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Review Article

Artificial Intelligence Applications in Clinical Pharmacy Practice: Opportunities and Challenges

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Abstract:
Artificial intelligence (AI) is rapidly revolutionizing the pharmaceutical sciences and clinical pharmacy practice by addressing ever-increasing data burdens and optimizing personalized patient care. This manuscript comprehensively explores the integration of AI across six critical clinical domains: medication safety and pharmacovigilance, pharmacokinetics and dose optimization, drug discovery and repurposing, therapeutic drug monitoring, patient adherence support, and pharmacy automation. While AI techniques, such as machine learning and deep learning, offer tremendous potential to enhance therapeutic efficacy, minimize errors, and streamline healthcare workflows, their clinical implementation remains highly complex. The paper underscores the absolute necessity of rigorous evaluation methods including experimental validation and randomized controlled trials to ensure system accuracy and generalizability across populations. Furthermore, realizing the full value of AI requires navigating significant operational and ethical challenges. These notably include ensuring data quality and privacy, mitigating algorithmic bias, and addressing the critical need for explainable AI (XAI) to foster trust among healthcare professionals. Shifting professional liabilities and the demand for updated regulatory frameworks are also thoroughly examined. Ultimately, proactive stakeholder engagement and standardized interoperability practices are essential to successfully harness AI's transformative capacity, ensuring it safely advances the modern pharmacy profession.

Keywords: *CArtificial Intelligence, Clinical Pharmacy, Pharmacovigilance, Machine Learning, Explainable AI (XAI), Precision Medicine*

1. Introduction

Artificial Intelligence (AI) is gaining worldwide importance and acceptance, particularly following the launch of ChatGPT in 2022 by OpenAI. The pharmaceutical industry is no exception to the urge to embrace AI, predominantly due to the ever-increasing data burden with tremendous implications on medication safety, adherence, and development. AI is revolutionizing the science of drug development, realization, and commercialization of sophisticated solutions that optimally leverage unique patient characteristics for better medications and improved adherence. Six critical areas of clinical pharmacy have emerged significantly as potential applications of AI technologies, namely medication safety and pharmacovigilance, pharmacokinetics and dose optimization, drug discovery and repurposing, therapeutic drug monitoring and personalized medicine, adherence support and patient engagement, and automation in dispensing and workflow optimization **(Hasan et al., 2024; Graafsma et al., 2024)**

1. Foundations of Artificial Intelligence In Healthcare

Artificial Intelligence (AI) is widely embraced in diverse sectors of humanity and has gained attention in the pharmacy context. It has contributed to medical applications, pharmacy practice, and clinical pharmacy. A substantial number of studies scrutinizing the roles of pharmacists pertain to developing countries such as Pakistan and Jordan, where AI can foster pharmaceutical care and optimize health outcomes. Several research works address the ethical dimensions of AI in pharmacy and at the student and professional levels in the broader healthcare setting. Furthermore, systematic reviews and questionnaires provide evidence of substantial acceptance of AI and recognition of its transformative potential in clinical and pharmacy services. Prototype applications are already being developed to facilitate diverse operations across pharmacy. (Zuhair et al., 2024; Nishan, 2025)

AI constitutes an ever-growing key technology featuring algorithms modeled after the brain that interact with vast data sets in a manner analogous to human **(Hasan et al., 2024)**. AI methods stand at the frontier of scientific and computational endeavor; however, the convergence of efforts towards humanistic utility generates a unique

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demographic with specific capability requirments. Thus, AI systems can currently exacerbate disparities in accessibility and participation. Given that misuse may jeopardize patient safety, considerable vigilance is required in the examination of AI inputs and outputs. (Farahani & Ghasemi, 2024; Ezenwa, 2025)

2. Applications of AI in Clinical Pharmacy

Artificial intelligence (AI) can analyze large datasets, identify previously undetected patterns, and generate knowledge from data, thereby transforming practices across the pharmaceutical sciences. AI techniques such as machine learning and deep learning can leverage diverse structured and unstructured data to advance drug discovery, development, and utilization. Just as AI has begun to address issues in precision medicine, the science of medicines, particularly their optimization, continues to benefit from AI 9(Carini & Seyhan, 2024). AI has the potential to greatly advance the pharmaceutical sciences. It also provides a large and diverse opportunity space for better health through greater focus on safety, personalization, and global health and equity. Within clinical pharmacy practice, AI can support the science of medicines through 30 applications in six categories.**(Singh et al., 2023)**

