

REVIEW ARTICLE

Personalized Medicine with Artificial Intelligence: A Mini Review of Current Approaches and Future Directions

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ABSTRACT

Artificial intelligence (AI) has made a remarkable impact in almost all fields and healthcare is a worth mentioning one in this context. The adaptation of AI in healthcare has not only added a new direction to healthcare but has also ignited new hope for patients. AI models are being smartly used for various aspects of healthcare that include, disease detection, diagnosis, analysing medical images, deciding effective treatment protocols, predicting possible response of patient to a specific treatment, predict pattern of disease progression and to decide effective medicine that may work for an individual depending on his personal genetic makeup and physiological conditions. Thus, AI in healthcare, especially in the field of personalized medicine has brought a revolution. Using AI and Machine Learning (ML) models, it is now possible to design a specific treatment strategy and provide specific medical aid to an individual patient depending on the unique features like genetic makeup, medical histories, lifestyle factors, allergic tendencies etc. This personalized medicine is way better and effective and compared to the conventional hit and trial treatments. Adding AI to this personalized medicinal approach has added to its effectiveness and has made it cost-effective, advanced and quick. The remaining fear and uncertainty in using AI in medical decision making etc. including personalized medicine due to unclear working pattern of the AI models has also been addressed by explainable AI. Explainable AI powered models now not only help in making accurate decisions in healthcare but also gives an explanation for its decision. Thus, working of AI models are now understandable, making them more reliable, dependable and user friendly. This mini review article briefs the various aspects of AI-powered personalized medicine.

1. INTRODUCTION

Personalized medicine is that branch of medical science that involves precise medical recommendation, treatments and medical intervention for a particular patient depending on the patient's unique characteristics like his genetic makeup, lifestyle factors, environmental conditions and medical history [1]. Personalized medicine is also known as precision medicine. In fact, precision medicine is a newer term for personalized medicine [2]. The term 'personalized medicine' typically seems to mean treatment or medicine for a person as per his personal conditions and requirements. Whereas, 'precision medicine' tends to mean precise medication for a specific medical condition. Thus, these two terms are widely overlapping and often used as synonymous [2].

Artificial intelligence (AI) in healthcare has opened up tremendous possibilities and has given a lot of hope to us to fight against various health ailments effectively [3]. AI and ML models

enable to decide suitable treatment regime for patients, select personalized treatments and medicines, to design and develop drugs, to analyze large data set of patients, to interpret clinical findings and to make various decisions related to diagnosis and treatment of patients. Robotics is also being used for addressing various health issues in combination with AI [4]. Various DL and ML models are being used in various components of the healthcare system. In spite of several limitations and challenges, AI has remarkably revolutionized the field of personalized medicine and has made it an integral part of 'smart healthcare' [5].

Merging AI with personalized medicine has opened up scope for providing more accurate diagnoses, effective treatments, and improved patient outcomes [6]. AI-powered personalized medicine can analyse large amounts of clinical data, identify patterns, and make predictions thereby helping in making better decisions about disease diagnosis and prognostics [7]. Applications of AI in medical and clinical practices come with certain challenges and limitations. Among these

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medico-legal issues and safety of patient are two prime ones. In this context, AI models earlier were like 'black box' i.e., the pattern and mechanism of their working was not understandable to human [8]. But with advancement of AI, certain techniques are now possible to be implemented in the AI models that can enable the models to give a clear explanation about the way it works to reach a decision. Thus, this interpretability of AI models has the goal of clearing the hurdles of ethical, medico-legal and safety issues at least to some extent [9].

With the evolution of personalized medicine, advanced integration of AI is playing a significant role in the development and better effective implementation of personalized medicine. AI is applied at various stages of personalized medicine [10]. AI is used in genomic analysis to predict the progression pattern of disease to prediction of possible response to treatments to personalized treatment planning, AI is being effectively used. With this increased use of AI in analysis of genomes, advancements in personalized medication and treatment of various diseases including cancer have been achieved [11]. This not only makes the process accurate and cost-effective but also accelerates the treatment regime of a specific patient. Though a lot of advancement has been made in the use of AI in personalized medicine, still there remains several challenges and limitations to be addressed [12]. This mini review provides insights into the various components of AI powered personalized medicine, current approaches, challenges and limitations and potential future directions. A compact idea of the role of AI in personalized medicine will help to understand the potential of the modern technology in transforming healthcare, reduce cost of healthcare, improve patient outcomes and improve overall quality of patient care. Ultimately, this mini review aims to provide a foundation for further research and development in AI-powered personalized medicine, paving the way for more effective and targeted healthcare interventions.

2. METHODOLOGY

A comprehensive literature search was carried out across major databases, that included PubMed, Scopus, ResearchGate, Web of Science, IEEE Xplore, Science Direct, and Google Scholar, using combinations of keywords such as "artificial intelligence," "machine learning," "deep learning," "personalized medicine," and "precision medicine." Publications from the last decade (2015–2025) were prioritized to capture the most recent advances, though earlier landmark studies were included when contextually relevant.

2.1. Inclusion Criteria

Peer-reviewed research papers and reviews focusing on the role of AI in enabling individualized diagnostics, prognostics, treatment selection, or biomarker discovery were included.

