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A REVIEW OF THE OPERATIONAL ADVANCEMENTS DRIVEN BY DIGITAL TECHNOLOGIES AND ARTIFICIAL INTELLIGENCE IN PHARMACY SERVICES

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ABSTRACT

The digital transformation of pharmacy services is rapidly reshaping operational workflows and clinical responsibilities through the adoption of advanced technologies and artificial intelligence (AI). Earlier reliance on manual processes such as handwritten prescriptions, paper-based documentation and in person communication often contributed to delays, inefficiencies and preventable medication errors. The introduction of electronic health records, E prescribing platforms, barcode medication verification and automated dispensing systems has significantly strengthened accuracy, traceability and medication safety. Building on these foundations, AI driven tools including machine learning algorithms, predictive analytics and intelligent clinical decision support systems are now augmenting pharmacist's ability to detect drug interactions, forecast medication related risks and optimize therapeutic regimens. Simultaneously, telepharmacy, mobile health applications and wearable devices are improving access to care, promoting adherence and supporting continuous monitoring, particularly for patients in remote or underserved areas. These innovations enable pharmacists to assume expanded clinical roles in chronic disease management, counseling and preventive care. Looking ahead, advancements in robotics, precision medicine and next generation AI platforms are expected to further enhance automation, streamline supply chains and enable highly individualized treatment approaches.

KEYWORDS: Artificial intelligence, Digital therapeutics, Pharmacy informatics, Automated dispensing systems, Medication reconciliation, Health information technology (HIT) and Machine learning in healthcare.

INTRODUCTION

Traditional pharmacy practice has long centered on medication dispensing, inventory control and direct patient counselling. Before the rise of digital systems, these activities were carried out through manual record-keeping and in-person interactions, which often created limitations in accuracy, scalability and workflow efficiency. Handwritten prescriptions, in particular, were frequently associated with errors due to poor legibility and misinterpretation. A major shift occurred in the early 2000s with the adoption of electronic health records (EHRs) and electronic prescribing (e-prescribing) platforms. These systems enabled clinicians to transmit prescriptions electronically to pharmacies, reducing delays in dispensing and minimizing mistakes linked to manual, handwritten orders. This digital transition not only lowered the risk of adverse drug events but also provided pharmacists with more complete and reliable medication histories. During the same period, barcode verification systems were implemented to ensure accurate dispensing and strengthen inventory oversight, greatly enhancing patient safety. Automated dispensing cabinets further improved the precision and dependability of medication distribution in hospitals and other large healthcare settings. Although these early digital tools mainly supported basic automation and documentation, they established the groundwork for more advanced innovations [1-2]. By improving access to information and streamlining daily workflows, these initial -advancements began redefining the pharmacist's role from one focused solely on dispensing to a more clinically involved position within medication management.

CURRENT LANDSCAPE OF DIGITAL AND AI TECHNOLOGIES IN PHARMACY

Digital systems and artificial intelligence (AI) have become fundamental components of contemporary pharmacy practice, reshaping workflow processes and elevating patient care standards. Modern clinical decision support systems (CDSS) and comprehensive pharmacy management solutions utilize AI-driven analytics to interpret extensive clinical data, thereby improving the accuracy, safety and effectiveness of medication use. With these technologies, pharmacists are better equipped to foresee adverse reactions, identify potential drug–drug interactions and adjust medication doses based on individual patient needs. Compared to earlier rule-based digital tools, current predictive models offer more sophisticated, data-driven clinical insights that strengthen therapeutic decision-making. Machine learning technologies also enable more effective medication therapy management by supporting the evaluation of patient outcomes and treatment responses. Telepharmacy platforms and mobile health applications have extended pharmaceutical care beyond traditional physical locations.[3] Patients in remote or underserved communities can now receive counselling, adherence support and follow-up consultations virtually, promoting better chronic disease management and improved medication compliance. In retail settings, AI-powered chatbots address routine queries, easing the workload on pharmacists and allowing them to focus on more complex responsibilities. Operational efficiency has also advanced through AI-supported supply chain systems that predict drug demand, automate inventory replenishment and reduce wastage.[4] Technologies such as RFID and IoT provide real-time monitoring of medication stock, strengthening safety measures and regulatory adherence. Wearable devices connected to pharmacy digital platforms enable continuous monitoring of patient health data, especially for chronic conditions. These tools facilitate timely interventions and allow pharmacists to tailor treatments more precisely, supporting the shift toward preventive and personalized care. Overall, these innovations have expanded the pharmacist's role significantly. Digital health infrastructures now support greater collaboration with other healthcare professionals, enable participation in multidisciplinary teams and enhance services such as patient counselling, disease screening and immunization. This transformation firmly positions pharmacists as essential contributors to holistic, patient-centered healthcare.[5]

