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Original Article

Artificial Intelligence in Medication Adherence and Personalized Treatment Plans

Akanksha Kukade*, Sayali kawade, Sonakshi lokare, Ankita kharage

Ashokrao Mane College of pharmacy, Peth vadgaon, affiliated to Shivaji University 416112, Maharashtra, India

ABSTRACT

Adherence to medication and personalized treatment constitute the cornerstones of effective chronic disease management, yet the realization of their intent remains challenged by patient-specific, therapeutic, and systemic barriers. Due to the advancing availability of big health data and computational techniques, AI has made its stride into the health scenario as a disruptive force. This review discusses a variety of AI-powered tools used to monitor and enhance medication adherence—smart pill bottles, ingestible sensors, wearables, mHealth apps, and predictive analytics—and their incorporation into real-time clinical decision-making. We further discuss AI's role in developing personalized treatment regimens based on genomic data, adaptive algorithms, and electronic health records (EHR). The ethics of these challenges, including data privacy, algorithmic bias, and accountability, are further elucidated, alongside issues of in-field implementation. Lastly, along with the topics mentioned earlier, the review talks about future ideas like explainable AI, federated learning, and closed-loop adherence systems, which could help make AI a key part of personalized, proactive, and fair healthcare.

Keywords: Artificial Intelligence, Medication Adherence, Personalized Treatment, Machine Learning, Predictive Analytics, Smart Healthcare, Clinical Decision Support, Digital Health, EHR Integration, Ethics in AI

INTRODUCTION

Adherence to medication is a critical aspect of effective health-care delivery and chronic disease management. This category ranges from diabetes to other cardiovascular disorders to psychiatric disorders. Irrespective of this importance, adherence rates still remain worryingly high, with estimates stating that almost 50 percent of patients do not take their medications as prescribed. This is a serious challenge before the clinician and the healthcare system, resulting in increased morbidity, hospitalizations, and health-care costs. Now this has resonated with some kind of an abdominal shift towards the patient, and treatment plans are becoming dependent on the predominant patient characteristics of emphasis (genetic makeup, lifestyle, and comorbidities). Personalized medicine apparently seems to be improving the therapeutic outcome with minimal effect; however, its potentials remain largely unrealized in the daily clinical setting. Artificial intelligence is transforming health care with a growing fascination, designing intelligent systems capable of analyzing vast amounts of patient data to predict adherence behavior and thus recommend treatment strategies tailored to the individual. Preventing medication non-adherence and enhancing individualized care will now be tackled along these integrated care pathways via the application of artificial intelligence (AI)-smart pill bottles, digital adherence monitoring systems, mobile apps, and clinical decision support tools. [2,3] The paper looks at how AI is currently being used in individualized treatment planning and drug adherence. The technology used in these activities will be covered, as well as their drawbacks and difficulties, moral and legal issues, and potential directions for AI advancement in healthcare.

2. An Overview of Healthcare Artificial Intelligence

AI is the replication of human intelligence in robots that have been trained to think and behave like people. AI in the health sector refers to a group of technologies that analyze complicated medical data

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and support clinical decision-making, including machine learning, deep learning, natural language processing, computer vision, and expert systems.AI technologies have demonstrated promise across a range of healthcare applications, from diagnostic imaging to patient triage and treatment optimization.[6] Machine learning algorithms can process high-dimensional data to identify patterns, make predictions, and continuously improve through experience.[7] NLP allows AI systems to interpret unstructured clinical notes, while computer vision tools are used for image analysis in radiology, dermatology, and pathology.[8] The applicability of artificial intelligence in healthcare mainly bases itself on the existence of sizable datasets and sources like electronic health records (EHR), genomic sequences, and real-time data collected from wearable devices. [9] Through these datasets, dummies are developed to assist predictive models that help clinicians try to guess the patient's outcomes, for recommending treatments, and even detect early signs of disease or deterioration. [10] Generative AI and large language models, specifically the ones under the umbrella of GPT-based systems, have ushered in several great possibilities in communication between patients and systems, summarization of data within a clinic, and instruction that is personalized in ways unimaginable before [11]. They have also been very useful in assisting a patient with medication adherence and for personalized treatment within a particular area of individual traits [12]. Although most of these developments have been made in AI whose transformations give adhesion over all forms of patient safety, ethical implications, and developments with data quality, algorithmic bias, as well as other regulatory compliance and trust among clinicians. Medication Adherence: Challenges and Current Strategies [13] Medication adherence means whether patients take medications according to the advice of their healthcare providers-whether or not the drugs are taken at the right time and in the right dosages and frequency. Non-adherence is a common problem, more so in chronic diseases, associated with increased morbidity and mortality and costs to healthcare. The World Health Organization states that about 50% of patients with chronic conditions do not adhere to their treatment and consequently obtain suboptimal clinical outcomes and poorer quality of life [1]