2.2. Exclusion Criteria

Studies unrelated to personalized medicine, lacking clinical or translational relevance, and non-peer-reviewed contents such as editorials, commentaries, and conference abstracts were excluded.

After screening titles and abstracts, full texts of potentially relevant studies were assessed. The selected literature was then

explored, with emphasis on AI techniques, clinical applications, benefits, limitations, and challenges in implementing personalized medicine. This approach allowed a balanced overview of the field while highlighting both current progress and existing gaps.

3. ABOUT PERSONALIZED MEDICINE

As evident from studies, certain populations at certain geographical region have varied response to specific pathogens. A geography of infectious diseases has been reported in several studies [13]. For instance, a pathogen may cause fatal infection in individuals of a specific region while people of other region may be resistant to such infection by the same pathogen. This depends on factors like the genetics, the immunity and environmental factors [14]. Similarly, a particular population of any region may respond effectively to any drug while the same drug may not be effective for people of some other region. This variation in response depends and is decided by the genetic profile of the population. Individual variations are also observed and are decided by personal genetic profile [15].

Pharmacogenomics is that branch of science that deals with the variation of response of people to specific pharmaceutical formulations depending on individual genomic profile [16]. Pharmacodynamics and Pharmacokinetics are also decided by individual genomic profile. With evolution of the raw draft of human genome it is now well understood that the variation on response to drug among individuals is due to genetic polymorphism in the enzymes associated with phase I and phase II drug metabolism. As a result of this genetic polymorphism, certain individuals in a population may exhibit a different pattern of drug bio-transformation [17]. Pharmacogenomics or pharmacogenetics refers to that kind of variation in drug bio-transformation in individuals due to genetic polymorphism of drug metabolizing enzymes [18].

4. CURRENT APPROACHES TO AI-POWERED PERSONALIZED MEDICINE

AI models can be used to analyse genomic data. Depending on the results, a particular treatment strategy can be decided. AI models trained with vast dataset of genetic profile from individuals, their genetic polymorphism for drug metabolising enzymes and their variation in response to specific drugs may be helpful for easily sorting and deciding the right drug for the right person [18]. Predictive analysis is a string tool used in healthcare to effectively predict progression pattern of a disease, impact of a medicine or treatment, possible patient outcome etc., [18].

By analysing genetic data, AI models can minimize adverse drug reactions, help to find the effective dosage of the effective drug for an individual and can even predict the time frame of reaction to the medicine and the pattern of response [19]. AI models coupled with personalized genetics, can predict well in advance, the possibility of onset of a disease in an individual, it can predict the vulnerability of an individual to a particular disease or infection. This helps to tailor strategies and medical interventions to prevent and treat the disease at an earlier stage, that too with genetically compatible personal medicines, that can help to prevent the onset or arrest progression or treat the disease effectively. Besides genetic makeup, other factors like

lifestyle and environmental factors play significant role in the vulnerability of an individual to a particular disease. Specially lifestyle diseases like cardiac diseases are remarkably regulated by such lifestyle habits, daily practices and even diets of an individual [20]. AI models can be used to analyse all these factors and recognize the potential risk factors for an individual to be affected by a particular disease and such risk factors can be timely ruled out from the person's routine to prevent occurrence of such diseases [21]. In a nut shell, AI models can analyse other factors like lifestyle, diet, daily habits, information about the environmental the individual lives in and help clinicians to identify risk factors and eliminate those. This can also help the clinicians to recommend a suitable diet and certain changes in the lifestyle that can prevent the onset of the disease [22,23]. Predictive analytics by AI models uses statistical analysis, data mining and machine learning algorithms. Data used for AI powered personalized predictive analytics considers data from various sources including clinical dataset, data from patient's wearable device etc. [24].

AI models are being extensively used for personalized treatment planning and for clinical decision support. A tailored personalized treatment planning is possible to be made by AI models by analysing and correlating the patient's various data [25]. This can help to select patient specific, better drug with improved outcomes. AI also helps to plan treatment regimes, the pattern of treatments to followed over a time frame a person depending on his individual specificities. AI models can also predict drug-drug interactions in an individual and thus can help to make decision about personalized drug selection and safety [26]. Table 1 shows some AI powered personalized medicinal approaches against certain diseases.

5. BENEFITS OF AI-POWERED PERSONALIZED MEDICINE

AI can be used to improve accuracy, reduce diagnostic errors and fasten the process of diagnosis and treatment of diseases in a specific manner suitable for an individual depending on various determinant factors of his response to treatment. Advancements in technology like DNA proteomics, wireless health monitoring devices, Deep Learning and Machine learning models etc. has contributed tremendously to the development of personalized medicine. AI may help to formulate novel drugs for individuals [40]. The various benefits of AI- and ML-powered personalized medicine are summarized in Figure 1.

5.1. Improved Accuracy

AI models can analyse vast amounts of patient data, including genomic information, clinical histories, and lifestyle factors, environmental factors, nutritional data and correlates all together to provide more accurate personalized diagnoses and treatment recommendations. AI efficiently handles vast complex data of patients. Predictive AI models help in accurate early detection of diseases. AI algorithms enable tailored designing of accurate drug for an individual that can yield best results considering the possibility of drug metabolism in his body depending on his pharmacogenomics. AI models also help to detect and identify disease specific biomarkers in an individual thereby helping in personalized targeted medication [41].

