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AI-Driven Pharmacogenomics and Precision Medicine: Future of Personalized Therapy

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Abstract

Pharmacogenomics and artificial intelligence (AI) are emerging as important drivers of precision medicine, enabling healthcare systems to adopt individualized therapeutic approaches. Pharmacogenomics examines how genetic variations influence drug response, efficacy, metabolism, and toxicity, while AI provides advanced computational tools for analyzing complex genomic and clinical data. This review highlights the integration of AI-driven pharmacogenomics in personalized therapy and its potential to improve treatment outcomes. Machine learning, deep learning, natural language processing, and big data analytics are increasingly used to identify genetic variants, predict drug responses, optimize medication selection and dosage, and reduce adverse drug reactions. These technologies support the interpretation of large-scale genomic information and facilitate evidence-based clinical decision-making. Significant applications have been demonstrated in oncology, cardiovascular diseases, neurological and psychiatric disorders, and rare genetic diseases, where personalized treatments can enhance therapeutic efficacy and patient safety. Recent advances in genomic sequencing, multi-omics integration, digital health technologies, explainable AI, and real-time patient monitoring have further expanded the scope of precision medicine. However, challenges related to data privacy, algorithm bias, regulatory frameworks, and clinical implementation remain. Future developments in explainable AI, predictive analytics, and AI-powered personalized therapy are expected to improve treatment precision and accelerate the realization of truly individualized healthcare. Overall, the convergence of AI and pharmacogenomics represents a transformative approach to modern medicine with substantial potential to improve patient outcomes and optimize therapeutic interventions.

Keywords: Artificial intelligence, pharmacogenomics, precision medicine, personalized therapy, machine learning

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INTRODUCTION

Personalized medicine is a paradigm shift in contemporary healthcare, altering the medical practice paradigm of a one-size-fits-all approach to the individualized prevention, diagnostic and treatment plans based on the individual genetic, molecular, environmental and lifestyle factors and needs of the individual patient. Personalized medicine has come to represent a broad concept whose development has been propelled by the development of genomics, molecular biology, high throughput sequencing technologies, and bioinformatics tools in the last 20 years. One of the key aspects of this paradigm is pharmacogenomics, which is the examination of the effects of genetic variations on the response, efficacy, metabolism, and toxicity of drugs. Pharmacogenomics is meant to maximize the effectiveness of their treatment by discovering genetic variables that determine individual responses to drugs, hence, selecting the best drug and dosage to treat a given patient [1]. Genetic differences in drug-metabolizing enzymes, transporters, receptors, and signaling pathways may cause great differences in the effectiveness of the treatment and the possibility of adverse drug reactions. Therefore, pharmacogenomics has turned into a critical component of precision medicine, especially in the areas of oncology, cardiology, psychiatry, neurology, and the management of infectious diseases. Even with a significant breakthrough in the use of genomic technologies, the clinicalization of pharmacogenomics has been challenging because of the vast and complicated genomic and clinical information produced within the contemporary medical care systems [2]. These multidimensional datasets need to be integrated and analyzed using powerful analytical methods that can extract useful biological trends and clinical implications. Artificial intelligence (AI) has become a potent enabling technology of precision medicine in this regard. AI includes machine learning, deep learning, natural language processing, and predictive analytics, capable of analyzing large volumes of genomic, clinical, pharmacological and real-world patient data with impressive speed and accuracy [3]. Such computational methods can be used to identify genetic variants related to drug response, predict therapeutic outcomes, optimize drug choice, and identify adverse drug reactions early in drug treatment. AI-driven models are increasingly being used to uncover complex gene–drug interactions that may not be apparent through conventional statistical approaches. Moreover, AI can also be used to combine various datasets, such as genomic profiles, electronic health records, proteomic, metabolomic datasets, and environmental factors, thus contributing to more comprehensive and tailored treatment decisions. The combination of artificial intelligence and pharmacogenomics is providing novel possibilities of predictive, preventive, and precision healthcare, by changing the way clinicians diagnose diseases and construct therapeutic interventions [4].

