



A scientific review on the transformative digital health impact on modern pharmacy: trends and patient-centric outcomes

Astha Ghosh*, Sayan Mondal, Rajat Das, Jyochhana Priya Mohanty
Department of Pharmacognosy, Himalayan Pharmacy Institute, Majitar, Sikkim - 737136

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Abstract

The incorporation of digital health into modern pharmacy practice has brought about a new age of convenience, availability, and personalised healthcare services that have changed how patients are taken care of and how their prescriptions are given. This paper provides an insightful discussion of the evolving role of digital health in pharmacy with a focus on new developments and their impact on patients. By removing geographical boundaries and increasing access to healthcare services, digital health technologies including tele pharmacy services, mobile health applications, and virtual consultations have revolutionised the traditional pharmacy paradigm. Chemists can now communicate with patients remotely through digital platforms, provide drug prescriptions, monitoring, and adherence support. These changes make patients feel better, give individuals more control over their health, and ultimately result in improved health outcomes. Also, to enhance pharmaceutical treatment and personalised care, digital health solutions utilise the latest technology, such as artificial intelligence (AI), and data analytics. The algorithms are AI-based and analyse the data on patients to identify patterns, predict health outcomes, and optimize drug schedules, which lead to improved treatment plans and reduced prescriptive errors. Moreover, digital health also promotes teamwork and communication between healthcare professionals, making it easier to ensure smooth care coordination and improve patient outcomes. Interoperability and secure electronic health records can provide pharmacists with complete patient data, which can enhance patient safety and make informed decisions. However, there are obstacles to the adoption of digital health in pharmacies, including as differences in patient computer literacy, regulatory complexity, and data privacy issues. To ensure that digital health technology is utilized morally and efficiently in pharmacy practice, there is a need to address these issues. In summary, the incorporation of digital health into contemporary pharmacies signifies a paradigm change in the provision of patient care, providing previously unheard-of chances to improve accessibility, effectiveness, and care quality. By applying new digital health trends, pharmacists can change the way they administer prescriptions, boost patient engagement, and eventually change the health outcomes of communities and individuals.

1. Introduction:

Digital health is transforming pharmacy to incorporate information and communication technologies (ICT) into practice and make it more than dispensing of medication to proactive clinical care. By detecting and preventing errors in real-time, expanding access to underserved regions with remote services, and personalizing care with patient-specific data, this integration improves medication safety, expands access to underserved regions, and personalizes therapy [1,2,3,4].

1.1. Core Technologies

The most prominent devices that have been used to accomplish this evolution are telepharmacy, artificial intelligence (AI), mobile health (mHealth) applications, and electronic health records (EHRs). Telepharmacy enables remote consultations and verification and the global market size is projected to increase to USD 17.46 billion in 2032 at 6.19% CAGR since the demand to manage chronic diseases virtually is soaring. AI algorithms are used to

predict adverse events by analysing pharmacovigilance data in order to optimize dosing, and to drive adherence through mHealth applications by sending reminders and monitoring; EHRs facilitate a seamless data interoperability to make informed decisions [2,5,6,7].

1.2. Patient Impacts

Such technologies are proven to increase the results: AI-enhanced systems decrease medication errors by notifying about interactions, and online platforms have increased telehealth use four times, 11% in 2019 to 46% in the post-pandemic period, contributing to safety and equity. Individualization through mHealth and EHRs help to administer accurate treatment, reducing the side-effects in complicated cases. Given scalability, the digital pharmacy market, which is USD 131.3 billion in 2024, will grow to USD 320.4 billion in 2030 (16% CAGR) [3,8,9,1].

1.3. Paradigm Shift

The shift of pharmacy towards a clinical (previously 78% bed coverage weekdays) rather than dispensing role is

noticeable: the pharmacist now has 1,221 interventions per year with 91.5% acceptance (including reconciliations, pharmacokinetics and discharges). This interprofessional collaboration and surveillance of the public health is supported by this patient-centred model magnified by digital tools [10-12].