A study compared performance of AI system for mammography interpretation in for cancer prediction in clinical settings. They used large datasets from the UK and USA. The system demonstrated AI system reduced false positives by 5.7% (USA) and 1.2% (UK), and false negatives by 9.4% (USA) and 2.7% (UK). The AI system outperformed all human readers i.e., in a comparison with six radiologists and the system achieved an AUC-ROC 11.5% higher than the average radiologist [42].

Table 2 summarizes some of the studies that uses AI and the advantages of using AI.

A nationwide real-world study (PRAIM), involving **463,094 women who have been** screened at 12 centers in Germany, reports that a **AI-supported double reading** achieved a **breast cancer detection rate of 6.7 per 1,000** and this was **17.6% higher** (95% Clearance Indicator: +5.7%, +30.8%) compared to standard double reading (5.7 per 1,000). The recall rate has been reported to be slightly lower with AI (−2.5% difference), while the positive predictive value (PPV) improved significantly i.e., 17.9% vs. 14.9% for recall and 64.5% vs. 59.2% for biopsy. These results demonstrate that AI integration enhances detection accuracy of cancer without increasing recall rates and this supports its effectiveness in large-scale screening [47].

Detection of Breast Cancer Lymph Node Metastases has been shown to be 50% more by pathologists with AI assistance compared to the conventional detection [48].

5.2. Specific and Effective Treatment Plans

AI-powered personalized medicine can help to develop tailored, specific and effective treatment plans considering and correlating an individual's unique characteristics, leading to more effective patient outcomes. Studies show that personalized therapeutic approach is highly effective in certain diseases like cancer. AI can help in early diagnosis, screening and to prepare specific, effective personalized treatment plans for such conditions. Predictive analysis can help to understand the treatment outcomes for an individual and this helps to make individualized treatment plans [46].

5.3. Increased Patient Outcomes

By providing personalized treatment plans, AI-powered personalized medicine can lead to significantly improved patient outcomes. AI models enable better disease management decisions based on an individual's personal requirements and conditions, reduced complications depending on an individual's genetic profile and other factors etc., reduced possibilities of adverse reaction of drugs, reduced possibilities of ineffective medications etc. AI models coupled with personalized medicinal approach can lead to overall significantly increased and improved response of an individual patient [49].

5.4. Increased Efficiency

Using AI, several tasks associated with personalized medicine can be automated. These include tasks like data analysis and pattern recognition, selecting effective treatment regimes, keeping clinical records in a sorted manner. Robotics coupled with AI

Table 1 | Examples of AI-powered personalized medicinal approach against various diseases

Serial no.	Disease	AI application	Personalized approach	Examples/tools	References
1.	Ovarian Cancer, Lung Cancer etc.	AI model is used for analysing genomic data and for predictive modeling	AI helps to integrate individual genomic or proteomic data to recognize patient-specific biomarkers for targeted therapy	IBM Watson for Oncology (WFO)	[27]
2.	Breast Cancer, Lung Cancer, Prostate Cancer	AI model is used for analysing genomic data and pathological images for decision making	AI helps to integrate individual genomic data and other clinical data like pathological data to identify targeted patient specific biomarkers for personalized therapeutic purpose. DL models also help to classify metastatic tumours from primary tumours based on mutational signatures	Deep Learning (DL) for mutational profiling	[28]
3.	Cardiovascular Diseases (CVD)	AI-driven ECG analysis, risk assessment, prediction and prediction of drug response	AI predicts individual risk factors for CVD using DL score and optimizes drug selection like anticoagulants, antihypertensives etc.	Deep neural networks risk scores are used for risk stratification of CVD in a person	[29]
4.	Diabetes Mellitus (Type 1 & 2)	AI models can analyse genomic data and can help with continuous glucose monitoring. Also, can help to optimize effective dose of insulin	AI can monitor insulin delivery using real-time glucose fluctuations; AI models can predict the possibility of occurrence of diabetes in an individual depending on his genetic profile and can also predict treatment response	AI-powered insulin pumps or Automated Insulin Delivery (AID) systems or artificial pancreases (Medtronic, Tandem Diabetes Control-IQ)	[30,31]
5.	Neurological disorders i.e., Epilepsy, Alzheimer's, Parkinson's etc.	Seizure prediction, drug resistance analysis and prediction of response to treatment	Personalized prediction of response to treatment, seizure detection in real time and early disease detection. AI models are used for detection of brain atrophy etc.	AI powered EEG analysis, ML-driven Alzheimer's progress prediction, Quibim's QP-Brain® for early detection of atrophy and lesions from imaging of brain helps to predict neurodegenerative diseases	[32–34]
6.	Psychiatric disorders i.e., Depression, Schizophrenia etc.	AI-based pharmacogenomics	Predicts patient-specific response to drugs like antidepressants/antipsychotics etc.	Machine learning models analyse, predict and decide by integrating genetic & clinical data; Stratified treatment algorithm in psychiatry (Psych-STRATA)	[35]
7.	Infectious diseases i.e., HIV, COVID-19, TB etc.	AI models identify active TB in asymptomatic patients; Helps in effective drug repurposing depending on pharmacogenomic data and immune response prediction	Personalized treatment strategies are decided and response to treatment is predicted by AI models based on host genetics and viral strain variability	Cognitive AI-driven personalized treatment of infectious diseases. Using AI platforms for personalized drug repurposing (e.g., BenevolentAI, DeepMind)	[36,37]
8.	Rare genetic disorders	AI helps in genome sequencing, analysis and variant interpretation. AI also helps to tailor patient specific treatment regime and repurpose, design or recommend personalized medicine for an individual depending on his exact genetic profile	AI algorithms identifies causal mutations and suggests tailored therapies targeting the altered biomarker for a specific disease	Deep learning models are used for variant classification etc. (e.g., DeepVariant, Alpha Missense)	[38,39]

