
**AI-POWERED PHARMACY: A REVIEW OF AUTOMATION,
PRECISION, AND PERSONALIZED MEDICINE**

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ABSTRACT

The pharmaceutical industry is undergoing significant transformation due to advancements in Artificial Intelligence (AI), automation, and robotics. These technologies are revolutionizing drug discovery, manufacturing, supply chain management, and patient care. AI accelerates drug development by analysing large datasets, while automation enhances efficiency and accuracy in repetitive tasks. Robotics, integrated with AI, enables faster, scalable, and precise manufacturing processes and is also used for efficient medication dispensing. These innovations drive the development of personalized medicine, offering tailored treatments based on individual patient data. Collectively, these advancements address industry challenges, including rising demand, regulatory compliance, and global health needs, paving the way for a more efficient and patient-centred pharmaceutical sector.^[1]

AI Artificial Intelligence (AI) is transforming the pharmaceutical industry by leveraging advanced computational methods such as machine learning and deep learning. These techniques are accelerating drug discovery and delivery, optimizing treatment regimens, and improving patient outcomes. AI's applications span target identification, excipient selection, synthetic route prediction, supply chain optimization, and continuous manufacturing processes, among others. While AI integration enhances efficiency, reduces costs, and improves drug safety and patient care, it also raises significant regulatory considerations. This review explores AI's role in drug discovery, personalized medicine, and beyond, using current research and case studies to highlight its transformative impact on the pharmaceutical industry and healthcare.^[2]

1. INTRODUCTION

The adoption of AI in the pharmaceutical industry has progressed significantly over the decades. In the 1980s and 1990s, AI was primarily used for basic computational models, focusing on molecular modelling and chemical structure prediction. These initial efforts paved the way for more advanced applications as computational capabilities improved. By the 2000s, machine learning algorithms enabled the analysis of complex datasets, streamlining drug discovery by predicting molecular interactions and optimizing formulations. ^[2] The 2010s marked a turning point, with advances in Big Data, deep learning, and the availability of extensive biological and chemical datasets driving widespread AI adoption. AI became integral to stages such as target identification, clinical trial design, and personalized medicine. Today, AI is a cornerstone of pharmaceutical innovation, accelerating drug discovery, optimizing clinical processes, and enabling data-driven, patient-focused research and development. ^[1]



Imagine: A pharmacy where computers can help pharmacists in amazing ways! This is the power of Artificial Intelligence (AI) in pharmacy. [Edited By Canva]

Think Over the past 25 years, the pharmacy sector has effectively addressed growing prescription demands, pharmacist shortages, rising costs, and lower reimbursements by leveraging automation and technology. Automated dispensing systems have improved workflow efficiency, enhanced safety, and allowed pharmacists to focus more on patient care, ultimately improving health outcomes. Since the 1980s, computers have been integral to pharmacy, enabling advancements in data collection, retail management, clinical research, education, and more. With the emergence of AI, pharmacy is poised for even greater evolution, including systems for drug therapy guidance, interaction monitoring, and

formulary selection. AI's potential impact on pharmacy practice continues to expand, offering promising opportunities for the future.^[3]



Image: Why AI in Pharmacy.[12]

1.1 Objectives

- To evaluate the performance of the new AI-powered pharmacy system in comparison to the old manual pharmacy system.
- To assess the impact of the AI-powered pharmacy system on efficiency, patient outcomes, cost savings, and regulatory compliance.
- To analyze the feasibility and practicality of implementing the AI-powered pharmacy system in different healthcare settings.
- To identify any potential drawbacks or challenges associated with implementing the AI-powered pharmacy system.
- To provide recommendations for future research and development of AI-powered pharmacy systems.^[6]



Image: Objectives of AI in Pharmacy [Edited By canva]

1.2 Barriers to AI in Pharmacy Practice

While artificial intelligence (AI) has significant potential in pharmacy practice, several barriers must be addressed to ensure its successful implementation. AI lacks the ability to provide sympathy and empathy, which are crucial for fostering meaningful pharmacist-patient relationships that improve care and patient compliance. Additionally, AI systems have limited creativity, rely heavily on existing data, and may struggle to handle unanticipated issues, potentially leading to errors or misleading outputs.^[6]