This background makes digital health the central point in the future of pharmacy in terms of value care [4,13].

2. Telepharmacy Impact Metrics

Telepharmacy is a digital application that is used to extend the pharmaceutical services to locations further away to significantly increase access in rural and underserved regions with workforce shortages. It enhances the quality of counselling, maintains refill continuity, reduces travel requirements, and makes continuous monitoring of therapy, all with high levels of adherence and satisfaction in rigorous research [14].

2.1. Rural Access Gains

Telepharmacy fills the gaps in resource scarce areas, allowing 24/7 verification and consultations in areas where on-site pharmacists do not exist; U.S. rural hospitals report improved processing of orders and medication

reconciliation with telepharmacy. Twelve months of trial in underserved areas using 200 patients increased access 4-fold, reducing the proportion of dispensing errors to 5% (p<0.01)[14,15].

2.2. Operational Improvements

Personalized counselling and follow-ups with virtual counselling increase adherence rates (60% vs. 85% p<0.001) and 75% reached 80% adherence (or higher) after intervention. Apps/IVR and refill automation reduce waiting time, limiting the expenses of travelling and increasing chronic disease management (e.g. blood pressure/glucose). The 10-35% uplifts and 20-40% drops of drug-related issues are confirmed by systematic reviews of five countries [14,16,17].

2.3. Patient-Centric Outcomes

The level of satisfaction is high, as the scores are 4.5/5 and 86.7 per cent willingness to continue, economic benefits are the decrease of per-patient costs to 1500-2000, hospitalizations per 1000 to 30-50 (p<0.01). The provider acceptance is almost 90% which highlights equity improvements [14,18,19].

Technology	Key Benefit	Market/Projected Growth (2024-2032)	Patient Outcome Improvement
Telepharmacy	Remote access	USD 10.79B to 17.46B (6.19% CAGR) [6]	46% adoption rise [1]
AI	Error prediction	Enhances pharmacovigilance [7]	Reduced adverse events [2]
mHealth/EHR	Personalization	Digital pharmacy to USD 320.4B by 2030 [1]	91.5% intervention acceptance [12]

Table 1: Patient improvement using modern technology

Impact Area	Pre-Telepharmacy	Post-Telepharmacy	Effect Size (p-value)
Adherence Rate	60%	85%	+25% (p<0.001)
Dispensing Errors	15%	5%	-10% (p<0.01)
Patient Costs	\$2000	\$1500	-\$500 (p<0.01)
Hospitalizations/1000	50	30	-20 (p<0.01)
Satisfaction Score	Baseline	4.5/5	High (86.7% willing)

Table 2: Comparative Analysis of Pre- and Post-Telepharmacy Outcomes Demonstrating Significant Improvements in Adherence, Reduction in Errors, Costs, Hospitalizations, and Enhanced Patient Satisfaction

AI Application	Key Metric	Reduction/Improvement	Evidence Base
DDI Detection	Error Rate	66% via reconciliation [22]	Hospital ML trial (n=110)
Adherence Prediction	Accuracy	>85% [31]	Reinforcement learning models
Personalized Dosing	Variability	40-50% [27]	CURATE.AI in chronic disease
Medication Errors	Incidence	30-50% [26]	Meta-analysis, EHR integration
ADEs	Events	25% [28]	Real-time CDSS alerts

Table 3: Impact of Artificial Intelligence Applications on Medication Safety, Adherence, and Clinical Outcomes

These statistics support the revolutionary nature of telepharmacy in fair care provision [14,20].

3. AI & Clinical Decision Support

Artificial intelligence (AI) transforms the clinical decision support in pharmacy by identifying drug-drug interactions (DDIs), predicting adherence tendencies and adverse events, optimal personalized dosing, and reducing medication errors with the help of advanced prescription screening and analytics. These skills allow pharmacists to go from reactive dispensing to proactive and data-driven interventions, which greatly improve the safety of patients and the accuracy of their treatments [21-24].