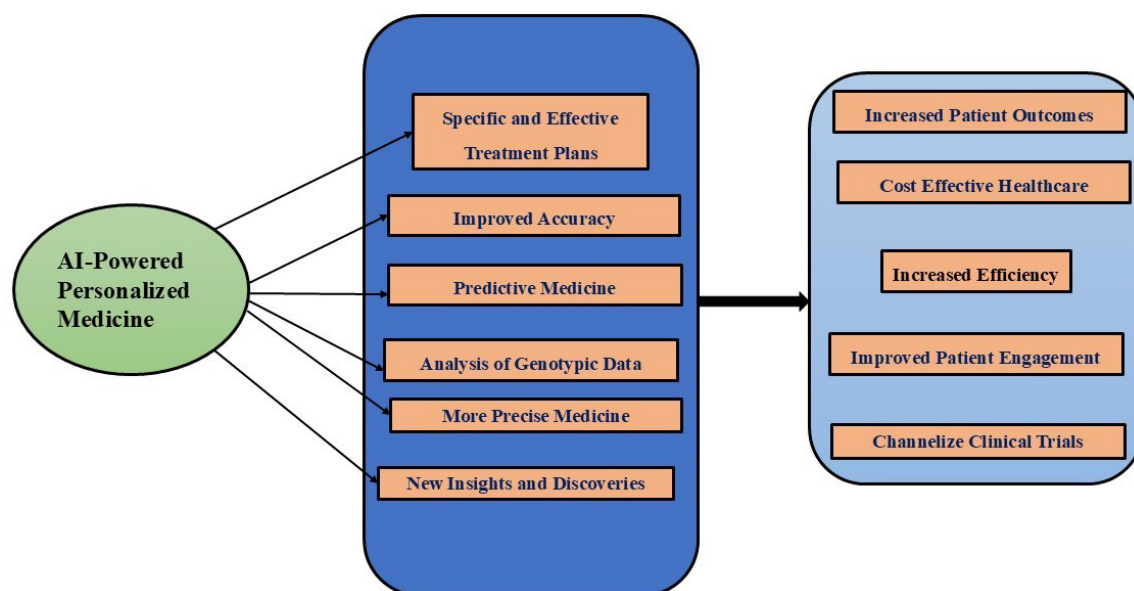


Figure 1 | Benefits of AI- and ML-powered personalized medicine.

Table 2 | Some of the studies that uses AI and the advantages of using AI

Serial no.	The study	Advantages of using AI	References
1.	Tested an AI tool called 'Sherpa Rx' that integrates Clinical Pharmacogenetics Implementation Consortium (CPIC) guidelines with Pharmacogenomics Knowledge base (PharmGKB) data and used to generate responses that are contextually relevant. A dataset of N = 260 queries, spanning 26 CPIC guidelines was used to evaluate dosing recommendations, drug-gene interactions, and therapeutic implications.	High performance: accuracy ~4.9/5, relevance 5.0, clarity 5.0, completeness 4.8, recall ~0.99. Also significantly outperformed a baseline (ChatGPT-4 "omni") in accuracy & completeness on a subset. This shows AI can closely match expert guidance in drug-gene interaction/dosing recommendation tasks.	[43]
2.	Review of integrating multi-omics (genomics, transcriptomics, proteomics, metabolomics) with AI modelling (deep neural networks, graph neural networks etc.) for drug response phenotypes	Shows that integrating multi-omics with AI improves predictive accuracy of drug response and reveals mechanistic insights, e.g. gene-gene & gene-environment interactions. Supports claims of improved precision & understanding of interindividual variability	[44]
3.	Review covering how AI is being used in target identification, virtual screening, de novo design, structure prediction (e.g. via AlphaFold), trial design (patient recruitment, predictive modeling), synthetic control arms, digital twins etc.	Provides multiple evidence i.e., faster & more efficient drug discovery, better trial design, possibly reduced failures & costs using AI. Supports claims about speed, cost, and efficiency improvements using AI.	[45]
4.	63 studies considered reviews how AI techniques improve cancer diagnosis, prognostic predictions, and treatment outcomes.	Shows measurable improvement in predictive accuracy.	[46]

can also add up to the efficiency of AI powered personalized medicinal approaches. These can free up healthcare providers to focus on more complicated and high-value tasks associated with personalized medicine and other aspects of clinical care that require human expertise [4].