Medication Safety and Pharmacovigilance

The increasing complexity of pharmaceutical products and their interactions in post-marketing surveillance (PMS) make it difficult to rapidly detect both known and unknown adverse drug events (Edrees et al., 2022). Artificial intelligence (AI) can assist in PMS by undertaking major activities and enabling timely actions. AI enhances the analysis of vast amounts of data during signal detection, providing early warning of risks associated with different products. In telehealth systems, AI can exploit patient information available in electronic health records (EHRs), health information technologies, and pharmacovigilance databases to prevent medication-related problems. (Wan et al., 2025)

The integration of telehealth and AI in PMS offers prospects for pharmaceutical companies. Rapid detection of known adverse drug events allows timely information dissemination to health authorities, organizations, and patients. New signals described in individual case safety reports (ICSRs) can be swiftly highlighted, facilitating investigation and probable action initiation by businesses. Cases of unknown adverse drug events can be identified through simple yet clever combinations, such as the imperfect balance analogy between product ownership and adverse event occurrence (Danysz et al., 2018). For instance, when a certain product starts being dispensed and adverse events are recorded, the AI system raises the attention level. Detection of undocumented adverse drug events requires more elaborate approaches, although AI techniques such as clustering, natural language processing, and graph techniques can aid in mining EHR data. (Chaurasiya et al., 2025)

Pharmacokinetics and Dose Optimization

Pharmacokinetic (PK) modeling and dosing strategies are becoming increasingly relevant. Personalizing drug doses based on PK evaluations, rather than relying on manufacturers' recommendations, has been shown to enhance therapeutic effects and reduce toxicity. AI is at the forefront of pharmacological advancement with respect to drug DDS optimization **(Gupta et al., 2021)**. The ability to determine patient-specific characteristics based on few observable data points provides a unique opportunity to advance PK and DDS methodologies. Machine-learning (ML) models can be trained on publicly available PK profiles to—using readily available features—predict patient-specific parameters in diverse patient cohorts. These patient-specific parameters can, in turn, be used with standard mathematical models to accurately predict drug concentrations following non-intravenous administration routes (Suksaeree, 2025).

AI-supported PK and dosing strategies have been evaluated in countless studies, addressing drugs, routes of administration, and diseases. Most studies leverage Multi-Task Learning or Meta-Learning concepts to ensure adaptability for PK and dosing methodologies across drugs and administrations. DDSs empowered by state-of-the-art deep learning (DL) approaches have been developed, demonstrating the relevance and potential impact of AI in these fields (Singh et al., 2023).

Drug Discovery and repurposing

Artificial intelligence (AI) is transforming many fields, and drug discovery is one of the most promising domains in which AI may have a substantial impact. Given the time and costs involved in pharmaceutical research and development, AI can minimize the time involved in the development of new drugs and the repurposing of existing compounds. Many analytical processes that are crucial to drug design are now being automated, including target identification and drug screening. AI is permitting unparalleled access to large data sets that are crucial to the identification of drug combinations and the evaluation of compounds already approved for other indications. Because pharmaceutical products must acquire official approvals, the artificial intelligence facility is invaluable to the evaluation of existing drugs, which can be investigated for new indications with relatively less time and cost.

The cost of the average drug development project was estimated in 2022 at close to USD 2 billion and roughly 10 years in duration (Singh et al., 2023). The estimated total cost includes investment in projects that do not progress to completion, with economically immature projects filtered out at the developmental stage. AI in conjunction with other technologies such as Bayesian learning is streamlining the formulation of hypotheses, development of lead compounds and the efficient use of other resources in drug discovery projects. AI is used in the production of nanoformulations, which are capable of

tailored release at multiple drug-target locations (Visan & Negut, 2024).

Therapeutic Drug Monitoring and Personalized Medicine

Therapeutic drug monitoring (TDM) and personalized or precision medicine (PM) aim to optimize individual patient therapy, considering interindividual PK variability and the influence of comedications and clinical factors on drug exposure 9. AI approaches modeling drug PK and PD in populations or individuals exploit various PMOTs, providing clinical decision support on dose adjustments for a more personalized approach and addressing accessibility issues in their conventional application. These tools can inform polypharmacy management and support personalized cancer therapy by detecting resistance and guiding combinations and sequencing (Carini & Seyhan, 2024) (Khude & Shende, 2025).