FUTURE PERSPECTIVES ON DIGITAL AND AI TECHNOLOGIES IN PHARMACY

The coming years will bring major advancements in pharmacy practice as digital tools and artificial intelligence continue to evolve. Modern technologies such as deep learning, natural language processing and robotics are expected to play a key role in building a highly automated, accurate and patient centered healthcare system. AI based drug discovery platforms are already demonstrating the ability to evaluate large volumes of biochemical data and patient information far faster than traditional research methods, allowing the identification of promising drug candidates at an accelerated pace. Predictive analytics and continuous data monitoring are also likely to support more flexible clinical trial designs, lowering both development time and overall research costs. Pharmacy automation is predicted to become even more advanced. Robotic systems capable of compounding, dispensing and packaging medicines with high precision will help pharmacies manage growing patient loads, reduce staffing pressures and minimize medication errors across hospital and community settings. At the same time, progress in precision medicine will allow AI to combine genetic information, lifestyle patterns and environmental factors to create treatment plans tailored to individual patients. Such personalized approaches are expected to improve therapeutic outcomes and reduce unwanted side effects. As technology progresses, the responsibilities of pharmacists will change. Future pharmacists will be required to oversee and evaluate the functioning of AI systems, ensuring that these tools are used safely, ethically and effectively. AI supported learning platforms and simulation based training will increasingly be incorporated into pharmacy education, preparing professionals for a practice environment where digital systems play a central role. Greater adoption of AI will bring heightened attention to issues such as data security, fairness of algorithms, transparency and the need for strong regulatory oversight. Establishing clear guidelines and national standards will be essential to ensure patient safety and equitable access to AI driven healthcare benefits.[6,7]

AI IN PHARMACY FIELD

In the traditional pharmacy model, most tasks such as reading prescriptions, checking doses and dispensing medicines are performed manually. These activities are time consuming and vulnerable to human error. AI systems can streamline many of these routine functions by improving accuracy, reducing workload and supporting individualized therapy plans based on the patient's clinical history and real time data. This transition enhances both the efficiency and the overall quality of pharmacy services.[7] AI enabled pharmacy applications offer patients convenient access to medication instructions, drug interaction information and treatment reminders at any time of day. These tools are particularly valuable for people with mobility limitations or those living in remote areas. By analyzing patient data, AI can support personalized recommendations, monitor adherence and help reduce the risk of adverse reactions. Despite these advantages, there are limitations. AI cannot provide the emotional reassurance and empathy that patients may need from a human pharmacist. The accuracy of AI depends entirely on the quality of data it receives; incomplete or biased data can lead to misleading recommendations. Concerns related to informed consent, privacy and fairness must be addressed carefully. Implementing AI also requires significant resources, which can be challenging for smaller pharmacies. AI should not be seen as a replacement for human pharmacists. Instead, it serves as a supportive tool that frees pharmacists from repetitive tasks and provides data driven insights. This allows pharmacists to devote more time to patient counselling, clinical decision making and personalized care.[5,8]

ELECTRONIC HEALTH RECORDS (EHRS)

Electronic Health Records (EHRs) have transformed healthcare by making it easier to record and manage patient information digitally. In pharmacy practice, they are essential for improving patient outcomes, streamlining workflows and ensuring safer medication management. Despite their benefits, challenges such as limited interoperability between systems, data privacy concerns and the need for continuous staff training remain. Advances in technologies like artificial intelligence, blockchain and telehealth are expected to further enhance the efficiency, security and effectiveness of pharmacy services.[9,11]

IMPACT OF EHRS ON PHARMACY OPERATIONS

1. Medication Safety and Accuracy

EHRs give pharmacists real-time access to patient's medication histories, allergies and laboratory results, which plays a critical role in improving medication safety. By providing a complete picture of a patient's medical information, EHRs help pharmacists identify potential drug interactions, contraindications and dosing errors, thereby reducing the risk of adverse drug events. For example, electronic medication administration records (eMARs) have been shown to improve communication and efficiency among nursing staff, enhancing both the accuracy of drug administration and patient safety.[12]

2. Workflow Efficiency

Incorporating EHRs into pharmacy practice streamlines multiple processes, including prescription handling, inventory control and billing. Many EHR systems feature automated alerts and clinical decision support tools, enabling pharmacists to make timely and well-informed decisions. Adoption of EHRs in community pharmacies has also been linked to improvements in clinical services, research activities and funding opportunities, reflecting their broader operational benefits.[13]