5.5. Predictive Medicine

AI-powered personalized medicine can help to predict possible risk and vulnerability of an individual to a particular disease depending on the individual's genetic profile, exposure to pathogen, pattern of immune reaction etc. [50].

AI helps in early diagnosis, to identify potential health issues before they become serious, predict possible effectiveness of

treatment, thus, enabling early intervention and prevention of diseases in individuals. Thus, AI powered personalized medicine can forecast disease risk and optimize drug selection in an individual [42].

5.6. Cost Effective Healthcare

Integrating AI in personalized medicine, it is possible to provide more effective treatment plans thus reducing the need for trial-and-error treatment approaches.

Thus, AI-powered personalized medicinal approaches can help to reduce healthcare costs. AI can also help to design effective drug for an individual depending on his genetic profile thus lowering ineffective medications and the cost for it [51].

AI models can provide accurate treatment plans and effective personalized clinical decisions leading to reduced cost for ineffective approaches, optimizing resource allocation, and to reduced cost of healthcare [22].

5.7. Improved Patient Engagement

AI-powered personalized medicinal approach can provide patients with more information about their genetics, health, disease vulnerabilities, immune responses, allergies if any, possible adverse reaction to drugs if any, suitable treatment options etc. This vivid information about oneself, enables them to take more active and timely self-care. This leads to overall improved patient engagement that is a significant key for effective treatment outcomes [52].

5.8. More Precise Medicine

AI can help detect, and analyse specific genetic conditions like mutations and biomarkers in an individual. Thus, helps to decide and intervene better and more precise personalized treatment targeting and reducing the risk of side effects. This also helps to identify precise drug combination that may work magically for an individual [53].

In this context, precision oncology has gained quite a momentum in current days. AI enabled personalized medicinal approach to diagnose cancer, analyses individual genomic data from tumours and identifies the specific mutation that has led to the formation of the tumour or neoplastic changes [54]. This identification of the mutation helps to design targeted drug for the phenotypic outcome of the specific mutation thus, increasing the effectiveness and accuracy of anticancer drug designing and selection against cancers like breast cancer and colon cancer [46].

5.9. Channelize Clinical Trials

AI powered personalized medicinal approach can help identify potential participants for clinical trials depending on the similarity or pattern recognition of pharmacogenomics of those individuals. This can optimize trial design, leading to more efficient, effective and accelerated clinical trials. Such approach can reduce ineffective trials and time, optimizing drug discovery and patient trials [42,55].

5.10. New Insights and Discoveries

AI-powered personalized medicine can provide new insights into disease mechanisms and treatment outcomes, leading to new discoveries and innovations in healthcare. Also, AI-powered personalized medicine can lead to identification if individual genetic risk factor for any specific drug adverse reaction leading to designing a modified pharmaceutical molecule that may work for an individual. AI models also help to identify patient-specific drug target molecule. Thus, AI models can suggest new effective drug candidates or derivatives for an individual depending on the results of analysis of his drug metabolizing enzymes. AI models can also help to design new drug molecules depending on the structure of the drug receptors and mechanism of bio-transformation of the drug in an individual. AI also plays a

crucial role in effectively predicting the outlines of trial of newly designed drug molecules [56].

6. CHALLENGES AND LIMITATIONS OF AI-POWERED PERSONALIZED MEDICINE

AI powered personalized medicine comes with several challenges, limitations and obstacles (Figure 2).

7. DATA INACCURACY, BIAS AND QUALITY

7.1. Data Quality and Heterogeneity

Data used in personalized medicine encompasses a wide range of sources, including clinical records, genomic sequences, imaging results, lifestyle information, and environmental factors influencing an individual's health. These datasets are often highly heterogeneous, varying in format, accuracy, and completeness, which poses a significant challenge for reliable analysis. For example, clinical records may have missing entries or inconsistencies, genomic data may contain sequencing errors, imaging data may differ in resolution or quality, and lifestyle or environmental data may rely on self-reports, which are prone to inaccuracies. Moreover, these large and complex datasets may include noise, random errors or irrelevant information. They may have inherent biases, such as underrepresentation of certain populations or systematic errors in data collection. Such imperfections can propagate through AI algorithms, resulting in flawed predictions, misclassification of disease risk, or inappropriate treatment recommendations. Consequently, the accuracy and reliability of personalized medicine approaches heavily depend on careful data curation, rigorous quality control, and the development of algorithms capable of handling noisy and biased inputs. It is necessary to address these limitations about data quality and heterogeneity to rule out AI-driven personalized medicine risks producing suboptimal or even harmful clinical outcomes [57,58].