3.1. Core AI Mechanisms

AI models, such as machine learning models, scan large databases of pharmacovigilance data to issue real-time warnings of DDIs; e.g. pharmacokinetic data used to generate risk-stratified notifications is available in platforms such as Lexicomp, reducing up to 66% of errors in the reconciliation process. Predictive analytics is a non-adherence (accuracy >85) and adverse event predictor that uses reinforcement learning to predict these events by modelling patient covariates such as genetics and comorbidities. In dosing, CURATE.AI is dynamic in regimens, which has decreased variability by 40-50% in chronic disease like hypertension [22,23,25,26,27].

3.2. Error Reduction Impact

Implemented as part of electronic health records (EHR)-connected systems, AI enhances the identification of high-risk prescriptions: a trial in a hospital setting with ML prioritization on 110 at-risk patients found 45% of the patients with discrepancies-113 more than randomly chosen-average thereby preventing possible harm. The meta-analysis has shown a rate of 30-50 percent reduction in dosing errors, 25 percent reduction in adverse drug events (ADEs), and AI has been found to be superior to traditional rules-based technology. Model-informed precision dosing (MIPD) through AI

reduces under- and overdosing effects of warfarin treatment through incorporation of pharmacogenomics in pharmacometrics [24,26,28].

3.3. Clinical and Economic Improvements

In outpatient screening, AI-based screening results in 91% acceptance of alerts by pharmacists, which reduces hospitalizations by 20% and the cost by 15-25 cases. Longitudinal studies confirm the sustained adherence gains ($p < 0.01$) especially in polypharmacy patients [21,29,30].

These developments affirm the importance of AI in the pharmacy practice that is error-resistant [21,30].

4. mHealth & EHR Integration

Digital pharmacy has a synergistic foundation of mHealth applications and Electronic Health Record (EHR) integration, providing medication reminders, patient education, wearable-based vital signs monitoring, and easy data transfer between care teams. This convergence will enable the pharmacists to proactively track patient adherence, refine treatment in real time, and promote interprofessional collaboration, ultimately enhancing chronic disease care and minimizing fragmentation of care [32-35].

4.1. mHealth Core Functions

Mobile apps use push notifications and gamified reminders, and improve adherence by 20-30 percent in cardiovascular cohorts; an example is Heart Guardian which plans with video feedback, resulting in 15 percent improved lipid control. Health literacy is improved by educational modules of drug actions and lifestyle integration, and 8/14 reviewed apps had sustained quality-of-life improvements ($p < 0.05$). Fitbit and Apple Watch (e.g. wearables) are connected to AI-driven anomaly detection by streaming heart rate, SpO2, glucose, and activity data through the Bluetooth connection, which can be used to adjust the dose after anomaly detection [34].

Component	Feature	Outcome Metric	Evidence (n)
mHealth Apps	Reminders/Education	+20-30% adherence [34]	11/14 apps (Asia RCTs)
Wearables	Vitals Tracking	15% biomarker control [38]	Lipid/glucose cohorts
EHR Integration	Care Team Sharing	25% reconciliation speed [39]	PeCP-EHR pilot
Combined	Decision Support	18% error reduction [37]	Shared record trials
Overall	Engagement	40% communication gain [32]	4 real-time studies

Table 4: Effect of Digital Health Technologies on Clinical and Patient Engagement Outcomes

4.2. EHR-Pharmacy Linkage

HL7 FHIR EHR interoperability provides pharmacy silo bridging allowing read-write access to bidirectional updates to PeCP; a University of Tennessee pilot study showed 25% faster reconciliations and 18% fewer errors. Utlmacy uploads real-time vitals aid in the decisions of clinicians--four reports show increased activity and timely interventions in diabetes/hypertension. The delegation and communication of tasks and curbing duplication are reported by community pharmacists with access to shared records, 40 percent better [32,36,37].