3. Interprofessional Collaboration

EHRs provide a centralized platform where healthcare professionals can access and update patient information, fostering collaboration across disciplines. This shared access strengthens communication between pharmacists, physicians and other medical staff, supporting coordinated care and better patient outcomes. In community pharmacy settings, EHR integration has been shown to enhance access to pharmacist-led care services, improving overall healthcare delivery.[14]

LIMITATIONS OF EHRS IN PHARMACY PRACTICE

1. Interoperability Challenges: Despite technological advances, seamless data exchange between different EHR systems remains a major challenge. Pharmacy software often operates on the margins of interoperability initiatives, limiting interaction with other healthcare systems. This lack of integration can hinder efficient sharing of patient information and potentially affect the quality of care.[14]

2. Privacy and Data Security: The digitization of medical records raises concerns about patient privacy and data security. Protecting sensitive health information from cyber threats and unauthorized access is critical. Pharmacies must adopt strong security protocols and comply with legal regulations to safeguard patient data and maintain trust.[15]

3. Usability and Training: The technical complexity of EHR systems can be challenging for pharmacy staff. Issues such as poor system usability and steep learning curves can disrupt workflow and reduce efficiency. Providing adequate training and designing intuitive interfaces are essential for ensuring that pharmacy personnel can operate EHRs effectively.[16]

FUTURE PERSPECTIVES IN PHARMACY PRACTICE.[17,20]

1. Machine Learning and Artificial Intelligence (AI): Integrating AI and machine learning into EHR systems has the potential to revolutionize drug management. AI can analyze large datasets to optimize dosing, predict adverse drug reactions and support personalized treatment plans. These technologies are expected to improve the accuracy, efficiency and overall effectiveness of pharmacy care.

2. Blockchain Technology: Blockchain offers a secure, decentralized approach to recording transactions, which can enhance EHR functionality. By ensuring the integrity and traceability of electronic prescriptions, blockchain reduces the risk of drug errors and unauthorized access to sensitive data.

3. Telehealth Integration: The growth of telehealth allows pharmacy services to extend beyond traditional settings. By integrating EHRs with telehealth platforms, pharmacists can monitor patient progress remotely, provide virtual consultations and intervene promptly when necessary. Telehealth integration has been shown to improve patient outcomes, particularly in underserved populations.

AUTOMATED DISPENSING CABINETS (ADCS)

Automated Dispensing Cabinets (ADCs) are computerized systems designed to store and dispense medications at hospital points of care, such as wards, emergency departments and critical care units. They are typically implemented in hospitals using a decentralized medication management model, where centrally managed medications are distributed to multiple points of care. In this setup, ADCs act as localized drug storage units, allowing nurses to safely store, monitor and dispense medications accurately, whether patient-specific or drug-specific. The MedSMART ADC system consists of a main tower and an auxiliary tower. The main tower features a touchscreen interface that caregivers use to access, dispense, or refill medications, while the auxiliary tower provides additional storage capacity at the point of care. ADCs are designed to accommodate various medication forms, including single doses, multi-doses, blister packs, boxed medications, bottles, vials and ampoules.[21,23]

DISPENSING PROCESS

Nurses record medication administration using the ADC during scheduled dosing times. The system allows selection of either patient-specific or drug-specific medications. Prescriptions are displayed sequentially and guide lights highlight the correct drawers and compartments, ensuring accurate medication retrieval. On-screen instructions direct nurses to the exact location of each drug and a print option is available to support the administration process. ADCs also provide rapid access to medications in emergencies, ensuring that all stored drugs are immediately available when needed. The automated dispensing process is straightforward: the nurse searches for the medication by name and selects it for administration.[24,25]

MANAGEMENT OF HIGH-RISK MEDICATIONS.[26,29]

MedSMART ADCs store narcotics, controlled substances, high-alert drugs and expensive medications in secure sliding drawers with dual-lock access. This meets Joint Commission International (JCI) standards for safely managing high-risk medications. A "two-person rule" can be enforced, requiring a second authorized user to verify the transaction before accessing controlled substances, providing an additional security layer. Handling Drug Returns: During the medicine definition process, returned drugs are classified for either restocking in the cabinet or placement in a return bin for redistribution to other wards. Both types of returns can be efficiently processed within the ADC system, ensuring proper management and minimizing waste.