The integration would speed up the drug discovery process, enhance clinical decision-making, decrease healthcare expenses, and increase patient outcomes with more focused and efficient treatment. Figure 1 demonstrates the connection between artificial intelligence, genomic data analysis, pharmacogenomic interpretation, clinical decision support, and personalized therapy, showing the multidimensional paradigm of AI-guided pharmacogenomics to support precision medicine and personalized patient care [5].

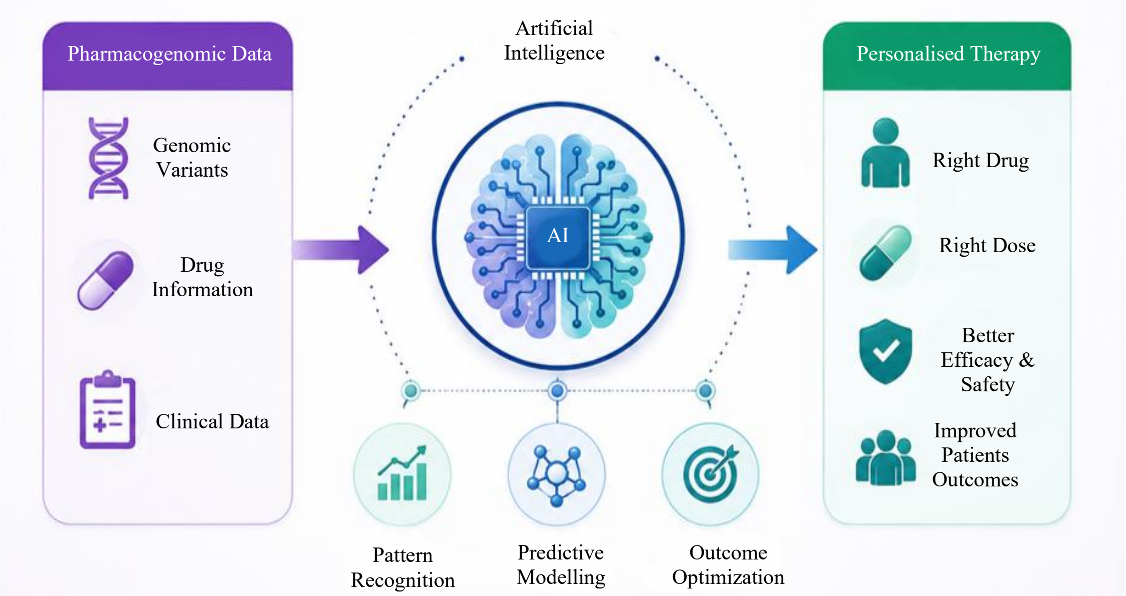

Figure 1. Integration of artificial intelligence and pharmacogenomics in personalized therapy.