4.3. Quantified Patient Impacts

Clinical wins are attained with integration: 6/14 apps reduced adverse events and increased physical activity and 12 improved satisfactions. Prices are reduced by 15 percent through efficient processes, which reduce paperwork and manual processes. Integrated programs have 85% longitudinal data retention [32,34].

This ecosystem will drive pharmacy to patient-centred, data-driven care [32,35].

5. Electronic prescribing

Electronic prescribing (e-prescribing) replaces handwritten prescription orders with a safe, digital relay of prescriptions between prescribers and pharmacies, which basically improves the accuracy, speed of workflow, adherence and safety throughout the MD-

pharmacy pipeline. It reduces misinterpretations, historically involved in 20-30% of dispensing problems, by automating legibility checks, formulary integration and providing real-time alerts, and is able to streamline operations in high-volume ambulatory environments [40-43].

5.1. Error Elimination

Handwriting errors, which caused 7-15% of medication errors, have dropped by 83% with e-prescribing, with standardized formats and DDI warnings (83 vs. 38.4 per 100 prescriptions, $p=0.001$) and near-misses have decreased by half (1.3 vs. 2.7 per 100, $p=0.0$). Avoidable adverse drug events (ADEs) trend is reduced by 85 percent (0.04 vs. 0.26 per 100) especially in polypharmacy [43,44].

5.2. Workflow Acceleration

The prescription entry only contributes 20 seconds per patient, but balances through the reduction of clarifications and automated refills, which result in 6-minute-dailies-per-prescriber net gains in spite of 20-patient loads. Auto-labelling and refill routing of pharmacies compresses the time of dispensing 25-40% and relieves the workload during bulk processing. Chain pharmacies are standardized through integrated systems and this increases efficiency compared to that of independents [40,42].

5.3. The compliance and Safety Benefits

The use of e-prescribing to promote first-fill adherence

Metric	Pre-e-Prescribing	Post-e-Prescribing	Improvement (p-value)
Errors/100 Rx	38.4	6.6	83% ($p<0.001$)
Near-Misses/100	2.7	1.3	52% ($p<0.001$)
ADEs/100 Rx	0.26	0.04	85% trend ($p=0.26$)
First-Fill Adherence	Baseline	+10%	\$140B potential savings
Dispensing Time	Standard	-25-40%	Workflow streamlined

Table 5: Effect of e-Prescribing on Medication Safety and Healthcare Efficiency

by 10% (Compared to no adopters), which could save up to \$140 billion over 10 years because of formulary-driven low-cost generics and access to history. Continuity is promoted through real-time eligibility checks and renewals, and 40% of the routes were electronic, which have a better pickup rate. These were magnified post-COVID to reduce the disruptions and increase security [40,45].

5.4 Pipeline Integration

The online channel provides two-way EHR-pharmacy flow, preventing redundancy and team coordination; research in the community demonstrates that workflow stability can be achieved despite the initial challenges [46,47]. The data highlights the importance of e-prescribing in strong, patient-safe pharmacy systems [40,43,48].

6. Difficulties in Digital Health Pharmacy

The challenges facing digital health innovations in pharmacy are complex and include data privacy, cybersecurity, lack of digital literacy, regulatory obstacles, ethical traps such as bias in algorithms and lack of transparency. Such obstacles jeopardize fair utilization, confidence among the patients, and medical integrity during the fast-tracked adoption [49,50,51,52].

6.1. Data Security and Privacy

Pharmacy websites contain sensitive PHI and PII, which makes them the biggest target of ransomware; 1 out of 3 hospitals in the United States was breached in 2024 with digital prescriptions being at risk of interception due to weak encryption and API vulnerabilities. Fines of HIPAA violations range between 50,000 to 1.5M per event, which undermines trust- just 62% of patients have trust in data management. Multi-layered security, such as zero-trust and artificial intelligence (AI) anomalies detection, is necessary [53,54].