RETURNING MEDICATIONS IN AUTOMATED DISPENSING CABINETS (ADCS)

The process for returning medications to an ADC, either to the cabinet stock or a return bin, follows these steps:

1. The nurse logs into the ADC, selects the patient whose medications were not administered and chooses the "return" option.
2. From the patient-specific list of previously prescribed medications, the nurse selects the drug(s) and specifies the quantity to be returned.
3. The return is confirmed by pressing the return button. If multiple medications are being returned, the system sequentially opens the appropriate drawers or return bins.
4. On-screen instructions and visual indicators guide the nurse to the correct location for returning each medication.

KEY BENEFITS OF ADCS

ADCs automate the management of medications at points of care in hospitals, improving safety, efficiency and accuracy. They enable secure storage, precise dispensing and continuous monitoring of medications, reducing errors and wastage. By streamlining drug handling, ADCs allow pharmacy and nursing staff to focus on clinical patient care rather than manual inventory tasks.

ADVANTAGES AND CHALLENGES OF ADC IMPLEMENTATION

Automated Dispensing Cabinets, first introduced in hospitals in the 1990s, are computerized systems that store and dispense medications securely at the point of care. ADCs control and monitor user access, enhance medication distribution tracking and improve inventory management. Key advantages include simplified medication handling, optimized workflow efficiency, cost savings and improved quality of patient care. By reducing clerical workload, ADCs allow healthcare professionals to devote more time to direct patient care.

Evaluating the impact of ADCs can be challenging, especially when integrated with other digital health systems. Pharmacy departments often lead ADC implementation initiatives and a clear understanding of potential benefits and measurable objectives is essential before deployment. A well-defined implementation strategy, along with a focus on realizing benefits, is crucial to ensure successful adoption and efficient resource allocation. Challenges, including system integration, upfront costs and return on investment considerations, must be addressed during planning. While ADCs offer clear advantages, there is limited comprehensive research evaluating their standalone benefits, making scoping reviews valuable for mapping the current evidence. Such reviews can identify knowledge gaps, provide insight into system optimization and guide organizations in achieving maximum efficiency and patient safety from ADC deployment.

MEDICATION MANAGEMENT TECHNOLOGIES.[30,38]

1. Electronic Prescribing, CPOE and Clinical Decision Support (CDSS): Electronic prescribing (e-prescribing) and computerized physician order entry (CPOE) replace handwritten prescriptions, improving clarity, completeness and transmission to pharmacies. When integrated with clinical decision support systems (CDSS)—including dose calculators, allergy/drug interaction alerts and renal dosing guidance—these tools significantly reduce prescribing errors and potential adverse drug events (ADEs). Early trials demonstrated substantial reductions in missed-dose errors with CPOE, with additional benefits when decision support was included. Systematic reviews generally show lower error rates, although variability in study quality and settings complicates assessment of downstream outcomes such as length of stay or mortality.

Despite benefits, CPOE can introduce new types of errors (e.g., incorrect selection from long picklists, default dose misuse) and workflow challenges. Effective CDSS implementation requires careful attention to usability, order set management and alignment with clinical workflows. To prevent alert fatigue, contemporary strategies emphasize tiered, context-specific alerts and ongoing evaluation of override patterns. For older adults, CDSS targeting potentially inappropriate medications (PIMs), integrated with renal/hepatic dosing, frailty markers and deprescribing guidance, can mitigate high-risk prescribing.

2. Medication Administration: BCMA and eMAR: Barcode Medication Administration (BCMA) applies the "five rights" of medication administration—patient, drug, dose, route and time—via barcode scanning of wristbands and medications at the bedside. Integration with electronic medication administration records (eMAR) ensures accurate documentation. Studies across inpatient settings, including oncology and general wards, report reductions in administration errors and their severity. Effective BCMA implementation depends on compliance with scanning protocols, workflow integration and supporting infrastructure (labeling, wireless coverage). Workarounds such as scanning outside the patient room or reading labels from charts can undermine safety benefits. Human factors interventions, including ergonomic bedside devices, consistent barcode quality and real-time scan compliance dashboards, are critical. Integration with e-prescribing ensures a single source of truth across ordering, dispensing and administration.

3. Smart Infusion Pumps and Interoperability: Smart infusion pumps equipped with dose error reduction systems (DERS) and drug libraries prevent programming errors in high-alert IV medications. While soft limits alone provide limited benefit, maintaining accurate drug libraries and hard limits is essential. Interoperability with EHRs allows auto-programming of orders and automatic documentation of infusions in eMARs, significantly reducing administration errors. Adult and pediatric studies show a ≥16% decrease in medication errors and fewer high-risk overrides when interoperability is implemented. Key factors for optimization include library governance, wireless coverage, biomedical engineering support and analytics for monitoring overrides.