The high costs of implementing AI—including initial investments, maintenance, and updates—pose another challenge. Moreover, pharmacists often lack familiarity with these technologies, necessitating extensive training to ensure they can effectively use AI systems.^[6]

Ethical considerations, such as addressing algorithmic biases, obtaining informed patient consent for data use, and ensuring system transparency and safety, are essential to maintaining patient trust and upholding healthcare standards. Addressing these barriers is critical to integrating AI into pharmacy practice while safeguarding patient rights and improving outcomes.^[6]

1.3 Recommendations to Overcome Barriers to AI in Healthcare

To fully harness the potential of AI in healthcare, several measures can be implemented:

- 1. Rigorous Testing:** Ensure AI systems undergo thorough testing to enhance accuracy and prevent medical errors.
- 2. Data Privacy and Consent:** Strengthen privacy measures, obtain explicit patient consent for data use, and establish systems for timely breach notifications.
- 3. Addressing Biases:** Regularly monitor AI systems to identify biases and build diverse, representative datasets for improved reliability.
- 4. Comprehensive Training:** Provide robust training for pharmacists to effectively utilize AI tools and maximize their benefits.

By addressing these barriers with proactive strategies, AI can significantly enhance patient care and healthcare outcomes.^[6]

2. Automation in Pharmacy

2.1 The Evolution of Pharmacy Automation

Pharmacy automation has become increasingly relevant as pharmacies face mounting pressures. Since the 1980s, automation has evolved from costly digital tablet counters to advanced, AI-driven systems. Modern AI technologies have transformed tasks like pill counting, improving accuracy, efficiency, and learning capabilities. Enhanced features, such as defect detection and pill classification, have made these tools indispensable for streamlining workflows and reducing errors, marking a new era in pharmacy automation. [7]



Image: Smart Technologies For Pharmacy Automation [13]

2.2 AI and Computer Vision in Pill Counting:

Manual pill counting, traditionally done with a tray and spatula, is straightforward but prone to errors due to its repetitive nature. Sustained attention is required, leading to staff fatigue and an increased risk of mistakes. Automating this process with AI and computer vision offers a more reliable and efficient solution. [7]

2.3 Benefits of AI-Powered Pill Counting Systems

AI-powered pill counting significantly enhances pharmacy operations by reducing manual effort and improving efficiency:

- **Increased Accuracy:** Automated systems reduce dispensing errors, with studies showing a 4.8% error rate compared to 12.6% for manual counting.
- **Time Savings:** Automation is faster, allowing pharmacists to focus on patient care, with manual methods found to be 42.3% slower.
- **Reduced Fatigue:** Automating repetitive tasks minimizes staff fatigue and distractions, improving overall performance.

- **Scalability:** These systems efficiently manage varying volumes without additional time or effort, supporting higher workloads seamlessly. ^[7]

How AI-Based Pill Counters Work?

AI-based pill counters use advanced deep learning algorithms to ensure accurate and efficient counting

- **Object Detection:** CNN architectures like YOLO identify and localize individual pills, regardless of shape, orientation, or overlap.
- **Segmentation:** Techniques like the Segment Anything Model (SAM) separate pills from the background and one another.
- **Tracking:** Algorithms such as ByteTrack track pills in video-based counting systems.
- **Counting:** Instance segmentation techniques distinguish individual pills, even when in contact.
- **Visualization:** Real-time visualization highlights detected pills and updates the count as pills enter or leave the view. ^[7]

3. Precision Medicine

Precision medicine is a rapidly growing field focused on tailoring healthcare based on an individual's genetic, environmental, and lifestyle factors. Initially inspired by the sequencing of the human genome, it now integrates multi-omic data, medical history, and social/behavioral determinants to define health states, diseases, and therapeutic options. The philosophy behind precision medicine aims to improve patient care through personalized treatment approaches, enhancing outcomes by considering the unique characteristics of each individual. ^[10]

3.1 Ongoing Challenges Using AI in Precision Medicine: While AI holds great promise for precision medicine, several challenges hinder its real-world application

a. Fairness and Bias

AI models can inherit biases from the data they are trained on, leading to unfair decisions based on age, gender, race, or socioeconomic factors. Addressing bias requires diverse data, improved sampling, and the use of fairness metrics and algorithms, with a collaborative effort between AI and biomedical communities. ^[10]

b. Socio-environmental Factors

AI models may struggle to perform effectively in diverse clinical environments due to varying conditions, workflows, and technical limitations, such as poor image quality or slow internet connections. This highlights the need for validating models in real-world settings and incorporating user feedback for continuous improvement.^[10]

c. Data Safety and Privacy:

It is With the increasing integration of sensitive data (e.g., genomics, medical history), concerns about data privacy and trust emerge. A secure ecosystem for data storage, management, and sharing, along with new regulations, is necessary to ensure privacy and build trust in AI-driven healthcare services.^[10]

d. Precision Medicine Approaches:

Precision medicine tailors treatments to individual characteristics, such as genetic makeup and biomarkers. By analyzing this data, healthcare providers can identify more effective treatment strategies for each patient, reducing trial and error and improving the likelihood of successful outcomes.^[8]

3.2 Future Synergies Between AI and Precision Medicine:

AI and precision medicine are converging to tackle complex personalized care challenges. These advancements offer potential progress in addressing key issues in healthcare, which are highlighted in examples of personalized healthcare practices that could benefit from AI integration.^[10]

4. Personalized Medicine in AI-Powered Pharmacy:

AI enables personalized medicine by analyzing genetic, lifestyle, and medical data to create individualized treatment plans. This approach enhances treatment effectiveness and minimizes side effects, especially for complex diseases like cancer, where patient responses to the same treatment can vary significantly.^[9]

4.1 Understanding Personalized Healthcare:

Personalized healthcare, or precision medicine, tailors medical care to individual patients by integrating data like genetics, biomarkers, clinical information, and lifestyle factors. This approach enables more accurate diagnoses, customized treatments, and precise predictions of disease progression.^[8]

4.2 The Role of Individual Variability and AI in Personalized Healthcare:

4.2.1 Individual Variability in Treatment Response: Patients respond differently to treatments due to genetic, physiological, lifestyle, and environmental factors. These variations influence drug metabolism, efficacy, and toxicity, emphasizing the need for personalized healthcare. ^[8]

- **Genetics:** Variations affect drug metabolism and efficacy, with pharmacogenomics aiding in predicting responses.
- **Physiology:** Factors like age, sex, and organ function impact treatment outcomes.
- **Lifestyle:** Diet, exercise, and environmental exposures also shape responses to therapies. ^[8]

4.2.2 Personalized Approaches and AI Integration:

Advances in AI and big data enable tailored treatment plans, improving outcomes:

- **Precision Medicine:** AI analyzes patient data (genetics, biomarkers) to design targeted treatments, reducing trial and error.
- **Real-Time Monitoring:** Wearable devices and AI provide continuous feedback, ensuring timely interventions.
- **Diagnostics:** AI enhances image recognition and diagnosis accuracy, enabling early disease detection. ^[8]

4.2.3 Companies Leveraging AI for Personalized Healthcare:

Notable companies include Health Joy, Google Health, Paige.AI, Tempus, Babylon Health, and Komodo Health, which use AI for diagnostics, tailored care, and predictive analytics. ^[8]

4.3 Benefits of AI in Personalized Healthcare:

- **Improved Diagnostics:** Early, accurate disease detection.
- **Customized Treatments:** Tailored plans for better outcomes and reduced side effects.
- **Enhanced Engagement:** Real-time feedback empowers patients.
- **Efficiency:** AI automates administrative tasks and optimizes workflows.
- **Cost Savings:** Early interventions and resource optimization reduce expenses.



Image: How AI is Revolutionizing Personalised Medicine.[14]

Personalized healthcare, driven by AI, transforms patient care by integrating variability and leveraging cutting-edge technologies. [8]

5. Challenges And Ethical Consideration:

5.1 Challenges: The use of AI in the pharmacy sector presents several challenges:

- a. **Bias:** AI models can produce biased outcomes if the data used reflects underlying healthcare system biases.
- b. **Clinical Implementation:** Limited empirical evidence from real-world clinical trials makes it difficult to validate AI interventions outside controlled environments.
- c. **Data Privacy and Security:** Concerns arise over the safety of sensitive patient information in AI datasets.
- d. **Data Integration:** AI systems may identify irrelevant connections between patient variables and outcomes, leading to inaccurate predictions.
- e. **Ethical Concerns:** Accountability is unclear when AI causes mistakes, raising questions about responsibility.
- f. **Patient Safety:** Inaccurate data collection and algorithmic errors can harm patient safety.
- g. **Social Concerns:** Healthcare workers fear job displacement due to AI, but understanding AI's benefits may help alleviate these concerns. [11]

5.2 Challenges and Limitations of AI in Personalized Healthcare:

AI in personalized healthcare faces several challenges, including:

- a. **Data Quality and Privacy:** Inaccurate or fragmented healthcare data can lead to biased AI models, while maintaining data privacy and security is essential to uphold trust and comply with regulations like HIPAA.