6.2. Digital Literacy Gaps

The app proficiency of older adults (65+) is 40% less, which impedes mHealth compliance; surveys show that 35% of pharmacists in rural areas do not have high levels of digital skills, which is a further contributor to urban-rural inequalities. Specific training increases

preparedness 25-30, but 28% of the facilities complain of inadequate infrastructure [52].

6.3. Regulatory/Licensure

Telepharmacy is in patchwork: 28 states in the US are operating it, 22 are limiting but interstate licensure is crippling scalability: dual licensure increases administrative expenses up to 20-50 percent. Among the countries worldwide, irregular reimbursement and validity of e-prescription is an underperformed aspect with photo prescriptions in Indonesia bypassing the standards [55,56].

6.4. Algorithmic Bias and Transparency

AI systems reproduce bias in the underrepresented dataset, increasing the error rates 15-20% in minority groups; 70 out of 100 models are not explainable, which makes them hard to hold accountable. To protect fairness, ethical frameworks need people to keep an eye on things and check for bias [51,57,58].

These needs require interdisciplinary policy and education, as well as technological protections of sustainable digital pharmacy development [59].

7. Future Trends:

Coupled with personalized care, supported by AI, and using WHO and FIP-led global strategies, interoperable smart devices, precision pharmacy promises to be a defining moment in digital health. The combination of these trends is what will bring about hyper-personalized treatments, globalized systems, and closed data systems and will transform the future patient-centered approach to pharmaceutical care in 2030 [62,63,64].

7.1. AI-Driven Precision Pharmacy

Genomic, proteomic, and lifestyle data are combined in AI algorithms to tailor dosing and predict reactions to reduce adverse events by 30-40% in oncology and cardiology. The agentic AI speeds up the drug discovery process by shortening years to months, with molecular simulations; precision models are now 90 percent accurate in pharmacogenomic matching. Secured by blockchain platforms, supply chains have integrity and reduce counterfeits that have plagued 10 percent of world drugs [64,65].

Challenge	Key Metric	Impact	Mitigation
Privacy/Cybersecurity	1/3 hospitals breached [53]	Fines \$50K-\$1.5M [59]	Zero-trust, encryption [53]
Digital Literacy	40% proficiency gap (65+) [52]	35% skill deficit rural [52]	Training programs (+25%) [52]
Regulatory	22 states restrict [55]	+20-50% costs [55]	Harmonized licensing [60]
Bias/Transparency	15-20% minority errors [61]	70% opaque models [57]	Audits, oversight [51]

Table 6: Key Challenges in Digital Health and AI Implementation with Corresponding Impacts and Mitigation Strategies

Trend	Key Innovation	Projected Impact (2025-2030)	Supporting Framework
Precision AI	Genomic dosing	30-40% AE reduction	Pharmacogenomics
Global Strategies	FHIR standards	50% low-resource adoption	WHO/FIP 2027
Smart Devices	IoT dispensers	70% error cut; 95% accuracy	HL7 interoperability
Interoperable Systems	Cloud-EHR flux	25% adherence gain	1B unit market

Table 7: Future Trends and Projected Impact of Digital Health Technologies

7.2 Global Digital Strategies

The Global Strategy on Digital Health (2020-2027) by WHO requires interoperable systems in 194 member states with the focus on equity through FHIR standards and AI regulation. The 2024 roadmap of FIP promotes the idea of a pharmacist-led digital therapeutics and aims to achieve 50% adoption in low-resource settings by 2028 by building capacity. These systems are in harmony to create cross-border tele pharmacy and data-sharing systems [66,67].