Adherence Support and Patient Engagement

Adverse outcomes of non-adherence, rooted in multifactorial causes, challenge health professionals. Sociobehavioral factors include limited motivation or understanding or social complexity. Limitations of healthcare systems include lack of diagnostic monitoring and clinical questioning. Structural intricacies comprise inappropriate drug selection or inactive substances. Misuse arises from improper intake frequency or temporal irregularities. Multiple anti-infective prescriptions in intensive therapies compound the problem, and chronic diseases with flats prescriptions, such as hypertension, diabetes, and asthma, increase non-adhesion risk. Aiming to enhance drug adherence, AI oversees therapy preparations through smart, integrated, and affective pharmaceutical expert systems. Smart monitoring, based on ubiquitous mobile devices, uses smartphone or a range of interactive electronic medicines, sensing and locating the intake of the prescribed drug nearby, while communication conducts automated pictoric and textual queries, questioning the temporal fulfillment or harmful interactions. Integrated tracking, rooted in the analysis of the delivery process, the integrated and inter-communication between three services (the doctor, the medication supplier, and the patient) each equipped by different interfaces, assists adherence analysis where medication allocations, activities log and medicine consumption behaviour are mined through tracking time-stamp of each record. Affective feedback based on Emotional Awareness Support Technology, monitors the subtle emotional state through emotion expressions, sounds, gestures…etc., reflecting emotion states towards therapies, which are comprehended and analysed to provide active support for adherences (Khude & Shende, 2025; Babel et al., 2021).

Automation in Dispensing and Workflow Optimization

To ensure patient safety and optimize the delivery of pharmaceutical products, some dimensions of drug preparation, dispensing, and workflow optimization in pharmacies have been automated. Autonomous robots can receive and store drugs in their respective compartments, allowing for the automatic filling of prescriptions, emergency kits, and multi-dose dispensing units for geriatric patients. Such systems streamline hospital pharmacies, enabling fast service without compromising safety (Alahmari et al., 2022). The broad adoption of AI-enhanced automatic dispensing solutions has increased prescription-filling capacity, improved dispensing accuracy, reduced drug-delivery errors by 51%, guaranteed compliance with strict safety regulations, additional investments in the pharmaceutical supply chain, and minimized delays and stockouts. Automated solutions help avoid the recruitment of extra personnel during peak prescribing hours, leading to significant cost reductions (Allam, 2025).

3. Evidence Base and Evaluation Methods

The preclinical evaluation framework of the Consortium for Essential Medicines defines outcomes associated with product quality, animal and human health. Product quality encompasses clarity on formulation, biodistribution, key performance parameters, preclinical characterization, and related research. During the drug development stage, a fresh approach prioritizes patient-centeredness and real-world, measurable clinical outcomes that matter to patients: effectiveness, safety, quality of life, and cost utility. Four mapping exercises conducted with 170 complicated cases covering 15 diseases highlighted a high diversity of immediate outcomes within broad outcome categories, where 86% of products incorporated efficacy, and 79% safety were the most-widely reported. Therefore, one way to encourage early emergence of safety and efficacy data at the preclinical stage is to clarify the range of immediate outcomes that a project-team considers and where the focus should go (Hasan et al., 2024; World Health Organization, 2023; Kumar et al., 2024).

Study Designs and Metrics

Study design is a critical factor influencing the estimated performance of AI technologies in pharmacy; Randomized controlled trials (RCTs) are considered the gold standard for investigating clinical questions, yet AI implementations are often described and evaluated in uncontrolled settings. Other relevant categorizations include observational studies versus interventional studies, and retrospective versus prospective studies (Singh et al., 2023; Graafsma et al., 2024).

An evaluation framework from the AI for Healthcare program of the UK's National Health Service (NHS) includes four high-level evaluation questions, which provide a guide to tailoring an appropriate evaluation strategy for a given AI technology (NHS, 2021): *Is the AI accurate?*; *Does the AI fit into the workflow?*; *Is the AI interpretable by users?*; and *How willing are users to use the AI?* These questions highlight the

importance of usability alongside the intrinsic performance of an AI technology, and different metrics are proposed to assess each area (Nilsen et al., 2023).

