers more evidence-based clinical decision-making than earlier rule-based computer systems [3],[5]. Machine learning algorithms also analyse pharmacy data to enhance the outcome of therapeutic interventions and administer pharmacological therapy more effectively.

Telepharmacy and mobile health applications have facilitated access to pharmaceutical treatment beyond physical facilities. Remote or underserved patients can now access counselling, medication adherence support, and consultations through online sources, enhancing the management of chronic conditions [1],[5]. AI chatbots also handle routine patient interactions and requests in retail pharmacies, enhancing productivity and allowing pharmacists to focus on more challenging clinical tasks [5]. AI models improve supply chain management through accurate estimation of medicine demand, automated restocking, and minimization of waste [1]. Real-time tracking of medicines with RFID and IoT connected to inventory systems contributes to better patient safety and compliance, particularly for chronic disease management where pharmacists monitor patient health data through wearable devices connected to digital pharmacy platforms [5]. These technologies have facilitated preventive care, enabling early intervention and customized treatment. Electronic health platforms allow pharmacists to collaborate with other medical professionals, participate in multidisciplinary care teams, and deliver services including patient education, disease screening, and vaccination [3],[5], making pharmacists key contributors to the overall treatment of the patient.

III. FUTURE PERSPECTIVES ON DIGITAL AND AI TECHNOLOGIES IN PHARMACY

The synergy of digital technology and AI shows enormous potential for advancing pharmaceutical sciences and pharmacy practice in the future. Future trends point to even greater reliance on deep learning, natural language processing, and robotics to process large volumes of biochemical and patient data [5],[6],[7]. Autonomous drug discovery systems would utilize AI to discover novel drug leads faster than current interventions [5],[6],[7]. Pharmacy automation will change with robots that can synthesize or assemble drugs more accurately and quickly than human employees, support more complex clinical trials by predicting and analysing real-time data, and improve flexibility in trial design. Automation will improve the ability to serve a high volume of patients in both hospital and retail environments, decrease labour costs, and minimize errors [7].

AI will also revolutionize personalised therapy by assessing genomic, lifestyle, and environmental factors to generate treatment tailored to each patient's needs. This precision medicine will improve therapeutic efficacy and reduce medication side effects [5],[7]. The future of pharmacy will likely involve supervising and controlling AI, using smarter systems to support clinical decisions while ensuring the ethical and safe use of the technology. Adaptive learning technologies powered by AI will also enhance the training and education of pharmacists for this new environment [3]. As AI use increases, patient data privacy, ethical use of AI, algorithm transparency, and government regulation will gain significant importance; strong norms and standards must exist to enjoy the benefits of AI safely and fairly across the healthcare sector [3],[5].

IV. AI IN PHARMACY OPERATIONS

AI is rapidly reshaping health care by helping clinicians and researchers better understand patients and their needs. With access to information from wearables, electronic health records, and genetic data, AI can sort through huge amounts of information far faster than humans, leading to quicker diagnosis, smarter treatment decisions, fewer medical errors, and more efficient care. From choosing the right cancer

therapy to predicting disease outbreaks, AI is becoming a trusted partner across the healthcare system. For pharmacies, AI opens the door to becoming much more than places where medicines are dispensed: with smarter systems, pharmacists can spot drug-related problems early, personalize care, and stay closely connected with patients, especially those at risk. Real-time data from health trackers can help pharmacists follow up, support patients with lifestyle changes, and improve medication adherence. In many ways, AI allows pharmacists to focus on what matters most — guiding people to better health, offering timely advice, and helping them make safe, cost-effective healthcare decisions [8].

The following subsections briefly examine some of the key digital technologies in current use.

A. Clinical Decision Support Systems (CDSS)

Clinical Decision Support Systems are built into pharmacy or hospital information systems, giving pharmacists and prescribers medication-related warnings and advice. They assist with clinical verification of drug-drug interactions, allergies, dosing errors, duplicate therapies, and contraindications. Approved versions of CDSS can use machine learning algorithms and real-time EHR data to personalize alerts to patient-specific parameters [9],[10].

Impact: CDSS can enhance patient safety by preventing medication errors during prescribing and dispensing. Research has demonstrated substantial decreases in adverse drug events (ADEs) and dosing oversights following CDSS implementation. CDSS also improves workflow efficiency by prioritizing pharmacist review tasks, minimizing manual verification time, and simplifying clinical review. Alert fatigue remains a critical problem, and AI-based adaptive alert models are under development to reduce non-relevant alerts [11],[12].

B. Robotics and Automated Dispensing Systems (ADS)

Automated dispensing systems (ADS), such as robotic dispensing machines and Automated Dispensing Cabinets (ADCs), automate the storage, selection, and dispensing of medications. Pharmacy databases and barcode verification are incorporated into these systems to guarantee accuracy and real-time inventory management.

Impact: ADS technologies are already applied in hospital and retail pharmacy settings with high or repetitive dispensing volumes, freeing pharmacists to devote additional time to patient care and clinical tasks [13],[14]. Decreases in technician preparation time and pharmacist checking time have been demonstrated following automation. Robotic dispensing also supports inventory tracking and provides continuous accuracy of dispensing [15],[16].

C. Barcode Medication Administration (BCMA)

BCMA is a system in which medications, patients, and healthcare professionals are identified through barcodes scanned prior to administration. Combined with pharmacy and EHR systems, BCMA checks the "five rights" of administration — right patient, drug, dose, route, and time — helping minimize human error in dispensing and administration.