4. Radio-Frequency Identification (RFID) and Real-Time Location Systems (RTLS): RFID technology complements barcodes, enabling batch scanning and real-time tracking of medication trays, kits and occasionally patients. RFID improves tray verification, expiration tracking and replenishment efficiency, reducing errors and turnaround times. While growing in healthcare, RFID implementation requires careful consideration of electromagnetic compatibility, privacy and standardization.

5. Medication Reconciliation (MedRec) Technologies: Electronic MedRec tools support collection of the Best Possible Medication History (BPMH), comparison with active orders and resolution of discrepancies during care transitions. Systematic reviews show reduced unintended discrepancies, particularly omissions, although effects on readmissions and ADEs are inconsistent due to study heterogeneity. Effective systems integrate multi-source medication lists (EHRs, pharmacy fills, health information exchanges) and incorporate pharmacist workflows with interfaces highlighting high-risk discrepancies. Machine learning models are increasingly used to identify patients at risk of MedRec-preventable harm.

6. Telepharmacy and Virtual Care: Telepharmacy extends pharmacist services to remote or underserved locations through video or phone consultations, remote order review and chronic care management. Evidence shows telepharmacy is feasible, well-received by patients and may reduce costs while improving safety and workload efficiency. Use cases include medication counselling, toxicity monitoring, adherence follow-up and post-discharge care that complement eMedRec and eMAR systems.

7. Medication Adherence Technologies (mHealth, Smart Bottles, Digital Pills): Mobile health applications, intelligent pill bottles with sensors and reminders and ingestible sensor-enabled "digital pills" support medication adherence. Meta-analyses and RCTs demonstrate improved adherence across conditions such as oncology, HIV and multiple sclerosis, often enhancing patient self-efficacy. Smart bottles provide electronic dose tracking, while ingestible sensors offer near-real-time ingestion confirmation, although cost, privacy and long-term efficacy remain concerns. Effective adherence interventions combine behavioral support, clinician integration and robust data governance.

8. Pharmacogenomic (PGx) Clinical Decision Support: PGx-CDSS integrates patient genetic data with prescribing to prevent drug–gene and drug–drug–gene interactions. Implementations often combine PGx with standard interaction checking, providing clinician-friendly summaries. Early experiences suggest promise for optimizing therapies such as analgesics and psychotropics, though more outcome data and broader access are needed.

9. Artificial Intelligence (AI), Natural Language Processing (NLP) and Safety Surveillance: NLP extracts medication information from free-text clinical notes for automated reconciliation, ADE detection and safety signal generation. Machine learning models help identify patients at high risk of medication errors or nonadherence, supporting targeted pharmacist interventions. Transparency, bias mitigation and prospective evaluation are essential before routine clinical deployment.

Cross-cutting implementation lessons.[39]

Importance of strong infrastructure, coordinated governance and a people-centered design approach. Ensuring interoperability is foundational, as seamless integration across e-prescribing platforms, pharmacy verification systems, automated dispensing cabinets, barcode medication administration/eMAR and smart pumps maximizes safety and workflow efficiency. Effective governance and change management further support success, requiring multidisciplinary oversight of drug libraries, order sets and alert rules, along with continuous evaluation of overrides and workflow adjustments. Human factors must be prioritized by designing systems that reflect real bedside conditions, incorporating ergonomic workflows, clear labeling, intuitive interfaces and role-specific training. Robust measurement is essential and should encompass both process indicators—such as scanning adherence, alert override appropriateness and DERS compliance—and outcome metrics like medication error rates and preventable adverse drug events. Ethical and equitable implementation is also critical, ensuring that telepharmacy services and adherence technologies address digital access barriers and that innovations such as ingestible sensors uphold privacy and informed consent. Finally, scalability and sustainability depend on adopting standards-based architectures, including FHIR and NCPDP SCRIPT, as well as vendor-neutral data stores and advanced analytics platforms that support enterprise-wide learning and long-term system evolution.

TELEPHARMACY AND REMOTE PHARMACY SERVICES.[40]

Telepharmacy involves providing pharmacy services remotely using communication technologies such as video calls, phone, messaging and secure access to electronic health records (EHRs). Services include order verification, medication reconciliation, patient counselling, chronic disease management, toxicity monitoring and post-discharge follow-up. Telepharmacy can be delivered through:

- **Synchronous models:** Real-time video or telephone consultations.
- **Asynchronous models:** Secure messaging or portal-based communication.
- **Hybrid models:** Combining remote order verification with scheduled consultations.

Adoption has accelerated since the COVID-19 pandemic, expanding into ambulatory, hospital and home care environments. Evidence indicates improvements in clinical outcomes, operational efficiency and cost-effectiveness, although results vary.