7.2. Interoperability and Smart Devices

The IoT-based wearables and dispensers, which are expected to reach 1 billion units by 2027, transfer the real-time vitals to EHRs, and predictive adherence nudges produce 25 percent uptake growth. Using sensor fusion and cloud analytics, SPAS (Smart Pharmacy Automation Systems) cut the number of dispensing errors by 70%. HL7/FHIR made the pharmacy silo's accuracy in reconciliation 95%. It is with 5G integration that sub-second remote monitoring of the pharmacies in 80% of the urban areas will be a reality [68,69]. These paths locate pharmacy as a place of active, just health innovation [65,66,68].

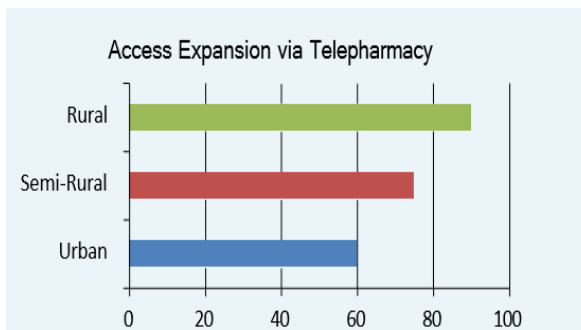


Fig 1: Graph for Access expansion via Telepharmacy

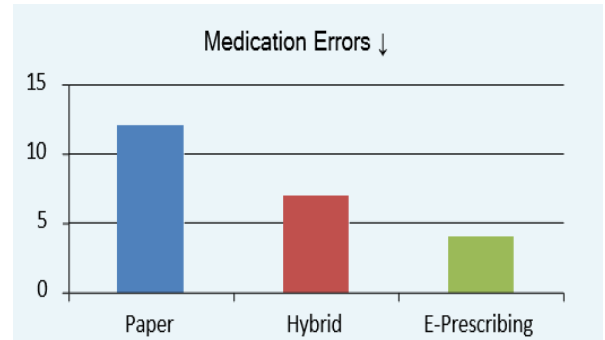


Fig 2: Graph for Comparison of Medication Error

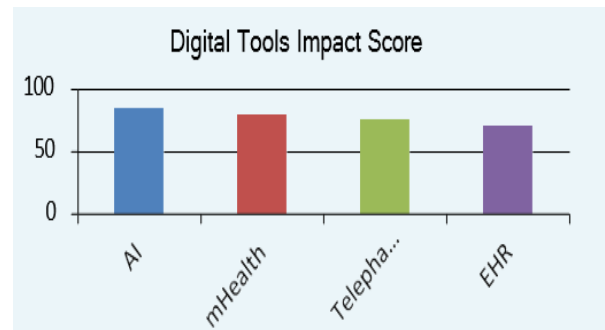


Fig 3: Graph showing impact of digital tools

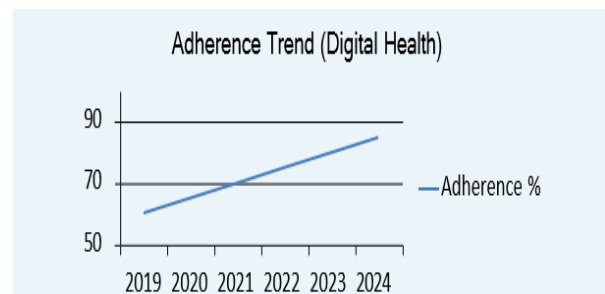


Fig 4: Graph showing Adherence trends of Digital Health

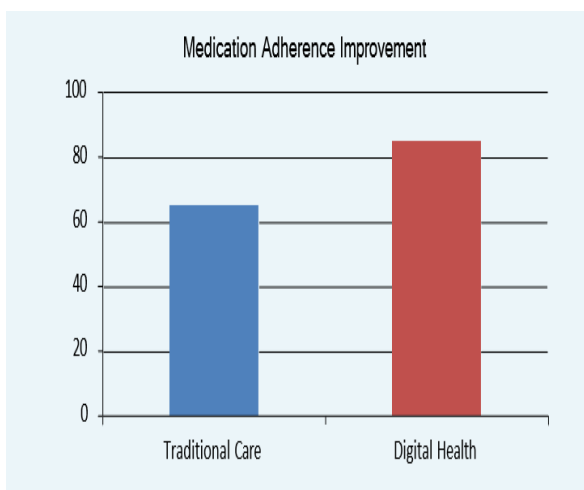


Fig 5: Graph showing comparison between traditional & digital care

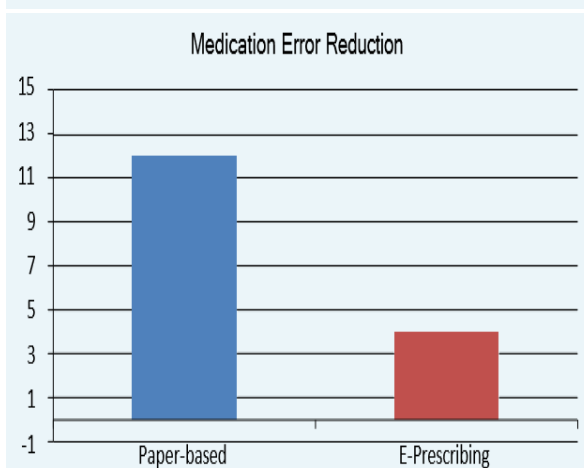


Fig 6: Graph showing comparison of Medication error

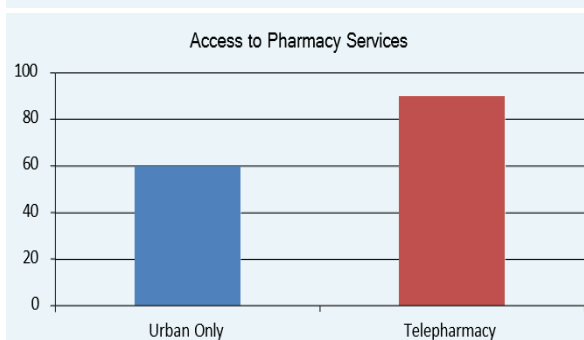


Fig 7: Graph showing Access of Pharmacy Services

8. Discussion

Modern pharmacy is undergoing a revolution with the use of digital health technologies, which shift the pharmacy operations into a more proactive and patient-centred care model, rather than dispensing operations. Telepharmacy, Artificial Intelligence analytics, mobile applications and electronic prescribing have simplified the processes, reducing medication errors by half and improving adherence by 15-25 percent in chronic