5.3 Ethical Considerations: AI must be transparent, fair, and accountable, ensuring unbiased decision-making. Healthcare providers must evaluate AI solutions for alignment with ethical guidelines to prevent harm and preserve patient trust.

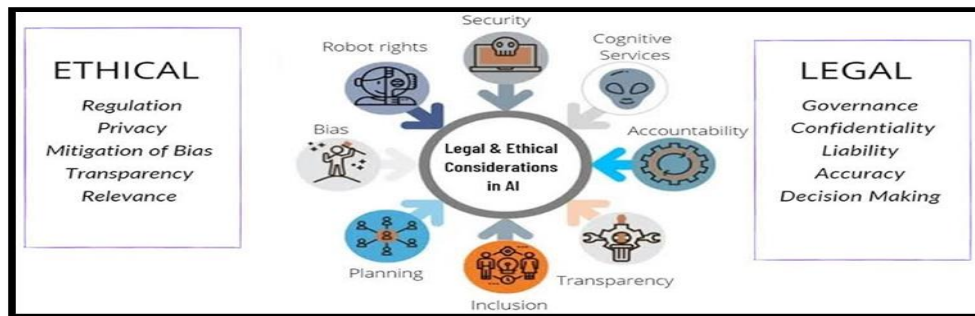


Image: Ethical Consideration [15]

- a. **Regulatory Frameworks:** The rapid advancement of AI necessitates comprehensive regulatory standards to protect patient safety, privacy, and foster innovation. Collaboration between regulatory bodies, healthcare professionals, and AI developers is essential.
- b. **Limited Generalizability:** AI algorithms may not generalize well to diverse patient populations if trained on non-representative datasets. Ensuring diversity in training data and ongoing model refinement is crucial to prevent healthcare disparities.
- c. **Human-Machine Collaboration:** AI should assist healthcare professionals, not replace them. Maintaining the role of human judgment in decision-making ensures optimal care and retains trust in the healthcare system.^[8]

5.4 Challenges and Ethical Considerations in AI Healthcare

AI in healthcare presents several challenges, particularly in data privacy, algorithmic bias, and accountability. Ensuring the security of patient data while adhering to regulations like HIPAA is crucial. Bias in AI models, stemming from non-diverse training data, can lead to disparities in healthcare outcomes. Clear accountability for AI errors is essential for trust. Additionally, the integration of AI requires significant investments in technology and training to ensure equitable access and effective use across healthcare systems.^[9]

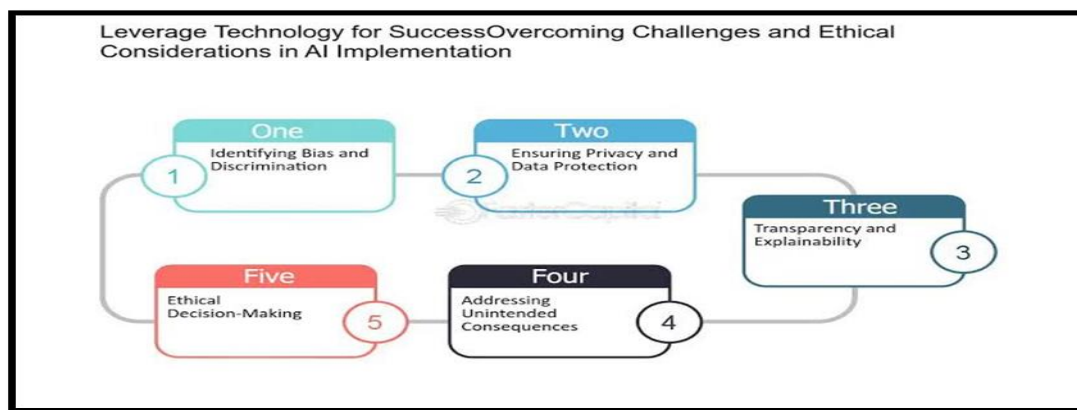


Image: Technology for success overcoming Challenges And Ethical Consideration.[16]

6. Future Prospects of AI in Pharmacy

The future of AI-powered pharmacy is promising, with opportunities to enhance global healthcare delivery.