FUNDAMENTALS OF PHARMACOGENOMICS AND PRECISION MEDICINE

Precision medicine and pharmacogenomics have become essential elements of the contemporary healthcare, striving to maximize the effectiveness of medical treatment by adjusting it to the individual genetic, molecular, environmental, and lifestyle factors. Conventional medical therapies tend to be based on generalized treatment regimens which may fail to recognize the high degree of biological variation in patients leading to variations in drug efficacy, safety and clinical outcomes. Pharmacogenomics can solve this dilemma because it studies the behaviors of genetic differences in response to drugs, thus making it possible to select the most efficient drugs and dosage to be used on particular patients. The field combines the concepts of genetics, genomics, pharmacology, molecular biology, and bioinformatics to learn the connection between genetic composition and response to drugs [6]. Genetic polymorphisms in drug-metabolising enzyme genes, transport proteins, receptors, ion channels, and signalling molecules can considerably change absorption, distribution, metabolism and excretion of drugs. The most widely studied examples of these variations are the cytochrome P450 enzymes including CYP2D6, CYP2C19, and CYP2C9, which determine the metabolite fate of many therapeutic agents, including antidepressants, anticoagulants, antiplatelet agents, and anticancer agents. Consequently, patients with particular genetic variations could undergo improved therapeutic reactions, less efficiency, or heightened vulnerability to drug responses. The knowledge of these genetic effects enables clinicians to adopt individualized treatment plans that will maximize benefits at the lowest toxicity. One of the determinants of interindividual differences in drug response is genetic variability, which is the core of pharmacogenomic-guided therapy. Genomic changes that include single nucleotide polymorphisms (SNPs), insertions, deletions, copy number variations and other changes to the genome play a role in gene expression and protein functioning variations, which in turn influence the pharmacodynamics and pharmacokinetic processes. These differences may affect the rate at which a drug is metabolized, the rate at which a drug reaches target tissues and the strength with which a drug binds to biological receptors. Therefore, two patients that are prescribed the same drug in the same dosage can display significantly different treatment results [7]. Precision medicine aims to overcome this variability through the combination of genomic data with clinical, environmental, and phenotypic data to make personalized healthcare decisions. The identification and use of measurable biological indicators of disease risk, diagnosis, prognosis, treatment response, or therapeutic toxicity is an essential part of this approach and is known as biomarkers. Examples of the biomarkers can be genetic mutations, profile of gene expression, proteins, metabolites, epigenetic changes, and other molecular features that present clinically useful data. Biomarkers are essential in-patient stratification, treatment choice, disease monitoring and prediction of treatment outcomes in personalized medicine. Biomarker-based interventions have taken on a special role in cancer therapy, cardiovascular care, neurology, psychiatry, and rare genetic diseases. The discovery of biomarkers and the clinical uses of pharmacogenomics are further accelerated by advances in the next-generation sequencing, high-throughput genomic technology, and computational biology. Combined, the principles of pharmacogenomics, genetic variability analysis, and biomarker-based methods contribute to the scientific background of precision medicine and help to convert to more effective, safer, and personalized therapeutic approaches in modern healthcare [8].

ARTIFICIAL INTELLIGENCE TECHNOLOGIES IN HEALTHCARE

Artificial intelligence (AI) has already become one of the foundations of the contemporary healthcare sector, allowing to analyze and interpret more complex biomedical data, something that traditional methods of analysis cannot handle. Within the framework of pharmacogenomics and precision medicine, AI technologies make it possible to extract clinically meaningful insights out of large volumes of data produced by genomic sequencing, electronic health records, biomarker profiling, medical imaging, and real-world patient data. Machine learning (ML) and deep learning (DL) are among the most popular AI approaches that have proven to have significant potential in pattern recognition, predictive modeling, and supporting decisions [9]. Machine learning algorithms can find latent associations between genetic variations, clinical features and therapeutic response through learning on vast amounts of data without any coding. There is increased use of supervised, unsupervised, and reinforcement learning methods to forecast drug efficacy, optimize dosing, find pharmacogenomic biomarkers, and estimate the risk of adverse drug reactions. A more advanced form of machine learning, deep learning (based on multilayered artificial neural networks), provides even more tools to analyze high-dimensional genomic and molecular data. Deep learning models can handle high-scale genomic sequences, transcriptomic, proteomic data, and metabolomic data to reveal complicated biological interactions and discover new therapeutic targets. Natural language processing