Validation, Generalizability, and Replicability

Demonstrating the effectiveness of health interventions is a prerequisite for their clinical implementation. Nonetheless, study outcome measures alone may insufficiently substantiate health intervention effectiveness because their attributes or the methods employed to assess them differ among investigations, thus limiting interpretation and comparison of the results. Various frameworks have been proposed to quantitatively express the generality of a study's findings. As all systems implemented in clinical pharmacy practice invariably stem from research, the ability to evaluate study effectiveness or a system's generality is indispensable (Marques et al., 2024).

Limited system generality hampers the application of health interventions. When systems are developed under restrictive circumstances or supervision, the resultant models may not translate well to more operational situations. Guidelines identify standards that assays must fulfil to demonstrate systemic generalization outside the exact environment in which they were created. Experimental validation or verification often represents the last phase of a developer's endeavour prior to system deployment. In the case of artificial intelligence systems, generality also implicates modeling effectiveness across different institutions and settings, thereby reassuring prospective adopters that proposed assets exhibit similar advantages (Singh et al., 2023; Ahmed & Tamim, 2025). Although the advent of artificial intelligence paradigms has substantially expedited the development and deployment of computational models in clinical pharmacy practice, major limitations persist in certain sectors. The intricate interplay of biological, chemical, ecophysiological, behavioral, and contextual data engenders dimensionality challenges in chemical compound design. Varying biological responses among diverse population cohorts still complicate prediction of patient reactions to medications, illustrating the indirect nature of causative evidence in healthcare. Analytical tools for evaluating the economic or public health ramifications associated with the implementation of artificial intelligence systems similarly remain highly undeveloped (Putri et al., 2025).

Economic and Health System Impact

The economic assessment relies on a broad measure of economic and health systems indicators, aligning with changes in the global economy. The need for a generic framework to assess the broader economic implications is emphasized, together with a categorisation of impacts in terms of production, consumption, investment, and depreciation. The trajectory of AI technology development is subject to the dynamics of the knowledge economy(Kalai et al., 2024). AI-related studies have so far been descriptive, reflecting the urgency of the issue. Few economic indicators and evaluation models specifically tailored to AI development are available. The further development of these components, alongside monitoring of public agency engagement and knowledge spillovers, is therefore recommended. Existing assessments indicate that AI contributes to GDP through multiple channels. At the production level, machine learning speeds up knowledge creation and enhances productivity growth. Commercial use of AI at the micro level improves organisational and labour productivity through management techniques and knowledge-sharing systems (Hasan et al., 2024; Huy et al., 2024)

4. Challenges and Ethical Considerations

The value offered by AI applications will remain unrealized unless specific challenges are addressed. First, the quality, privacy, and security of healthcare data are paramount concerns. Since AI algorithms require substantial amounts of high-quality data, investments are needed to collect, annotate, integrate, and maintain natively generated datasets. Any software operating on sensitive patient information must provide data privacy and protection safeguards. Regulations such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR) have emerged to outline such protections (Singh et al., 2023; Mennella et al., 2024). Second, biases in AI systems can adversely affect vulnerable populations, highlighting the importance of fair and equitable design. System evaluations need to monitor how AI affects outcomes for different cohorts and determine which groups, if any, remain at a disadvantage. Furthermore, organizations must ensure accountability and responsibility to avoid placing the onus of negative findings entirely on the AI model. Third, organizational and professional roles may shift, requiring pharmacists to adapt and obtain liability protection. Finally, ensuring that AI solutions are transparent, interpretable, and explainable is critical to establishing confidence and acceptance in new applications (Pasricha, 2022).

Data Quality, Privacy, and Security

To successfully leverage artificial intelligence (AI) and machine learning (ML) models and tools in the healthcare and pharmaceutical sectors, organizations must transparently address data quality, privacy, security, and ethical biases. Data quality is paramount for developing accurate, generalizable, and robust AI models, and healthcare and pharmaceutical sectors benefit from a variety of internal and publicly available datasets to enhance AI capabilities. AI-based recommendations will only yield positive outcomes if patient and organizational data are clean, minimally erroneous, proper in terms of structure type and dimension, reliable, adequately distributed, and independent from any kind of bias, including time-series and temporal biases (Singh et al., 2023; Carini & Seyhan, 2024; Enshaei & Naderkhani, 2024).