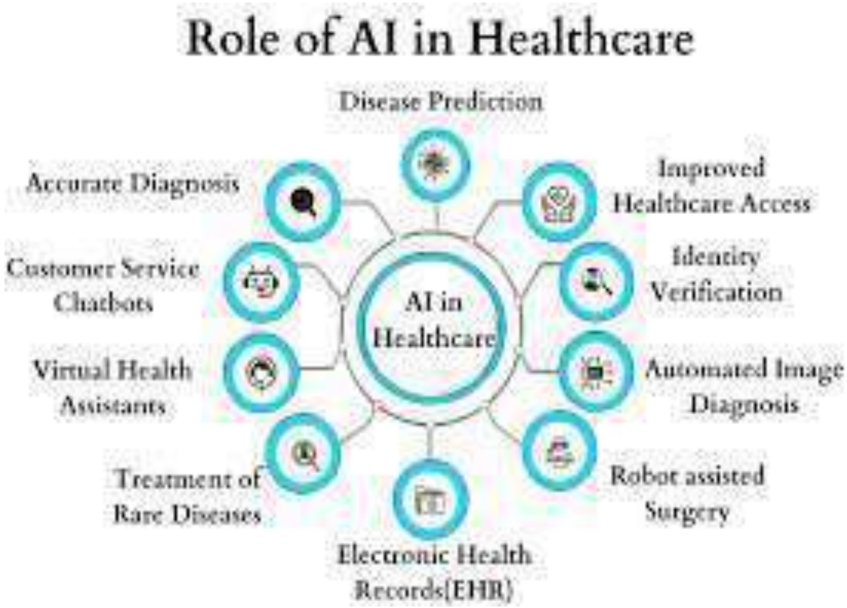


Fig. No. 1 Role of AI in healthcare

2.1 Remaining challenges in medication adherence

Such a range of adversities are brought together as leading to an event of medication non-adherence. Among these are:

- Patient-related factors: Problems in adherence may result from a large number of obstacles such as forgetfulness, lack of health literacy, anxiety over side effects, or misunderstanding of treatment instructions.
- Drug-related factors: Adverse reactions, complicated drug regimens, or protracted

duration of treatment may affect the patient's adherence to the medication.

- Socioeconomic factors: High medication prices, lack of social support, and lack of access to healthcare facilities significantly affect adherence.
- Factors supplied by the health system: Suboptimal provider and patient communication system, poorly integrated deliver care, and insufficient follow-up systems support the environment of non-adherence.
- Psychological & behavioral factors: Cognitive impairment and depressive mental state may interfere with the patient's ability to follow the prescription [14].

2.2 Current Strategies to Improve Medication Adherence

- Educational approaches: Patient-directed counseling and written materials to improve understanding of the disease and the importance of medications.
- Behavioral approaches: Reminder tools, such as pillboxes, alarms, and medication schedules.
- Support programs: Case management, support groups between peers, and pharmacist-led adherence clinics.
- Therapy simplification: Lessening the burden by simply decreasing the number of pills, using a fixed-dose combination, or long-acting preparations.