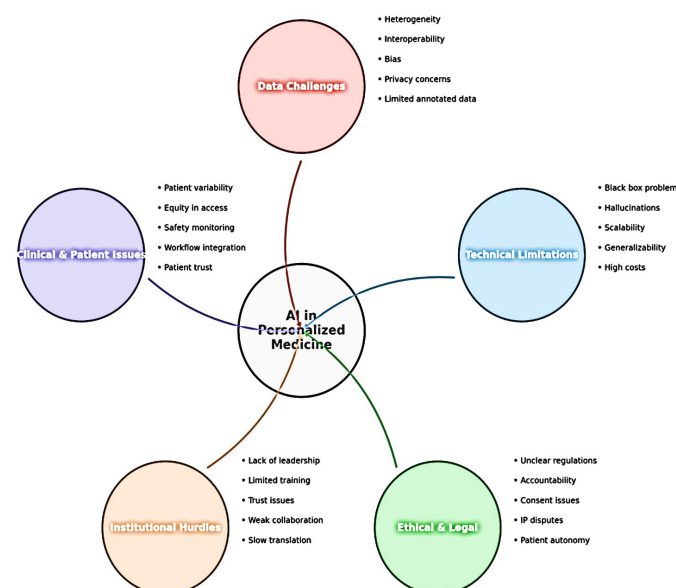


Figure 2 | Limitations and obstacles to widespread application if AI in personalized medicine.

7.2. Data Availability and Sharing

Data related to patients are mostly regulated by medico legal issues and human ethical concerns and guidelines. Such data of patients are mostly fragmented across institution, multiple hospitals, clinics, and laboratories, with each institution maintaining its own systems, formats, and standards. This fragmentation makes it difficult to integrate data at scale. Also, these kinds of data are often restricted to be shared, limited to be used for research purposes and for training purposes of AI models. This limitation in data availability and sharing restrictions impose challenges in designing new AI models for healthcare including personalized medicine [57,58]. This limited and restricted availability and sharing of patient data represent a major limitation in the development and deployment of AI in personalized medicine. High performing accurate AI models require large, diverse, and representative datasets to learn complex patterns and make accurate predictions. Moreover, strict regulations on patient privacy, informed consent, and ethical use of medical information limit the ability to freely share data between institutions or across research groups. Even when data sharing is possible, legal, administrative, and technical barriers, such as lengthy approval processes, data anonymization requirements, and lack of interoperable systems can significantly slow down or restrict access. Additionally, many datasets are small, biased toward specific populations, or limited to certain conditions, reducing the generalizability of AI models. The lack of centralized, accessible, and standardized datasets impedes the training, validation, and benchmarking of AI algorithms, ultimately constraining their reliability and effectiveness in personalized healthcare. To address this, efforts are needed to develop secure data-sharing frameworks, federated learning approaches, and standardized data formats that allow collaborative model development while protecting patient privacy and complying with ethical guidelines [59,60].

7.3. Bias in Datasets

Underrepresentation of any data from diverse group for instance minority groups i.e., women, elderly patients, or individuals from specific geographic or socioeconomic backgrounds can lead to biased predictions, reducing effectiveness in diverse populations. When these groups are poorly represented in training datasets, AI models may fail to learn patterns relevant to them, leading to predictions that are less accurate or even systematically unfair for these populations. In addition to underrepresentation, datasets often contain noise, including errors, inconsistencies, or irrelevant information, which can further distort model learning and amplify bias [61,62]. Bias in datasets is a critical challenge for AI in personalized medicine, as it can significantly compromise the accuracy and fairness of predictions. Imaging artifacts, incomplete clinical records, or mislabeled genomic data can mislead AI algorithms, producing predictions that favor well-represented or higher-quality data groups. Such biases not only reduce the overall effectiveness of AI-driven personalized medicine but also risk perpetuating health disparities by providing unequal levels of care across different populations. Addressing dataset bias requires careful design of data collection protocols, inclusion of diverse populations, rigorous data cleaning, and algorithmic strategies that detect and mitigate bias to ensure equitable and accurate AI-assisted healthcare outcomes.

8. REGULATORY, LEGAL AND ETHICAL CONSIDERATIONS

Using AI in healthcare comes with regulatory, medico legal and ethical concerns. Issues of data privacy, informed consent, and potential biases in AI algorithms must be carefully addressed to ensure equitable and transparent healthcare. Additionally, the reliance on AI decision-making may challenge traditional patient–physician relationships and may raise questions about accountability and trust. Balancing these ethical concerns with the potential benefits is essential for responsible, full proof and effective implementation of AI in personalized medicine.

8.1. Patient Privacy and Security

Personalized medicine requires access and analysis of sensitive genomic and clinical data of patients. There remains a raising risk of misuse or breaches of such sensitive individual patient data [63]. Personalized medicine relies heavily on the collection, storage, and analysis of sensitive patient data, including genomic information, clinical records, imaging data, lifestyle factors, and environmental exposures. While access to this data is essential for developing accurate and effective AI-driven interventions, it also raises significant concerns regarding patient privacy and data security. The increasing digitization and sharing of medical information make it vulnerable to unauthorized access, cyberattacks, or misuse of data, which may lead to identity theft, discrimination, or stigmatization of patients. Moreover, even anonymized datasets can sometimes be re-identified by combining multiple data sources, further increasing privacy risks. Certain regulatory frameworks and national or regional laws provide guidelines for protecting patient information, but strict compliance requirements can also limit data accessibility for research and AI model development. Ensuring robust data security measures, including encryption, secure storage, controlled access, and audit trails along with ethical handling of sensitive data, is essential to maintain patient trust and safeguard the integrity of personalized medicine initiatives. Additionally, patient education and transparent communication about how their data will be used can foster informed consent and participation in AI-based healthcare programs [63].