Impact: Implementation of BCMA has been shown to reduce errors in medication administration and improve accountability. It also improves workflow efficiency by optimizing medication tracking, decreasing time spent on manual documentation, and preventing wrong-patient or wrong-dose situations. Used together with CDSS, BCMA supports end-to-end safety from prescription to administration [17].

D. Telepharmacy

Telepharmacy allows pharmacists to deliver clinical and dispensing services using telecommunication technology. It involves remote prescription ordering, patient counselling through video conferencing, and pharmaceutical therapy support for rural or underserved populations [18],[19].

Impact: Telepharmacy improves access to pharmaceutical care, particularly where local pharmacists are unavailable. Research indicates that remote verification enhances safety and precision and improves service coverage. Telepharmacy also minimized delays in drug delivery and permitted round-the-clock monitoring during COVID-19 despite lockdowns, and enhances workflow efficiency through centralized pharmacist reviews, staffing optimization, and reduced wait times [20],[21].

E. Inventory Management Systems and Analytics

Inventory systems in pharmacy have been digitalized to track stock, usage, and demand. AI and predictive analytics models are combined to automatically reorder inventory and reduce wastage.

Impact: These systems increase operational efficiency by decreasing stockouts and overstocking, ensuring timely stock replenishment, and lowering waste. Predictive analytics enhances procurement planning, saving costs and minimizing human error in inventory management [13].

F. E-Prescribing and Electronic Health Record (EHR) Integration

E-prescribing systems enable physicians to transmit prescriptions directly to pharmacy information systems, minimizing manual entry and transcription errors. Combined with EHRs and CDSS, pharmacists can access complete patient data, including lab results and medication history, improving prescription accuracy, decreasing dispensing time, and enhancing communication with clinicians [22].

Impact: E-prescribing improves the quality of prescriptions and decreases dispensing time, while improving communication between pharmacists and clinicians. Interoperability with EHRs facilitates better decision-making and workflow effectiveness by centralizing clinical information; other technologies such as CDSS, telepharmacy, and AI depend on this interoperability [23].

V. FUTURE DIRECTIONS

The integration of advanced artificial intelligence (AI) and machine learning (ML) into core pharmacy functions is among the most significant future directions, as practice moves beyond simplistic rule-based alerts toward adaptive, patient-specific decision support. A systematic review on artificial intelligence in clinical pharmacy explains how ML, deep learning, natural language processing, and robotics are changing clinical pharmacy, while noting the challenge of moving these technologies into clinical practice. The implication for pharmacy operations is that future pharmacist intervention will increasingly rely on AI prioritization of high-risk prescriptions, predictive drug-adherence interventions, enhanced inventory management, and patient-centred interventions, without implying that virtual pharmacies will replace physical ones [24].

A futuristic perspective on pharmacy in 2050 envisions the profession shifting from logistics toward constant clinical engagement through digital platforms [28]. Wearables, smart dispensers, mobile applications, home monitoring, and remote verification will extend pharmacy services to patients' homes and communities, beyond the physical pharmacy setting. Alongside these changes, concerns around regulation, interoperability, human factors, and ethics will become increasingly urgent. A systematic review of digital technologies in hospital pharmacy notes that despite the positive impact of automation and digital systems on efficiency and safety, successful implementation depends on institutional readiness, infrastructure, and human factors [26]. Similarly, a review of automation models in hospital pharmacy highlights cost, integration with existing processes, and personnel training as ongoing challenges [13]. Going forward, pharmacy practice should incorporate sound data governance, explainable AI, inclusive design, user-centred workflow redesign, and cross-system interoperability to avoid new bottlenecks or safety risks.

A scoping review of AI applications in current pharmacy practice found that existing applications are dominated by workflow and productivity gains — such as stock management and order classification — rather than direct improvement of patient outcomes, identifying this as a gap and an opportunity for future research [25]. This suggests that future efforts must translate operational gains into clinical ones, including improved adherence, reduced adverse events, and better health-related quality of life, supported by standardized criteria for assessing digital pharmacy transformation. Achieving this will require collaboration across pharmacy, informatics, data science, and regulatory fields, along with long-term strategic investment.

VI. CONCLUSION

Integration of digital technologies in pharmacy practice has transformed conventional methods of medication management, patient counselling, and healthcare delivery. Pharmaceutical errors, accessibility gaps, and workflow inefficiencies have all been addressed through automated dispensing technologies, electronic health records, telepharmacy, and mobile health applications. This review indicates that these technologies, when used correctly, can enhance patient safety, compliance, and pharmacy efficiency, allowing pharmacists to extend their role into personalized medicine and community health

management. Pharmacists can make more accurate, evidence-based recommendations using real-time data and decision-support tools, helping to minimize preventable adverse drug events and build stronger pharmacist-patient relationships through continuous monitoring and personalized care.

Despite rapid progress, obstacles remain. Data protection, system integration, workforce adjustment, and regulatory alignment must all be addressed to ensure long-term success, and the cost of modern equipment remains a limiting factor for resource-constrained health facilities. Pharmacy will become increasingly connected with continued development in artificial intelligence, robotics, blockchain, and wearable health technologies, transforming pharmacies into proactive, technology-driven healthcare facilities while enhancing operational efficiency. Long-term cooperation between medical professionals, policymakers, and technology developers will be crucial to this digital future. Digital tools are no longer peripheral to pharmacy practice — they are now central to it. With sustained commitment to innovation despite implementation challenges, pharmacy practice can become a more patient-oriented, efficient, and robust system capable of meeting growing global healthcare demands.\

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