AI models developed for multiple prior organizations were openly disclosed and made available to ensure broader adoption and speedier research capability development. To comply with and accommodate ethical regulations and obligations, organizations are required to assure that any data made available through public licenses is anonymized or abstracted so as not to lead to a clear identification of individuals, their entities, or even the nature of the case. Techniques such as differential privacy or cryptography-based methods are also urged to secure patient data, and data sharing remains encouraged under heavy anonymity and privacy constraints (Gadotti et al., 2024).

AI/ML tools are typically regarded as complements to human behavior and neither replace, surpass, nor eliminate the human factor; hence, no responsibility should fall on either the models or the patient record. Many prior initiatives demonstrated that even GBL threats imposed on AI models could still deliver high-quality performance. AI completion remains limited to healthcare-provided information or publicly accessible online data on common medications; it does not encompass private organizational references, internal guidelines, or medical knowledge. The target information an organization wishes to enforce must hence be made publicly available for the specific organization while remaining protected for each organization separately (Akhtar & Rawol, 2025). Analyst reporting remains restricted to prior descriptions without the consideration of new ideas or innovative behavior so that no bias or originality threat is imposed on the finished product. The health dataset surfaced obstacles of anonymization and identification since, under the considered dimension, time-series or temporal bias could implicitly re-identify the individuals, thus ensuring a synergy of anonymization and ethical dispositions both on quality and privacy (Alnattah et al., 2025).

Bias, Fairness, and Equity

Artificial Intelligence holds enormous potential for advancing clinical pharmacy practice in ways that can improve patient care. Once this goal has been achieved, there are additional considerations. Like any other health technology, Artificial Intelligence requires careful evaluation of its safety and efficacy, as well as consideration of potential unintended consequences. These are addressed throughout the discussion. Topics include leveraging the skills and knowledge of various stakeholders, data provenance to ensure accurate provenance and traceability of dataset lineage, and avoiding duplication of existing capabilities by focusing on new processes, services, or products. Collaboration reduces the risk of individuals or groups monopolizing datasets and ensures equitable access and consideration of diverse health determinants across the population.

Algorithmic bias occurs when a system produces prejudiced results owing to erroneous assumptions in the machine learning process. Although the presence and severity of bias will depend on the specific application, exposure to algorithmic bias can have obvious negative implications. The prevailing notion of fairness in the scientific community refers to the idea that two individuals who are similar in all relevant ways should receive similar predictions. People, however, differ over their definition of similarity, and research suggests numerous technical definitions of algorithmic fairness—as well as disagreement over the prioritisation of various kinds of fairness criteria. The appropriate definition in any particular context often remains unclear. Stakeholders may also be affected by nonintrinsic factors, such as how widely a model will be deployed, its remoteness from critical decision points, its relevance to distribution of a population of interest, the density of that population, and the potential for societal or environmental impacts.

Health disparities are preventable differences in the burden of disease and opportunities to achieve optimal health that are experienced by socially disadvantaged populations. Algorithmic tools used in health systems design, medical diagnosis, decision support, or treatment allocation may therefore reinforce or exacerbate systematic inequities, while deployment of digital health technologies may inadvertently divert attention away from situations of greater need. Health disparities discourage many from adopting Artificial Intelligence yet addressing the topic is imperative. Algorithmic-health-disparity considerations have only recently entered the conversation, even as widespread deployment continues. Frameworks capable of characterising such consideration are similarly scant (Hasan et al., 2024; Singh et al., 2023; Wang & Chung, 2022).

Transparency and Explainability

Artificial Intelligence (AI) has the potential to revolutionize clinical pharmacy practice, but this technology struggles with transparency and explainability, limiting accessibility and adoption. AI models are often considered black boxes because they obscure the underlying knowledge and rationale used to formulate predictions; this lack of transparency may hinder healthcare professionals from trusting and integrating the results. Furthermore, many drug-acquisition procedures involve complex databases with uncertain information across modalities, posing additional challenges to transparency. Transparency empowers pharmacy professionals to conduct thorough scrutiny of AI prediction processes, ensuring alignment with established pharmacological and pharmaceutical knowledge. It is vital to ascertain that the processed information and prediction factors are clinically recognized, a principle that can be clarified through explainable AI (XAI). With algorithmic development and prediction evaluations complete, XAI can provide visibility into the features of a trained AI model and the decision-making source. Transparency helps promote model generalization across different datasets, safeguards against learning misleading biases from training data, and enables validation of AI-generated

drug-related recommendations based on understood correlations (Singh et al., 2023; Mesinovic et al., 2023).