8.2. Consent and Transparency

In personalized medicine, patients may not fully understand how their detailed clinical, genomic, and lifestyle data are collected, processed, and used by AI models to tailor treatments. This lack of clarity can create confusion or mistrust, making patients hesitant to provide informed consent for the use of their data in AI-driven personalized healthcare. Ensuring transparency about how AI systems analyze data, the purpose of data usage, and the potential risks and benefits of AI-guided interventions is essential to build trust. Clear communication, simplified explanations, and educational initiatives can help patients make informed decisions, while also fostering greater acceptance and participation in AI-powered personalized medicine. Enhancing technical awareness among patients and healthcare providers alike is crucial for overcoming ethical and practical barriers to consent and for promoting responsible adoption of AI tools in healthcare [64].

9. TECHNICAL LIMITATIONS

9.1. Black Box Problem of AI Models

Many AI algorithms, particularly deep learning models, have traditionally operated as “black boxes,” meaning that the reasoning behind their predictions or recommendations is not readily interpretable. This lack of transparency can make it challenging for clinicians to trust, validate, or act upon AI-generated insights, especially in high-stakes fields like healthcare and personalized medicine. Decisions made by opaque models may be difficult to explain to patients, regulators, or other stakeholders, raising concerns about accountability, reliability, and clinical adoption. However, the development of explainable AI (XAI) techniques such as Grad-CAM, SHAP, and LIME has significantly mitigated these issues by providing visualizations and interpretable explanations of how models reach specific decisions. XAI allows clinicians to understand which features or data points most influence predictions, helping validate outcomes, identify potential errors, and increase confidence in AI-assisted decision-making. As a result, the combination of AI's predictive power with XAI's interpretability has enhanced transparency, promoted ethical usage, and facilitated more accurate, trustworthy implementation of AI in healthcare, including personalized medicine. Continued research in XAI is also expanding its capabilities to make complex models even more understandable, bridging the gap between computational intelligence and clinical practice [65].

9.2. Integration with Clinical Workflow

Many AI tools and models are found to be incompatible with Electronic Health Records (EHR) of patients or with the routine medical practices. Many AI tools and models face challenges in being seamlessly integrated into existing clinical workflows. Often, AI systems are incompatible with EHR platforms or do not align with routine medical practices, making their adoption cumbersome for healthcare providers. Such incompatibility can lead to increased workload, workflow disruptions, or underutilization of AI insights, limiting their practical benefits in personalized medicine. Addressing this limitation requires rigorous standardization of AI algorithms, development of interoperable systems, and careful alignment of AI outputs with clinician needs. Ensuring smooth integration into clinical settings is essential for AI to effectively support personalized treatment decisions and improve patient care outcomes. This needs rigorous standardization of AI algorithms and is a limitation to clinical workflow related to healthcare and personalized treatment [7].

10. WAYS TO OVERCOME THE CHALLENGES AND LIMITATIONS OF AI IN PERSONALIZED MEDICINE

To overcome the challenges and limitations of AI in personalized medicine, a multifaceted approach is needed. First, robust regulatory frameworks and clear ethical guidelines needs to be established to ensure patient privacy, data security, and algorithmic transparency. Second, diverse and high-quality datasets must be used to minimize bias and improve the accuracy of AI models across different populations. Third, interdisciplinary collaboration between clinicians, data scientists, ethicists, and policymakers can bridge technical and clinical gaps. Fourth,

continuous validation and monitoring of AI systems in real-world clinical settings will help maintain reliability and safety. Finally, educating healthcare professionals and patients about AI's capabilities and limitations can foster trust, accountability, and informed decision-making.

11. LIMITATIONS OF CLINICAL ADOPTION AND VALIDATION

11.1. Limited Clinical Validation

Several AI tools remain at research level or at pilot stages. Lack of robust large-scale clinical trials prevent their implementation. Thus, this limitation has led to slowed rate of evolution of AI models in real-time clinical set up and personalized medicinal approaches [66].

11.2. Physician Acceptance

Physicians and healthcare practitioners still lack enough acceptance of AI generated decisions. This resistance due to lack of trust, or insufficient AI training and awareness among clinicians needs to be addressed [67].

11.3. Overreliance Risk

Blind trust and faith on AI without human oversight and monitoring can be dangerous. AI models are basically run by background algorithms and a possibility of error remains [68].

12. LIMITATIONS OF UNDERSTANDING HUMAN PHYSIOLOGY AND PATHOPHYSIOLOGY

12.1. Incomplete Physiological Understanding

Human biology, disease mechanisms and individual Pathophysiology for specific diseases are highly complex. It is not possible for trained AI models to AI completely comprehend and capture unknown interactions and pathophysiological mechanisms that it has not been trained on [69].

12.2. Dynamic Nature of Health

Genetic, epigenetic, lifestyle, nutritional, metabolic and environmental factors change over time, age and daily habits of an individual making static models less accurate. Thus, AI powered personalized medicine may require evolution over time scale for an individual [70,71].