Even if valuable, all those tend to have very high demands on human resources and also cannot always be sustainable or individualized. This lack opens up an avenue for continuous individual support assisted by AI through solutions enabled by technology. [15,16]

3. The Future of AI in Healthcare

The future of medical AI appears bright because engineers expect to develop its uses in healthcare through increasing sophistication. AI-driven advances in healthcare will become more visible through three key innovations which consist of virtual health assistants, robotic-assisted surgeries, and AI-powered mental health support systems. These systems could provide personalized and timely support, potentially reducing the burden on mental health professionals and improving patient outcomes. Integrating AI with blockchain technology will enhance patient data protection and the security of confidential patient information. The management of medical records through blockchain technology is a tamper-proof decentralized system that protects and gives authorized staff members complete access to medical information. The future of healthcare stands transformed because AI possesses revolutionary capabilities beyond what people could have predicted. AI-driven healthcare benefits patients when ethical matters receive proper attention. AI algorithms achieve high standards, and organizations implement AI responsibly. [17]

4. AI-Related Tools for Monitoring and Enhancement of Medication Compliance

Medication non-adherence is a multifactorial problem with causes, which include forgetfulness, an inadequate treatment understanding, side effects, poor finances, and lack of need perception. Old-school methods such as patient education and counseling, reminders, pill organizers, and many similar approaches have proven inadequate over time. With the increasing possibilities of artificial intelligence (AI), a new, dynamic generation of smart tools is emerging that will provide real-time, personalized, and adaptive interventions to manage adherence. [18]

4.1 Smart Pill Bottles and Ingestible Sensors

A smart pill bottle is a type of smart medication container that uses sensors built into the container to sense the opening of the container and log the time and frequency of a medication intake event. Such devices could communicate with cellphone apps or cloud systems for reminders and alerts to be made available to patients and/or caregivers. Products like Adhere Tech and Medication Event Monitoring System (MEMS) are examples of such devices. And ingestible sensors (e.g. Proteus Digital Health) embedded within pills can transmit data post-ingestion to confirm actual consumption. This system integrates artificial intelligence in analyzing the study of ingestion patterns; it thus flags the inconsistencies or missed doses [18].

Fig. No.2 smart pill bottles with ingestible sensor

4.2 Mobile Apps and Chatbots Internally Powered by AI

AI features in mHealth applications help provide intelligent medication reminders, dosage tracking, and adherence motivation. Most of them use machine learning (ML) algorithms that learn users' behavior and adapt reminders accordingly. AI-enabled chatbots (Woe Bot, Tess) can provide conversational support, addressing patient concerns, and motivating engagement. These applications may also use natural language processing (NLP) to interpret patient responses and develop caring, human-like interactions that have been associated with greater adherence [19].

4.3 Wearable Devices and Behavioral Monitoring

Wearable like smart watches and fitness trackers could monitor activity and some physiological parameters of the patients. In conjunction with AI algorithms, these instruments can distinguish behavioral patterns that signal medication adherence or potential lapses. For instance, the detection of an alteration in normal physical activity patterns might drive a check-in on missed doses [20].

Fig. No.3 Types of wearable devices

4.4 AI-Driven Predictive Models for Adherence

Machine learning models can analyze large datasets—EHRs, pharmacy refill data, social determinants of health—to predict which patients are at risk for non-adherence. This insight into patient behavior allows the clinician and health systems to proactively step in before any issue arises. The systems can also be set to dictate the way in which adherence interventions would be delivered, how often that would happen, and what content would be delivered. [21]

Table: AI-Powered Tools for Medication Adherence

Tool Type	Technology Used	Example Tools/Systems	Function
Smart Pill Bottles	IoT, Sensors	Adhere Tech, MEMS	Detect bottle opening, log intake, send reminders [18]
Ingestible Sensors	Biosensors, Wireless Comms	Proteus Digital Health	Confirm ingestion, transmit data to mobile app [18]
Mobile Apps & Chatbots	AI, ML, NLP	Medi safe, Woe Bot, Tess	Smart reminders, adherence tracking, conversational support
Wearable Devices	Sensors, Behavioral Analytics	Apple Watch, Fitbit	Monitor activity, detect behavioral changes [20]
Predictive Adherence Models	Machine Learning	AI-based adherence dashboards	Identify high-risk patients, suggest interventions [21]
EHR-based AI Integration	Deep Learning, CDSS	Epic Systems, IBM Watson	Real-time alerts, adherence flags in clinical workflow [25]