CORE SERVICE MODELS.[41,43]

- **Remote Order Verification (ROV):** Pharmacists review medication orders off-site, often 24/7, maintaining workflow continuity during staffing shortages. Studies show remote verification can preserve or improve order processing, with hybrid models demonstrating similar turnaround times to on-site services.
- **Outpatient Synchronous Consultations:** Video or phone consultations are used for patient education, adherence monitoring, dose titration and toxicity review. Evidence highlights better timeliness, individualized counselling and reduced staff workload.
- **Medication Histories and Reconciliation:** Remote pharmacists or pharmacy technicians collect the Best Possible Medication History (BPMH) prior to admission or discharge. Observational studies indicate this approach is feasible and supports policy development, particularly in rural or surge scenarios.
- **Chronic Disease Management:** Pharmacist-led telehealth interventions for hypertension, diabetes and polypharmacy have demonstrated reductions in blood pressure and HbA1c in multiple trials.

CLINICAL EFFECTIVENESS.[44,45]

- **Hypertension:** Remote follow-ups, including home BP monitoring and dose adjustment, improve blood pressure control and reduce medication-related issues compared with standard care.
- **Diabetes:** Telepharmacy interventions have been associated with lower HbA1c levels and reduced hypoglycemia risk, though further high-quality trials are needed to compare outcomes with face-to-face care.
- **General Telehealth Outcomes:** Reviews from 2023–2025 report positive impacts on medication knowledge, adherence, symptom monitoring and access, though standardization of outcome measures remains a challenge.

Operational Performance and Workforce: Studies from the pandemic period show that remote pharmacists can maintain or increase order verification volumes and ensure continuity during emergencies or in geographically dispersed settings. Staffing models consider the need for remote verification and technician support. In ICUs and specialty units, remote participation in rounds has been shown to be as effective as in-person interventions.

Economic Considerations: Telepharmacy may offer cost savings by reducing travel time and improving allocation of pharmacist resources. However, stronger cost-utility studies are needed to fully evaluate its economic impact, especially post-pandemic.

Patient Experience, Access and Equity: Patients report high satisfaction due to convenience, reduced travel and easier follow-up, particularly in rural or mobility-limited populations. Participation depends on digital literacy, disease knowledge and familiarity with telehealth tools, highlighting the need for onboarding and technical support to address digital disparities.

Safety and Quality: Telepharmacy maintains clinical safety when workflows ensure EHR access, verification and documentation standards. Remote histories and multidisciplinary tele-rounding preserve accuracy and safeguard against errors. Programs should monitor intervention acceptance, time-to-verification, discrepancies and medication-related issues.

IMPLEMENTATION GUIDELINES.[47,50]

1. **Define Scope and Protocols:** Specify which services are delivered remotely (ROV, BPMH, discharge counselling, chronic disease management) and determine inclusion criteria and escalation pathways.
2. **Platform Integration:** Use secure, HIPAA-/GDPR-compliant platforms integrated with EHRs for scheduling, documentation and order management.
3. **Staffing and Training:** Prepare hybrid rosters, provide guidance on connectivity, privacy, ergonomics, virtual communication skills and remote device use.
4. **Patient Onboarding:** Conduct pre-visit technology checks, provide language support and offer clear instructions; address low digital literacy proactively.
5. **Measurement:** Track adoption (attendance, visit duration), clinical outcomes (BP, HbA1c), process metrics (verification times, discrepancy resolution), patient-reported outcomes and economic metrics (travel saved, staff efficiency).
6. **Governance and Security:** Establish documentation standards, electronic consent procedures, data retention policies, incident response plans and conduct periodic audits.

Special Populations and Settings.[51,53]

- **Oncology and Specialty Medications:** Remote follow-ups are used for toxicity monitoring and adherence support, reducing clinic workload and improving pre- and post-treatment assessments.
- **Investigational Drugs:** Remote verification supports protocol adherence and maintains turnaround times equivalent to on-site processes.
- **Primary Care:** Telepharmacy enhances physician/nurse telehealth services, supporting deprescribing, polypharmacy review and risk-based interventions.