13. FUTURE DIRECTIONS FOR AI-POWERED PERSONALIZED MEDICINE

AI powered healthcare is the future of personalized medicine. Integrating advanced sophisticated AI technologies in personalized medicine can take personalized medicine to a different level with excellent patient outcomes. AI can be used to collect

real-time data of an individual from personal wearable bioelectronic devices like smartwatch equipped with sensors etc. [72]. The future of AI-powered personalized medicine is heading towards bright tomorrow with integration of advancements and sophistication in AI that will help to overcome the current limitations with AI in personalized medicine [73].

The future directions include the development of 'Digital Twins'. These are virtual replicas of patients with setup that simulate disease progression pattern and optimize treatment plans. The other component that's going to be a part of the future of AI in personalized medicine is 'Quantum Computing'. This will further empower computational technologies, enabling more complex biological simulations to be used and hassle-free analysis of vast complex data [74]. Mathematical modeling of physiological systems, mimicking original physiological conditions will also be integrated with AI technologies to get a real-time understanding for individual physiological pre dispositions and make accurate personalized medicinal decisions based on that [75].

Additionally, 'AI-powered Nanobots' may also be a significant player in the future that may revolutionize personalized drug delivery and accurate diagnostics at the cellular level. Neurorobotics and AI may also be used together for advanced outcomes in personalized medicine [76]. The impact of the Healthcare Internet of Things (IoT) on remote patient monitoring using integrated AI, cloud-based analytics, and real-time alerts have been evaluated in a study. The study reveals that compared to traditional wearable sensor fusion methods with an accuracy rate of 76%, the suggested IoT-based approach achieved 89% accuracy. The diagnostic precision improved by suggested IoT-based approach 88% compared to 73% by traditional wearable sensor fusion methods. The recall rate was 68% with suggested IoT-based approach. This advanced system enhances both the speed and accuracy of diagnostics while remaining cost-effective, making it highly suitable for hospitals and clinical applications.

These innovations will lead to more precise, specific, accurate, efficient, and accessible personalized, unique healthcare solutions for every individual, transforming patient care and outcomes.

14. CONCLUSION

The use of AI in healthcare provides great opportunity in the diagnosis, prediction and treatment of disease effectively. From the available data AI and ML models are able to design drug, treatment regimens and can interpret the extent of the disease. Personalized medicine is effective in treating a disease based on the individual requirement. The dose, duration and treatment strategy vary as per some factors like age, sex, medical history, life style, genetic makeup, etc. Combining AI with personalized medicine made huge success in the field of healthcare. The use of AI and data-driven approaches not only improves the speed of clinical decision-making but also reduces the likelihood of human error.

It provides accurate diagnoses, effective treatments, and improved patient outcomes. AI-powered personalized medicine can make better decisions by handling huge clinical data. Pattern recognition, prediction and disease diagnosis are more accurate and less time consuming with AI and personalized

medicine. With the advancement of AI now it's easy to explain the way of decision making thus the interpretability of AI is clear to some extent. Personalized medicine, that customizes healthcare interventions and approaches to the unique needs of each individual, has already shown significant promise in improving patient outcomes. Factors such as age, sex, medical history, lifestyle patterns, environmental impact, and genetic makeup all play a critical role in determining the effective dose, duration, and treatment strategy for a particular patient. The integration of AI with personalized medicine has accelerated progress in healthcare by enabling predictive modelling, early detection of disease risks, and precise therapy selection, thereby ensuring more effective and timely patient-centered care.

In AI assisted personalised medicine, data bias and generalizability remain major issues specially as and when AI models are trained using demographically narrow datasets that reduces in performance across diverse populations. Regulatory and ethical uncertainties also remain and these include patient privacy, model transparency, and liability. These need to be addressed in order to ensure safe deployment of AI assisted personalised medicine. Another essential requirement for sustainable implementation AI in personalized medicine is workflow integration into EHR. Clinician training programs are also essential.

Future research needs to focus on developing multicenter, multinational registries for validation, conducting clinical trials that will compare AI-assisted versus standard care outcomes, assessing cost-effectiveness and usability, establishing clear regulatory frameworks for data governance and accountability, and for increasing explainability and human-AI collaboration.

However, there is a strong need to move towards a collaborative, multidisciplinary, and federated AI development model. Open and inclusive networks encourage innovation, reduce bias, and make AI tools more adaptable to real-world clinical settings. In contrast, closed, top-down approaches often lead to limited improvements, overfitting, and resistance to actual implementation. By embracing a more universal and cooperative paradigm, AI in healthcare and personalized medicine can achieve broader acceptance, greater impact, and long-term sustainability. To ensure safe and ethical use of AI in healthcare, governments, scientific bodies, institutions, and patients all need to be actively involved. Strong leadership is required to set clear rules, certify AI tools as medical devices, and regularly check their effectiveness, while also providing continuous feedback to prevent errors or "hallucinations." Future directions include the integration of multi-omics data with AI models to achieve deeper insights into complex diseases and the development of explainable and ethically robust AI systems that are dependable, trustworthy and that trust of clinicians, ensuring equitable healthcare delivery across diverse populations.

DECLARATIONS

Conflict of Interest

The authors declare that they have no conflicts of interest.

Authors' Contribution

Dr. DG contributed in conceptualization and writing; Dr. SD contributed in writing and reviewing the manuscript.

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