5. AI and Age Personalization Treatment Plans

Precision medicine or personalized treatment entails adjusting the medical treatment modality according to each person's specific characteristics. The integration of genetic information, lifestyle, environmental exposures, and comorbidities increasingly informs care decision-making. With this, AI is now making more enhanced interventions in smart systems that provide the technology to analyze complex, multimodal datasets, in real time, into recommendations that are specific to individuals.

Fig. No. 4. personalized treatment plans

5.1 Patient Data Analysis and Risk Stratification

AI algorithms analyze large amounts of structured and unstructured health data such as demographics, electronic health records (EHRs), laboratory values, imaging results, and patient-reported outcomes. This allows patients to be classified into risk categories. Such categories are needed to personalize treatments according to the severity of the disease, to the progression risk associated with it, and to the potential response to therapy.

5.2 AI Application in Genomics and Pharmacogenomics

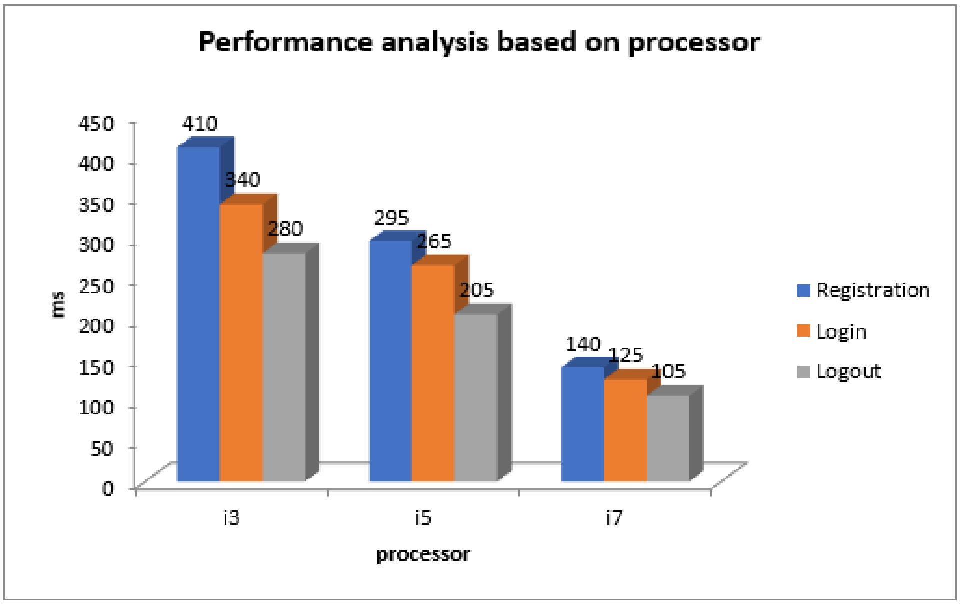
AI systems facilitate understanding genomic sequences and provide treatment decisions based on them. Machine-learning and deep-learning-powered tools can also identify genomic variations that are connected to disease predisposition and drug response. AI is used for discovering biomarkers that predict drug metabolism or response for therapeutic purposes and adverse-effect reduction. [23]

5.3 Adaptive Algorithms in Chronic Disease Management

Applications are capable of constantly assessing patient data and adjusting recommendations in chronic diseases, like diabetes, hypertension, and asthma. For example, AI tools such as IBM Watson for Oncology or Dreamed Advisor process entries of patients, clinical guidelines, and research literature to originate treatment algorithms that more or less consider the best treatment protocols. These systems offer the clinician's support to facilitate the self-management of patients' conditions, which are co-managed with modifications in their medication, diet, or lifestyle as recommended by AI. [24]