(NLP) is another crucial AI technology in health care because it allows computers to interpret, comprehend, and draw valuable insights out of unstructured written information. Healthcare systems produce huge amounts of clinical notes, pathology reports, scientific literature and electronic health record documentation which has valuable pharmacogenomic information [10]. The genetic data, medication history, treatment results, and adverse event reports can be automatically extracted by NLP algorithms through these textual resources, thus enhancing clinical decision-making and precision medicine programs. Moreover, NLP enables literature mining and knowledge discovery to discover new gene-drug relationships and clinically significant pharmacogenomic evidence. Besides machine learning and NLP, big data analytics has emerged as a fundamental aspect of genomic medicine. Recent developments in next-generation sequencing technologies have led to the creation of large amounts of genomic data that necessitates advanced computational frameworks to be stored, integrated, processed, and interpreted. Big data analytics integrates computational biology, bioinformatics, cloud computing, and AI-based approaches in managing and analyzing such complex datasets. Using the combination of genomic data and clinical history, environmental exposures, personal lifestyles, as well as population health data, big data analytics will contribute to identifying predictive biomarkers and personalized treatment plans [11]. The key artificial intelligence technologies that are in use today in pharmacogenomics, such as machine learning, deep learning, natural language processing and big data analytics, are listed in a summary in the table below, which is referred to as Table 1.

Table 1. Major artificial intelligence technologies used in pharmacogenomics.

AI technology	**Principle**	**Pharmacogenomic application**	**Key advantages**	**Example use cases**
Machine Learning (ML)	Learns patterns from structured datasets	Predicts drug response and treatment outcomes	High predictive accuracy	Drug efficacy prediction, dose optimization.
Deep Learning (DL)	Multi-layer neural networks analyze complex data	Identification of genomic patterns and biomarkers	Handles large-scale genomic datasets	Variant detection, disease risk prediction.
Natural Language Processing (NLP)	Extracts information from unstructured text	Analysis of clinical records and scientific literature	Automated knowledge extraction	Gene–drug association mining.
Big Data Analytics	Integrates and analyzes massive datasets	Combines genomic, clinical, and environmental data	Comprehensive patient profiling	Precision medicine decision support.
Artificial Neural Networks (ANNs)	Mimics human neural processing	Predicts pharmacokinetic and pharmacodynamic responses	Captures complex nonlinear relationships	Personalized drug selection.
Support Vector Machines (SVMs)	Classification and pattern recognition algorithm	Identification of genetic variants associated with drug response	Effective with high-dimensional data	Pharmacogenomic biomarker discovery.
Random Forest Algorithms	Ensemble learning using multiple decision trees	Prediction of adverse drug reactions	Robust and accurate predictions	Drug safety assessment.
Reinforcement Learning	Learns optimal decisions through feedback	Adaptive treatment planning	Continuous optimization	Personalized therapeutic strategies.
Computer Vision	AI-based image interpretation	Analysis of histopathology and molecular imaging data	Automated image analysis	Precision oncology and biomarker evaluation.
Explainable AI (XAI)	Provides interpretable AI decisions	Clinical validation of pharmacogenomic recommendations	Improved transparency and trust	Clinical decision support systems.

The general workflow of collecting, analyzing, interpreting and translating genomic data into patient-specific therapeutic advice using AI-based computational systems is depicted in Figure 2, which explains the importance of artificial intelligence in converting pharmacogenomic data into clinical actionable data to support precision medicine.