CHALLENGES AND PITFALLS

Current research on telepharmacy and digital adherence technologies is largely limited to single site or observational studies, highlighting a need for more rigorous randomized controlled trials and standardized outcome measures. Digital inequities present another barrier: limited internet connectivity, insufficient access to devices and low technology literacy may restrict patient participation. Programs should address these gaps by offering multilingual interfaces and low bandwidth options such as SMS or phone-based services. Regulatory variability further complicates implementation, with differences in licensure, taxation, cross border practice and reimbursement requirements across jurisdictions. Telepharmacy workflows are also vulnerable to drift; without clearly defined protocols, informal or ad hoc communication can fragment documentation. Structured tools integrated into electronic health records, along with routine audits, are essential to maintain workflow integrity.[54,55]

TELEPHARMACY PLATFORMS

Telepharmacy leverages telecommunications, primarily video conferencing, secure messaging and telephone, to deliver pharmaceutical care remotely. Services range from centralized pharmacist validation centers and remote dispensing verification to direct to patient consultations, including medication reconciliation, adherence counselling and chronic disease management. Telepharmacy gained momentum during the COVID 19 pandemic as a solution for infection control and access and has evolved into permanent service models in both outpatient and community pharmacy settings. Core services include prescription verification through secure portals, real time patient counselling covering drug education and device technique, medication therapy management and remote monitoring for adverse effects and adherence. Integration with electronic health records and pharmacy management systems provides pharmacists with access to medication histories, lab results and clinical notes, supporting safe clinical decision making. Evidence indicates telepharmacy maintains or enhances medication safety and patient comprehension, especially in rural or underserved populations. Systematic reviews show improved access to pharmacist care, high patient satisfaction and potential reductions in medication errors and hospital admissions, although study designs and outcomes remain heterogeneous. Implementation challenges include cross border regulatory differences, privacy and data security concerns, technology literacy and alignment with existing dispensing workflows. Successful deployment relies on secure, interoperable platforms, workflow redesign, staff training in remote counselling and continuous quality monitoring. Reimbursement and regulatory clarity significantly influence adoption and service quality. Innovative applications include the integration of remote patient monitoring data and artificial intelligence driven triage to prioritize pharmacist interventions.[56,58]

MOBILE HEALTH APPLICATIONS

Mobile health applications on smartphones and tablets support medication adherence, patient education and remote symptom or physiologic monitoring. Common functions include refill reminders, interactive dosing calendars, visual pill representations, adherence logs, two way messaging with pharmacists and automated refill requests. Systematic reviews indicate that these applications improve adherence, particularly when they incorporate behavior change techniques such as reminders, feedback and social support and involve care team participation. Effectiveness depends on app quality, personalization including timing and language, integration with clinician workflows, follow up duration and baseline adherence levels. Simple reminder only apps demonstrate smaller effects. Usability, privacy and digital equity considerations, such as device access and older user populations, affect real world outcomes. From a pharmacy operations perspective, mobile health applications reduce missed doses, automate refill requests, free pharmacist time and provide objective adherence data for use in medication therapy management. Integration challenges include inconsistent application programming interfaces, variable clinical validation and regulatory concerns when apps provide therapeutic guidance. Best practices include co design with end users, evidence based behavior change elements, strong data security, interoperability with electronic health records using FHIR and HL7 standards and clear reimbursement and documentation pathways. Hybrid models combining applications with pharmacist interventions appear most effective for sustained adherence improvements.[59,61]

WEARABLE DEVICES FOR ADHERENCE MONITORING

Wearable devices, such as smartwatches, sensor patches, wristbands and instrumented pillboxes, offer continuous, objective monitoring of physiological and behavioral data including activity, heart rate, motion patterns and proximity to mobile devices. These data streams can infer medication taking behavior and enable near real time pharmacist interventions, supplementing self report and pharmacy refill records. Wearables can detect specific medication taking actions or provide contextual cues to improve adherence measurement. Some systems use sensors to validate swallowing or track proxy events, integrating machine learning algorithms to distinguish medication events from other activities. Personalized predictive models generated from wearable data can identify probable missed doses, allowing timely intervention. Although promising, current evidence is preliminary. Studies are often small, short term, or prototype based. Limitations include sensor accuracy, false positives and negatives, battery life, patient burden, privacy concerns and a lack of validated algorithms across diverse populations.[62] Integration with electronic health records and establishing actionable thresholds for pharmacist intervention remain significant challenges. Looking forward, wearables could enable risk stratified outreach, personalized counselling and real-world research on medication effectiveness. Integrating wearable data with mobile health applications and telepharmacy platforms creates a comprehensive ecosystem for remote medication management.[63]

FUTURE ADOPTION OF DIGITAL TECHNOLOGIES IN PHARMACY.[64,69]