6.Integration with Electronic Health Records (EHRs) and Telemedicine

Integration of AI with EHRs and telemedicine systems is a milestone in achieving a connected, efficient, and patient-focused healthcare system. With AI, these technologies would allow real-time analysis of incoming data, provide decision support, predict outcome chances, hence facilitating medication adherence and personalizing treatment plans. [25]



Graph No. 1. EHRs system based on Development for Study on EHR Data-based Early Prediction of Diabetes Using Machine Learning Algorithms

6.1 AI-Powered Tools Enhance EHR for Clinical Decision Support

AI-based systems integrated with EHRs enhance timely visibility of patient data for clinical decision support (CDS). The systems raise alerts to clinically relevant issues like drug interaction, omitted medications, and deviation from treatment protocols. Founded on predictive modeling, the intervention could also identify patients at a high risk of nonadherence or poor outcome. Particularly, the deep learning systems were aptly tested in providing quite dramatic predictions on patient outcome from EHR evidence. Moreover, AI can actually support the process in directing the routine documentation so that clinicians will spend more time carrying out direct care. [25]

6.2 Real-time alerts and adherence monitoring

With the help of artificial intelligence and subsequent additions to EHR systems, alerts can be integrated into the workflow to inform providers when a patient has not refilled a prescription, has missed a dose of medication (using synced smart pill bottles), or is potentially experiencing side effects. These alerts could connect automatically to a messaging system or telehealth follow-up to intervene sooner.[26]

6.3 Telemedicine platforms for remote adherence support

Telemedicine gained its importance, especially during the COVID-19 period, thus evolving to become one important route for remote healthcare delivery. AI adds value to telemedicine platforms by means of automated symptom checkers, triage bots, remote monitoring dashboards, and intelligent scheduling. The AI algorithm can assess patient interactions, engagement trends, and biometrics (heart rate, blood glucose) to explore risks to adherence and customize treatment recommendations even in the virtual space [27].

6.4 An Inclusive Ecosystem of Data for Continuity of Care

Artificial intelligence enables coordinated data flow of electronic health records, pharmacy systems, devices in remote monitoring, and telehealth systems. Comprehensive data ecosystems in their own right can longitudinally monitor integrated behavior patterns across the patient medication spectrum with clinical outcomes and provider interactions—the holistic representation of care across settings. Such continuity across settings is important not only for personalized medicine but also for pathways related to adherence. [28]

6.5 Patient Portals and Support for Digital Literacy

AI-enabled patient portals help patients to navigate personalized dashboards using medication schedules, adherence information, laboratory results, and even AI-generated health advice. Other functionalities of the portal include natural language processing to answer patient queries about health-related issues and generalize inquiries and reword complex health information into simpler forms for self-management, particularly for patients with very limited health or digital literacy. [29]

7. Ethical, Legal, and Privacy Issues

AI promises much in the area of treatments pertaining to compliance as well as individualization. However, the ethical, legal, and privacy issues have to be addressed for its reasonable and just implementation of progress in this area. Within these, the aforementioned issues have included data protection, algorithmic fairness, informed consent, and even the changing roles of healthcare providers themselves in the ecosystem augmented by AI technology. [30]

7.1 Data Privacy and Security

AI systems usually make use of large patient input data usually from sources like electronic health records, wearables, and mobile applications. It is crucial yet challenging to ensure confidentiality, integrity, and data security of this sensitive human health data. Breach, unauthorized access, or misuse of data is bound to break patient trust and can also be out of the legal framework, as in the case of the Health Insurance Portability and Accountability Act (HIPAA) in the United States and General Data Protection Regulation (GDPR) in the EU. [30]

7.2 Algorithmic Bias and Fairness

Not only health disparity, but algorithmic bias has been found to actually augment health disparity, which can happen if algorithms are applied on biased or non-representative datasets toward training. For example, a model developed largely from particular demographic groups will not make a right prediction about the underrepresented population, resulting in inappropriate treatment recommendations or risk stratifications. Bias has to be corrected through the processes of transparency in algorithm development, diverse data collection, and periodic auditing for equity of outcomes [31]]

7.3 Informed Consent and Patient Autonomy

Patient autonomy is preserved through genuine, straightforward, and informed continuous consent concerning AI healthcare tools. The patient will find what is being done to his data, how existing and future decisions will be undertaken by AI, and what rights he holds regarding data sharing, opt-out, and interpretation of AI-generated recommendations [32].