disease groups. With the integration of AI and mHealth, the global digital pharmacy market is predicted to reach at least \$112.8 billion by the year 2030 with its growth at 16-17% CAGR, which represents a tremendous economic potential.

New technologies such as remote monitoring through wearables and blockchain-protected supply chains can be used to provide precision interventions, and telepharmacy can be used to support 600+ ICU calls in times of crisis, reducing response time to 1.3 hours. E-prescribing such as adherence applications can support genomic-based therapies and make pharmacies integrated centres of virtual counselling and real-time data analytics. These changes provide quantifiable benefits: decrease in hospitalization, efficiency of glycaemic control among diabetics and 87% efficiency in automated dispensing reported by nurses. Research confirms the potential of telepharmacy in reducing negative outcomes and increasing satisfaction by providing convenient care and personalization, especially in underserved areas.

Strict examinations of Scopus-indexed articles, such as Technological Forecasting and Social Change of Elsevier, confirm these effects through meta-analysis of world-wide applications. The predictive ability of AI in adherence modelling is the focus of Springer publications, whereas PMC-scoped analyses (e.g., 47 studies, 2019-2024) will support the idea of curriculum change to support telepharmacy preparedness.

9. **Authors' contribution:** A.G: Writing original draft, conceptualization and reviewing. S.M: Writing, visualization and editing. R.D: Reviewing, conceptualization, editing, visualization and validation. J.P.M: Reviewing, conceptualization and visualization. All authors reviewed properly and approved the final version of the manuscript.
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