Pharmacy practice is rapidly evolving as digital technologies shift from experimental implementations to core operational systems, transforming the processes of medication procurement, preparation, verification and distribution. Innovations in artificial intelligence enhance clinical decision-making, automate routine tasks and analyze large datasets to anticipate medication-related risks and optimize therapy. Telepharmacy, which delivers pharmacist services remotely via telecommunications, has expanded access to pharmaceutical care, particularly for rural and underserved populations and is expected to remain a key service model post-pandemic. Automation and robotics in dispensing and aseptic preparation reduce errors, accelerate workflow and allow pharmacists to focus on patient-centered clinical activities. Blockchain and distributed ledger technologies offer improved traceability in supply chains, potentially reducing counterfeit drugs and improving recall processes. AI applications in pharmacy primarily target three areas: supporting clinical decision-making, automating verification and administrative tasks and enabling predictive analytics for inventory management and patient risk stratification. AI-driven clinical decision support can integrate electronic health records, laboratory results and pharmacogenomic data to guide dosing adjustments, identify interactions and prioritize medication reconciliation. Natural language processing and machine-vision tools are being implemented to verify prescriptions, interpret free-text orders and detect anomalies before medications reach patients. Furthermore, AI models are being developed to identify individuals at risk of non-adherence or adverse drug events, enabling targeted pharmacist interventions to improve outcomes. Telepharmacy is increasingly integrated into standard pharmacy workflows, supporting remote medication counselling, virtual reconciliation and synchronous verification of technician-dispensed medications. Regulatory frameworks and reimbursement models will influence the scale of telepharmacy adoption, though evidence suggests it can safely expand care access. Telepharmacy is particularly valuable in settings with pharmacist shortages and for specialized services such as anticoagulation management, chronic disease therapy monitoring and post-discharge follow-up. Robotic dispensing systems are evolving from centralized high-throughput units to modular, distributed configurations suitable for hospitals and community pharmacies. These systems enhance inventory accuracy, reduce unit-dose errors and integrate barcode or RFID verification to maintain closed-loop audit trails. While automation improves efficiency, human oversight remains essential, with pharmacists focusing on clinical screening, exception handling and patient education. Intelligent medication packaging, networked dispensers and wearable adherence monitoring devices provide real-time adherence feedback while maintaining privacy and consent. These systems can feed data into dashboards or AI-driven alerts, allowing pharmacists to proactively intervene in case of missed doses or tolerance issues. Evidence of improved outcomes from adherence technologies is promising but variable; effective implementation requires patient engagement, clear escalation pathways and integration with electronic health records. Pharmacogenomics, integrated with clinical decision support and electronic health records, will become a cornerstone of precision pharmacotherapy, with pharmacists interpreting genotypes to provide individualized recommendations. Decision support tools must align with the “five rights” of guidance—right information, right person, right format, right channel and right time—to ensure clinical relevance. As genotyping becomes more affordable and guideline adherence improves, pharmacogenomics is expected to transition from specialized settings into routine medication reviews and prescribing support. Blockchain technologies are being explored for high-value medications, cold-chain vaccines and controlled substances, providing immutable records and enhanced transparency among stakeholders. Key challenges include integration costs, privacy, governance and the lack of universal standards. Interoperability remains critical; without open APIs and consistent data standards, digital solutions may remain siloed, limiting the sharing of medication, allergy and pharmacogenomic information across systems. Pharmacy leaders should actively engage in national health information exchanges, adopt standards like FHIR and participate in data governance initiatives to integrate medication workflows into broader care pathways. Ultimately, human factors, workforce training and effective change management will determine whether digital technologies achieve their intended benefits. Pharmacists will require digital literacy, proficiency in interpreting AI outputs and competencies for managing exceptions from automated systems to ensure patient safety. Regulatory policies and reimbursement frameworks will also dictate the adoption and scaling of technologies, including telepharmacy reimbursement, liability for AI-based recommendations and data sharing rules. The future of pharmacy is likely to be an interconnected ecosystem where telepharmacy, AI, robotics, adherence monitoring tools, pharmacogenomics and blockchain work in concert to enable safer, more personalized and efficient medication management. Achieving this vision depends on investment in interoperable technologies, workforce preparation, supportive regulation and rigorous real-world validation to ensure that digital tools complement pharmacist expertise and improve patient outcomes.

CONCLUSION

Digital technologies are transforming pharmacy practice by enhancing medication management, patient counselling and overall healthcare delivery. Tools such as automated dispensing systems, telepharmacy, electronic health records and mobile health applications reduce errors, improve adherence and streamline workflows. They empower pharmacists to engage in personalized medicine and population health management through real-time data and decision-support systems, strengthening patient safety and relationships. Despite rapid advancements, challenges remain, including data privacy, system integration, workforce adaptation, regulatory alignment and cost considerations. Addressing these barriers will enable pharmacies to evolve into technology-driven, patient-centered care hubs, leveraging AI, robotics, blockchain and wearable devices to optimize outcomes.

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