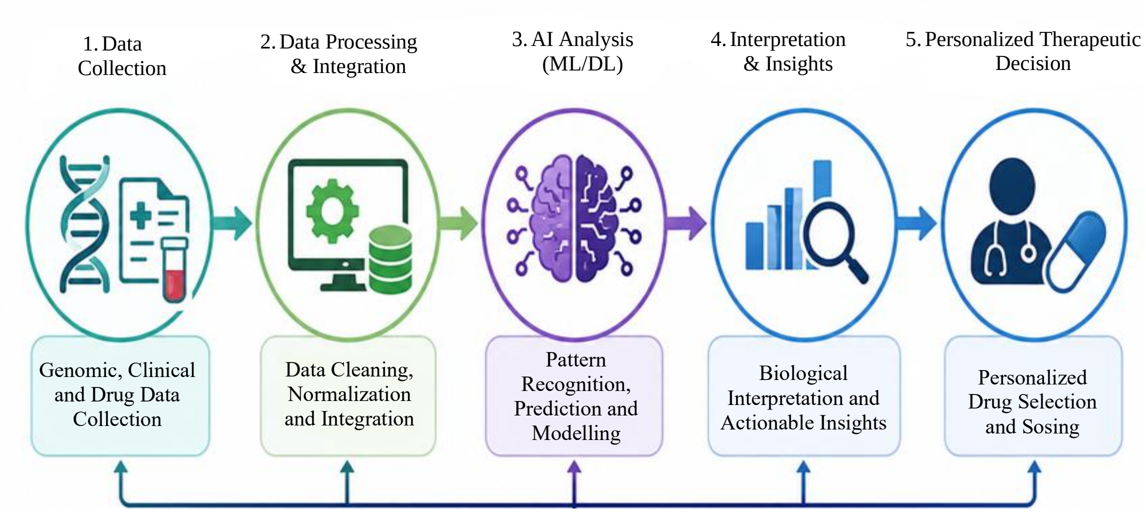

Figure 2. AI workflow for pharmacogenomic data analysis.

AI-DRIVEN PHARMACOGENOMICS FOR PERSONALIZED THERAPY

Pharmacogenomics is changing through artificial intelligence (AI), which is the ability to analyze complex genomic and clinical data to aid in making individualized therapeutic choices. The incorporation of AI in pharmacogenomics has greatly enhanced prediction of drug response, identification of clinically relevant genetic variations, optimization of drug selection and dosage, and adverse drug reactions, furthering the objectives of precision medicine. Trying to predict drug response is one of the most critical pharmacogenomics uses of AI [12]. Genetic variations tend to influence individual variation in treatment outcomes due to their impact on drug metabolism and transport as well as the interaction of the drugs with their target. Conventional forms of analysis often fail to recognize the multifaceted interactions between several genetic and clinical factors. Large-scale genomic, transcriptomic, proteomic, and clinical datasets can be analyzed with AI-based machine learning and deep learning algorithms to detect patterns that are related to treatment failure and therapeutic efficacy. These proactive models can help clinicians determine the way individual patients are likely to react to certain drugs before they are administered to enhance the success of the treatment and reduce unnecessary intervention. The other important use is in identifying genetic variants of drug response and disease vulnerability [13]. The next-generation sequencing technology has resulted in large volumes of genomic data, which makes it more difficult to interpret manually. The algorithms of AI can quickly scan genomic sequences and identify single nucleotide polymorphisms, copy number variations, and other genetic modifications affecting pharmacokinetic and pharmacodynamic processes. AI aids in the creation of personalized treatment plans based on the genetic profile of a patient by determining clinically relevant variants. Moreover, AI is essential in streamlining the selection of drugs and their dosage. Personalized medication recommendations should be based on combining pharmacogenomic information with demographic, clinical, biomarker profiles, and environmental factors. ML algorithms can suggest the most effective therapeutic agents and identify the most effective dosing regimens based on patient-specific characteristics [14]. The method will minimize trial-and-error prescribing, lead to better treatment efficacy, and patient outcomes. Particularly, AI-assisted dosing algorithms have shown utility in the management of drugs with small therapeutic indices, including anticoagulants, cancer drugs, and immunosuppressive drugs. Besides enhancing efficacy, AI helps to reduce adverse drug reactions (ADRs) which have continued to be a significant cause of morbidity, mortality, and healthcare spending in most parts of the world. The AI systems could help forecast individuals at risk of adverse events by analyzing genomic variants linked to drug toxicity and combining the information with clinical data prior to treatment. Early detection of high-risk patients can enable clinicians to change therapy, alter dosage or use other drugs, thus enhancing patient safety [15].

Table 2 provides a summary of the key uses of artificial intelligence in the field of pharmacogenomics such as predicting drug response, identifying genetic variants, personalized drug selection, dosage optimization, and preventing adverse drug reactions. Taken together, these innovations underscore how AI-driven pharmacogenomics is enabling more accurate, efficacious, and safer treatment approaches, and eventually speeding up the process of personalizing healthcare and treating patients individually.

Table 2. Applications of AI in pharmacogenomics and personalized therapy.