7.4 Accountability & Legal Liability

With AI systems recommending or making decisions affecting diagnosis, treatment, or medication, it is uncertain who will be held responsible in the event of a mistake or adverse outcome—for example, the developer, provider, or healthcare institution? The law is still being developed to elucidate the liability of AI-assisted clinical decisions. There is an additional fear that in doing so, clinician judgment might erode, particularly if these AI recommendations are followed without adequate oversight or validation [33]

7.5 Transparency and Explainability of AI

Many AIs, in particular, models based on deep learning, act as "black boxes." For this reason, understanding how a given input leads to some outputs are rather limited. The clinical field needs to uphold trust and transparency. This lack of explainability is thus impeding AI acceptance. Explainable AI (XAI) attempts to develop models that are understandable and feed backable by clinicians and patients [34]

8. Future Perspectives and Challenges

There is great promise for AI in healthcare, but with it comes a great deal of challenge. AI technologies will feature heavily in medication adherence and personalized systems of care, but it will be important for both anticipating future evolution and actively addressing existing limitations in scalability, regulation, ethical adoption, and interdisciplinary collaboration as these promises become reality. [35]

8.1 Looking from Archived Doors of Opportunities

• AI-Driven Precise Medicine at Scale: The convergence of multi-omics data (genomics, proteomics, metabolomics) with lifestyle and behavioral data will ultimately yield treatment optimized for an individual.

• Closed-Loop Medication Adherence Systems: an AI-smart device-digital therapeutic synergy would be complete autonomous adherence tracking and real-time intervention systems.

• Decentralized Clinical Trials & Real-World Evidence: revolutionizing our very `practical' considerations when regarding the effectiveness and adherence of drugs in terms of studying real-world settings and improving the external validity possible.

• Federated Learning Models: expand fair AI access by allowing for AI to learn with decentralized data while maintaining patient privacy. [35]

8.2 It faces various challenges like:

• Regulatory Uncertainty-The FDA in the US and EMA in Europe are still setting up their environments to consider the continuous learning nature of AI.

• Interoperability and Data Standardization: AI systems require clean, consistent, interoperable environments, which is largely unavailable within the frail ecosystems of healthcare.

• Trust of Clinicians and Patients: Poor explainability, excess perceived complexity, and digital illiteracy can all contribute to resistance.

• Algorithmic bias and inequities in health: AI might similarly design by default or buttress or neutralize distinctions mostly among under-represented populations." [36].

Visual Table: Future Challenges and Solutions in AI-Driven Healthcare

Challenge	Description	Proposed Solution
Regulatory Ambiguity	Lack of clear AI approval & update pathways	Adaptive regulatory frameworks (e.g., FDA's AI/ML-based SaMD Action Plan) [36]
Algorithmic Bias	Unequal accuracy across population groups	Diverse training data; equity audits [37]
Data Fragmentation	EHRs and health systems lack interoperability	Standardized APIs (e.g., HL7 FHIR), federated learning [38]
Privacy Concerns	Risks in sharing personal health data	Differential privacy, federated models [39]
Explainability of AI	Difficulty interpreting deep learning decisions	Investment in explainable AI (XAI) techniques [40]
Clinician Resistance	Fear of job displacement, lack of training	Co-design systems with clinicians, provide AI literacy training [41]
Patient Trust & Digital Literacy	Misunderstanding or mistrust of AI recommendations	Patient-centered interfaces, transparency in data use [42]