Professional Roles and Liability

Artificial Intelligence (AI) constitutes a revolutionary technology with reported implementation in many fields and industries, including healthcare. The AI-based analysis of medical data offers a cost-effective solution to enhance existing services, provided that the process is transparent and ethical. Its sophisticated applications in clinical pharmacy practice could extend patient care beyond medication supply and advice alone. Applications of AI in clinical pharmacy practice, nevertheless, pose a range of challenges, including issues related to professional liability and roles. Unregulated and unmonitored AI systems may compromise patients' safety and violate their dignity, leading to dangerous errors, decision-making biases, and financial loss. Specific human skills and insights are required to effectively assess the performance and robustness of AI systems. AI systems also raise concerns regarding professional liability and malpractice, given their capacity to generate information and predictions automatically. These systems cloud the professional responsibility of pharmacists and other stakeholders, heightening the risk of liability. The extent to which these entities remain accountable for the use of AI technologies is legally unregulated. A comprehensive assessment of the state-of-the-art knowledge on the impact of AI-based systems, including its applications, implications, and challenges, is, therefore, critical to the safe and efficient integration of these solutions in clinical pharmacy practice (Hasan et al., 2024; Jassar et al., 2022).

5. Implementation and Change Management

The implementation of AI tools in clinical pharmacy practice requires careful management of the associated change process. Stakeholder engagement and training are critical for establishing buy-in, addressing misconceptions, and building trust and knowledge. For clinical pharmacy AI applications to achieve their full potential and become routine practice, pharmacy regulators and professional organizations must develop regulatory and governance frameworks that clearly delineate the roles and responsibilities of various stakeholders throughout the AI system life cycle. Furthermore, achieving interoperability and the use of common data standards will be important for encouraging the broader adoption of these AI-enabled services (Hasan et al., 2024).

Stakeholder Engagement and Training

Adoption of AI is influenced through systematic engagement with internal and external stakeholders. In an Austrian health service, tailored awareness-raising and workshops with the executive board and representatives of each department successfully achieved this. Stakeholder involvement contributes to developing local requirements and disseminating knowledge that is crucial for implementation of AI. Commitment from external stakeholders, including AI specialists, ethics committees, funding bodies, educational institutions, and pharmaceutical companies, is also valuable. Furthermore, early identification of key individuals who can advocate for AI increases the chances of successful implementation.

Educational efforts focused on raising awareness of AI in pharmacy, explaining AI terminology, demonstrating current applications, and clarifying legal and regulatory aspects are essential for stakeholder engagement. Workshops and the production of short videos, posters, and brochures that address specific and often widely misunderstood aspects of AI have proved effective. Continuing professional education involves teaching subjects such as data preparation, algorithm selection, programming, and presenting outputs aimed at pharmacy professionals, pharmacy students, and postgraduate students (Hasan et al., 2024; Singh et al., 2023).

Regulatory and Governance Frameworks

The rapid proliferation of AI solutions for healthcare is quickly outpacing the development of principles and policies that can guide their adoption. Before those who wish to deploy these technologies can decide which solutions to use, many key ethical and regulatory questions require clearer definition. Although the vast majority of AI programs remain prototype applications awaiting robust real-world testing, an extensive collection of products has already received commercialization endorsements from various health authorities. At the system level, two broad thematic priorities for regulatory coverage emerge: ensuring that safe systems are created, maintained, and made accessible versus preventing and managing the adverse effects that might arise from these technologies' systematic deployment. Regulatory frameworks depend on an understanding of the functions and operational mechanisms of the products, but sufficient clarity lacks concerning diverse system attributes, operational regimes, and intended functions (Mennella et al., 2024; Panch et al., 2022).

The ultimate objective should be a global regulatory framework comprehensive enough to preserve the balance among desirable attributes while also accommodating rapidly evolving technologies. The U.S. Food and Drug Administration has acknowledged the challenges and launched a digitized patient management platform that uses AI to assist broader delivery of diabetic retinopathy screenings. The American College of Radiology and the Radiological Society of North America have issued a joint position statement on machine learning, prescribing transparency of algorithm development, documentation of training data extracted from dual sources and pre-processing applied to ethical acquisition, post-market quality control, user-centered design, and routine monitoring for model drift (Zhou & Gattinger, 2024).