Application area	AI approach	Pharmacogenomic function	Clinical benefit	Example outcome
Drug Response Prediction	Machine Learning	Predicts individual response to medications	Improved treatment efficacy	Selection of most effective therapy.
Genetic Variant Identification	Deep Learning	Detects clinically relevant genetic variants	Enhanced precision in diagnosis	Identification of actionable mutations.
Drug Selection	Predictive Analytics	Matches drugs with patient genomic profiles	Personalized treatment planning	Right drug for the right patient.
Dosage Optimization	Machine Learning Models	Determines individualized drug dosage	Reduced under- or overdosing	Improved therapeutic outcomes.
Adverse Drug Reaction Prediction	AI Risk Assessment Models	Identifies patients at risk of toxicity	Enhanced patient safety	Prevention of severe side effects.
Pharmacokinetic Modeling	Neural Networks	Predicts drug absorption, metabolism, and elimination	Better dose adjustment	Optimized drug exposure.
Pharmacodynamic Analysis	Deep Learning Algorithms	Evaluates drug-target interactions	Improved efficacy prediction	Enhanced treatment response.
Clinical Decision Support	Explainable AI Systems	Provides evidence-based recommendations	Improved physician decision-making	Personalized prescribing support.
Biomarker Discovery	Big Data Analytics	Identifies predictive genomic biomarkers	Early disease and therapy stratification	Precision medicine implementation.
Oncology Precision Therapy	AI-Driven Genomic Analysis	Selects targeted cancer therapies	Improved survival and treatment response	Personalized cancer management.
Cardiovascular Pharmacogenomics	Machine Learning	Predicts response to anticoagulants and cardiovascular drugs	Reduced adverse events	Optimized warfarin dosing.
Psychiatric Pharmacogenomics	AI Prediction Models	Predicts antidepressant and antipsychotic response	Improved mental health outcomes	Reduced trial-and-error prescribing.

CLINICAL APPLICATIONS AND RECENT ADVANCES

Clinical medicine is changing speedily with the integration of artificial intelligence (AI) and pharmacogenomics, which allows predicting the outcome of treatment much more accurately, designing therapeutic regimens tailored to each patient, and providing more efficient care to a broad spectrum of diseases. Oncology is one of the most important fields of implementation where AI-controlled pharmacogenomics has turned out to be a fundamental pillar of personalized cancer treatment. The genetic heterogeneity of cancer is marked by a great deal of it, and specific treatment selection is crucial to achieving the best clinical outcome. Genomic sequencing data, tumor biomarkers, and gene expression profiles, as well as clinical data, can be analyzed using AI algorithms to identify actionable mutations and predict responses to targeted therapies, immunotherapies, and chemotherapeutic agents. The capabilities will aid customized treatment planning and promote the creation of accuracy oncology plans that enhance survival rates and reduce toxicity. Pharmacogenomics with AI is becoming more common in cardiovascular medicine to maximize the selection of medications and doses of drugs like warfarin, clopidogrel, statins, and antihypertensive drugs. Genetic differences in drug metabolism and drug response can have a considerable impact on the treatment outcomes and the risk of adverse events [16]. AI models combine genomic, clinical, and demographic information to produce personalized treatment prescriptions that increase the effectiveness and minimize adverse events. Like progress is being witnessed in neurological and psychiatric ailments where treatment reactions tend to be widely different in each patient. The use of AI in pharmacogenomic methods is aiding in the identification of genetic variation linked with antidepressant, antipsychotic, antiepileptic, and neurodegenerative disease treatments. These technologies help to implement more effective and personalized treatment plans by estimating the individual reaction to drugs and determining the risk of adverse drug reactions in patients. Moreover, pharmacogenomics is gaining relevance in the treatment of rare and genetic diseases, most of which have generally had no readily available treatment therapies. The discovery of disease-causing mutations, therapeutic targets, and personalized treatment opportunities are becoming easier due to advances in genomic sequencing and artificial intelligence analysis tools. AI may process intricate genomic data to reveal clinically significant patterns that might not have been detected previously, thus aiding in earlier diagnosis and more accurate interventions on rare diseases [17].