6.1 The Future of AI in Healthcare

The future of AI in healthcare holds significant promise. As AI technology advances, it will enable more precise personalized medicine, allowing treatments to be tailored to individual patient needs. AI-driven wearable devices will play a key role in monitoring health in real-time, preventing medical emergencies. Additionally, AI will revolutionize medical training through virtual reality (VR) and simulations, offering immersive experiences for medical students. AI-powered decision support systems will assist healthcare professionals by providing real-time insights for better decision-making. However, addressing challenges such as data privacy, bias, and accountability will be essential to fully harness AI’s potential in improving patient outcomes and creating a more efficient healthcare system.^[9]

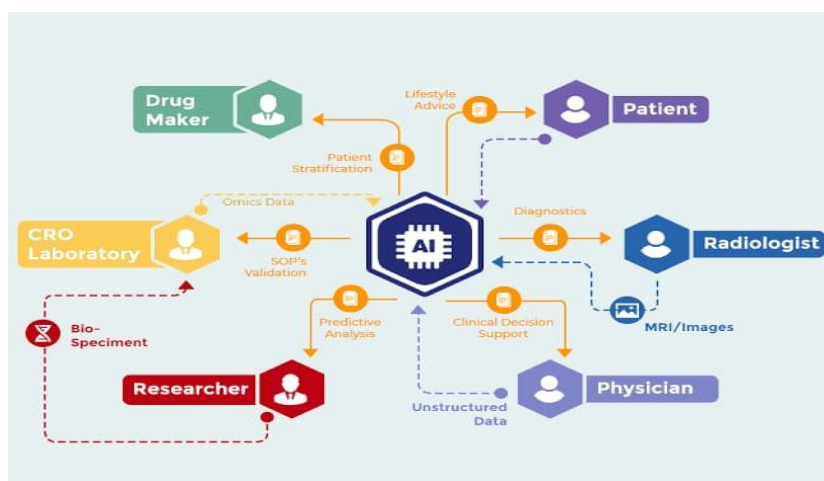


IMAGE: Future Prospective Of Ai In Pharmacy.[17]

6.1 Future Directions and Opportunities for AI in Healthcare

- 1. Integration of Multi-Modal Data:** AI can enhance predictions by incorporating various data sources like genetics, clinical data, environmental factors, and social determinants. This holistic approach offers more accurate, personalized insights.^[8]
- 2. Explainable AI:** Efforts are focused on developing AI systems that can explain their decision-making processes, fostering trust among healthcare providers and patients by enabling transparency and collaboration.^[8]
- 3. Continual Learning and Adaptation:** AI models can evolve by learning from new data and real-world feedback, improving accuracy and adapting to changing patient needs, medical knowledge, and care standards.^[8]
- 4. Expanded Access to Healthcare:** AI can increase healthcare access by supporting telehealth, virtual consultations, and remote monitoring, especially in underserved or remote areas. AI-powered tools can also enhance patient education and self-management.^[8]
- 5. Advancements in Genomic Medicine:** As genomic data analysis advances, AI can predict disease risks and guide personalized treatment options, harnessing the power of genomics to offer tailored healthcare based on an individual's genetic profile.^[8]

CONCLUSION

AI is changing the way pharmacies work, making them faster, more accurate, and more patient-focused. From automating routine tasks to creating personalized treatment plans, AI is helping pharmacists provide better care. It's not just about technology—it's about making healthcare safer and more efficient for everyone.

But as we move forward, we need to be mindful of challenges like data privacy, fairness, and accessibility. AI can't replace the human touch in healthcare, but it can support professionals to do their jobs better. By working together—pharmacists, tech developers, and regulators—we can make sure these tools are used responsibly and benefit everyone, not just a few.

AI has the potential to transform pharmacies and improve lives. With the right balance of innovation and care, we're on the way to creating a smarter, more personalized healthcare system that truly puts patients first.

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