Interoperability and Data Standards

Interoperability and standards for health data exchange facilitate access to patient information for clinical decision support on various scales: local, regional, national, or international. Machine learning applications typically require large amounts of training data across diverse patient populations. Regulatory frameworks such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States specify the requirement for secured data access without compromising patient privacy. However, the need for availability of diverse health data for algorithm training creates concern over potential misuse and inappropriate data exposure (Gujar, 2025).

More specifically, data protection regulations impact the extent to which data is made available for development of artificial intelligence algorithms, directly influencing innovations on both data and moa30df271-d47f-4c3f-b19f-bccff5d54ef8 sides. For example, development of artificial intelligence moa30df271-d47f-4c3f-b19f-bccff5d54ef8s addressing drug–target interaction cannot easily leverage publicly available data because release of universal datasets is limited by commercial interests in these data. The situation is similarly challenging for AI innovation in drug repurposing and toxicology prediction, for which data are distributed in various formats that differ from one country or regulatory authority to another. Standardized data formats would generally enhance collaboration and availability of open datasets (Del Rio-Bermudez et al., 2020).

6. Future Directions and Strategic Implications

Health systems worldwide continually explore transformation through the adoption of digital technologies that facilitate contemporary patient-centric care. Clinical pharmacy services remain firmly aligned with this movement, even in developing nations. The potent force of machine learning (ML) in reshaping healthcare's landscape has emerged, capturing the interest of pharmacy professionals and educators alike. As it becomes firmly embedded in pharmacy curriculum across educational institutions, preparing students and practitioners for its application in clinical pharmacy practice remains imperative. The proliferation of AI-based applications has ushered in a new era for pharmacy-oriented digital health solutions. Innovative ideas flourish on the doorstep of this global transformation, and the profession possesses a strategic opportunity to yield wide-ranging benefits to patients and the broader health system through adopting AI-based applications (Hasan et al., 2024; Harrer et al., 2024; Karvannan, 2025).

Pharmaceutical professionals are poised to accelerate the adoption of clinical AI applications. Identifying clear, informative, and evidence-based pathways for the profession's involvement in the age of AI remains crucial. Committed stakeholders must agree on these pathways to ensure the ongoing development of AI solutions that advance the pharmacy profession, rather than undermining it.

7. Conclusion

Artificial Intelligence (AI) has grown into a powerful and influential technology during the past decade, promoting innovations across various fields. Throughout its evolution, AI has increasingly permeated the health sector. Hospitals, clinics, organized health systems, and governmental agencies worldwide have started to employ AI in a wide range of applications, including diagnosis, prognosis, treatment, administration, and policymaking. As such, the health sector has witnessed the birth of an AI revolution and a pivotal moment in its history (Hodge, 2023).

AI has also penetrated the discipline of pharmacy, a highly knowledge-based profession deeply integrated into diverse multinational health-care systems. Pharmacy practices comprise a multitude of direct and indirect services provided by health-care professionals aimed at enhancing patients' access to and proper usage of medicines, improving patients' health outcomes. Although widespread adoption of AI-powered pharmacy applications has yet to occur in practice, over 90% of pharmacy professionals expect AI to have a high-impact or transformative influence on the discipline. AI technologies hold significant potential to enhance the performance, efficiency, and quality of pharmacy applications in both clinical and other pharmacy fields. AI models can analyze vast quantities of heterogeneous data, extract features, identify patterns, and generate interpretations at an unprecedented rate human professionals would find extremely difficult, if not impossible, to accomplish. AI technologies also enable continuous learning on incremental data streams and support both holistic perspectives and objective insights that practitioners may overlook. The capacity of automation further liberates professionals from time-consuming routine activities, allowing them to focus their expertise on more high-value, higher-order matters. However, challenges remain regarding data availability, quality, protection, and governance associated with historical and emerging AI applications (Hasan et al., 2024; Allam, 2025).

In summary, the influence and significance of AI technologies in pharmacy are poised to grow considerably, necessitating academia and practitioners to actively monitor the advances in the field and interrogate their current capabilities and surrounding conditions. These insights will facilitate further developments while informing strategic planning to adapt to the anticipated changes.

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