Figure 3 displays the wide range of clinical use of AI-powered pharmacogenomics in the oncology, cardiovascular diseases, neurological, psychiatric, and rare genetic diseases, which demonstrates its increasing personalization in healthcare. Simultaneously, there has been substantial technological growth in 2020–2026 such as in machine learning algorithms, deep learning-based genomic analysis, explainable AI systems, biomarker discovery platforms, clinical decision support systems, and AI-assisted drug development. Such innovations have made pharmacogenomic applications significantly more accurate, scalable, and useful to clinical practices [18].

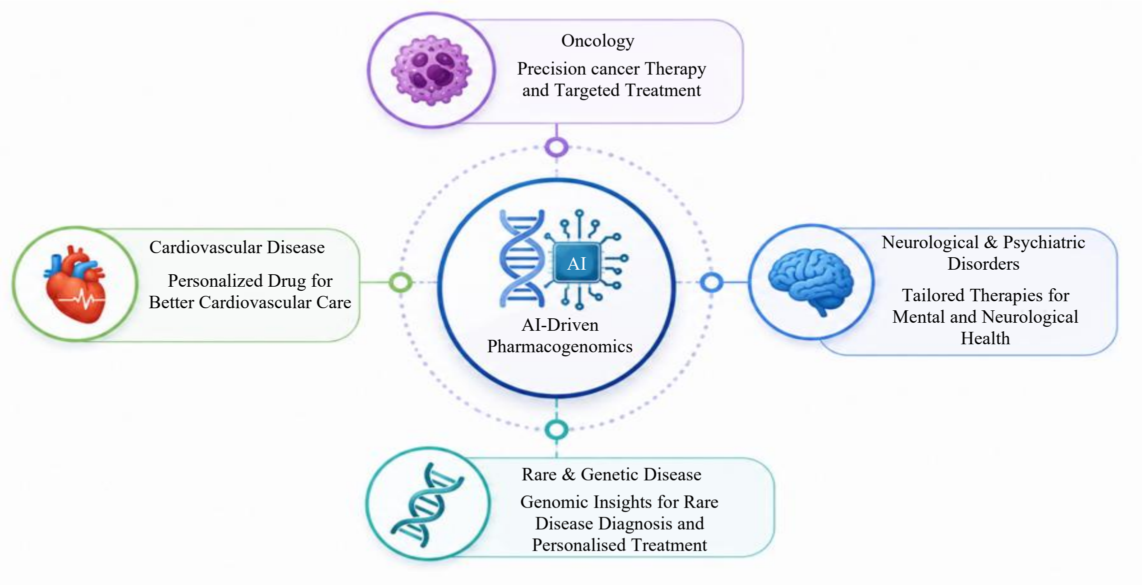

Figure 3. Clinical applications of AI-driven pharmacogenomics.

The latest trends and advances in AI-based pharmacogenomics are outlined in Table 3, showing that the sphere is evolving fast and plays a greater role in precision medicine. All these developments point to the fact that AI-based pharmacogenomics is becoming an indispensable part of modern healthcare because it allows conducting safer, more effective, and highly personalized treatment methods that enhance patient outcomes and form the future of personalized medicine [19].

Table 3. Recent advances in AI-driven pharmacogenomics (2020–2026).

Year	Recent advance	AI technology used	Pharmacogenomic application	Clinical impact
2020	AI-based genomic variant interpretation platforms	Machine Learning	Identification of clinically relevant variants	Improved genetic diagnosis.
2020	Integration of pharmacogenomic data with Electronic Health Records (EHRs)	Big Data Analytics	Personalized prescribing support	Enhanced clinical decision-making.
2021	Deep learning models for drug response prediction	Deep Learning	Prediction of therapeutic efficacy	Improved treatment outcomes.