9. AI in Pharmacovigilance and Adherence Optimization

The usage of artificial intelligence becomes essential in the synonymity of pharmacovigilance. This includes the systematic monitoring, detection, assessment, understanding and prevention of adverse effects or any other possible drug-related problems. Currently, AI tools capture adverse drug reactions through automated retrieval of reports from electronic health records (EHRs), social media, and online health communities. Such information is critical because unreported side effects have been known to prompt non-adherence to medical therapy. The adverse effect detection capabilities of AI systems can help providers adjust therapies before it becomes a problem for adherence. For example, Med Watcher Social is a system that utilizes natural language processing (NLP) and machine learning (ML) capabilities to extract ADRs from user-generated online content, alerting both clinicians and patients in real time. [43]

10. Role of AI in Behavioral Psychology Integration for Adherence

They are using behavioral psychology to look at patterns such as mood, other social behaviors, and stress, which may serve as valid predictors for non-adherence; They are AI-driven platforms assessing digital biomarkers of typing speed, screen time activity, and voice response patterns. [44] They inform Just-in-Time Adaptive Interventions (JITAIs) by discerning high-risk psychological states with real-time responses. An example of Mind Strong is that it uses AI applied to smartphone metadata to detect mental health changes predictive of nonadherence. [45]

11. AI in Socioeconomic Risk Profiling for Adherence

The interconnectedness of social determinants of health (SDOH) improves the potential of AI models to discern patients who are likely to become non-compliant with health regimens due to extrinsic reasons such as being unable to afford care, lack of housing, or even public transport to their healthcare provider's office. An AI could then suggest possible remedies or interventions tailored to an individual's context. Social workers, for their part, may also now be able to prioritize patients needing urgent resources. One such example is the study that showed that in the absence of such features added, disparities in health outcomes increase. [46]

12. AI-Powered Gamification for Long-Term Engagement

Encouragement through gamification techniques enhanced by artificial intelligence is also gaining attention with regard to improving long-term medication adherence. Reinforcement-learning-based algorithms are used to dynamically calibrate difficulty, rewards, and user engagement features of these apps. Gamification of mundane everyday behaviors with AI aims to render adherence rewarding and fun. With Pill Pal, dynamic and personalized motivational experiences are built depending on the user's adherence behavior. [47]

13. Conversational AI and Multilingual Adherence Support

With the very nature of multilingual conversation AI systems, they pull down walls of language and health literacy. Using GPT-based NLP, these chatbots compete to provide a communication style that considers local context and culture enhancing understanding of complicated regimens. This promotes outreach among populations of different linguistic backgrounds and supports a platform for shared decision-making and building trust. [48]

14. AI-Augmented Community Health Worker (CHW) Systems

AI-Strengthened apps empower Community Health Workers (CHWs) in low-resource settings to perform triage and adherence risk assessment during home visits. The tools also provide real-time intervention and educational content. Essentially, "Babyl" in Rwanda enables CHWs to manage chronic diseases by using AI decision trees and data-collecting apps. [49]

CONCLUSION

In 2022, the United States Department of Health and Human Services Office for National Statistics noted that rapid development is something that varies with different countries. Through this, artificial intelligence has evolved to incorporate nonadherence and personalized treatment plans into health services. This article will review research on how AI solves the age-old problem in chronic diseases—from smart pill bottles, ingestible sensors, and predictive analytics to genomics and adaptive treatments. AI enhances personalized and real-time interventions, helps in common clinical decision-making using large multimodal data sets, and integrates with. It opens up opportunities to view healthcare as more proactive and patient-centered but does not, however, eliminate the many barriers. Systematic ethical analysis in the areas of data privacy, algorithmic fairness, accountability, and transparency must precede the definition of new ethical frameworks for tomorrow. There are also regulatory issues, interoperability issues, lack of trust, and many more challenges towards institutionalization of these innovations. Possible future developments include the increasingly exciting and promising applications of explainable AI, federated learning, and closed-loop adherence systems. But interdisciplinary collaboration, equitable access to data, and implementation all still need to be highlighted to ensure AI does indeed create the best possible health outcomes. For a thorough and truly AI-integrated.

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