2021	AI-assisted biomarker discovery systems	Machine Learning	Identification of predictive biomarkers	Better patient stratification.
2022	Explainable AI (XAI) in pharmacogenomics	Explainable AI	Transparent genomic interpretation	Increased clinician trust.
2022	AI-driven precision oncology platforms	Deep Learning	Targeted cancer therapy selection	Improved cancer treatment precision.
2023	Multi-omics data integration for personalized medicine	Big Data Analytics	Combined genomic, proteomic, and metabolomic analysis	Comprehensive patient profiling.
2023	Natural Language Processing (NLP) for pharmacogenomic literature mining	NLP	Discovery of gene–drug interactions	Accelerated knowledge generation.
2024	AI-guided dosage optimization systems	Machine Learning	Individualized drug dosing	Reduced adverse drug reactions.
2024	Real-time clinical decision support tools	Predictive Analytics	Personalized therapeutic recommendations	Enhanced patient safety.
2025	AI-powered digital twin models for therapy simulation	Deep Learning	Prediction of individual treatment responses	Precision treatment planning.
2025	Federated learning in genomic medicine	Distributed AI	Secure multi-center genomic analysis	Improved data privacy and collaboration.
2026	Autonomous AI pharmacogenomic platforms	Advanced AI Systems	Automated treatment recommendation generation	Faster precision medicine implementation.
2026	AI-integrated precision healthcare ecosystems	Multi-Modal AI	Continuous genomic monitoring and therapy optimization	Personalized lifelong healthcare management.

CHALLENGES AND ETHICAL CONSIDERATIONS

Artificial intelligence (AI) integration into the field of pharmacogenomics and precision medicine has massive potential to enhance individualized healthcare, but several ethical, technical, regulatory, and implementation issues would need to be resolved to provide a safe and fair clinical implementation. Among the most crucial issues is the issue of data privacy and security. Pharmacogenomic systems are based on the gathering and measurement of high amounts of sensitive genomic, clinical, and personal health data. Due to the unique nature of genomic data, which can be easily identified, unauthorized access, breaches of data, and misuse of genetic information can undermine patient privacy and trust.

It is thus critical to ensure that there are solid cybersecurity provisions, the protection of data stored, informed consent practices and adherence to privacy standards. The other significant risk is the bias of algorithms and interpretability. The quality, diversity and representativeness of training datasets are extremely important to AI models. In case genomic databases are heavily biased with certain groups of people, AI can make biased predictions that underperform in groups that are poorly represented, which can worsen healthcare disparities [20–22]. Moreover, several state-of-the-art deep learning models are black-box systems whose decision-making can hardly be explained by clinicians and patients. The absence of transparency might restrict clinical trust and impede the large-scale application.

There are also still significant regulatory and clinical implementation issues. The current healthcare laws were not initially tailored to the fast-changing AI technologies and this posed ambiguity in terms of validation requirements, accountability, liability and approval processes of AI-based clinical decision-support systems. Before the extensive use of AI-assisted pharmacogenomic tools, regulatory bodies need to come up with clear frameworks on how to assess their safety, effectiveness, reliability, and clinical utility. Also, to be successful, it must be incorporated into everyday clinical practice, electronic health records, and health infrastructures. Most healthcare facilities are constrained by technical resources, interoperability, staff training, and investment. Specialized training might also be needed to enable clinicians to interpret pharmacogenomic reports and AI-generated recommendations [23, 24]. Ethical issues of informed consent, ownership of genetic information, equity in access to precision medicine technologies, and possible discrimination by genetic characteristics make the efforts of implementation even more complicated. The multidisciplinary efforts of researchers, clinicians, policy makers, regulatory bodies, bioethicists and technology developers will be needed to address these challenges. Further progress in data governance, open AI practices, harmonization of regulations, and infrastructure development in healthcare would be necessary to enable effective implementation of AI-based pharmacogenomics in a responsible, safe, and equitable way that fully utilizes its potential in improving patient outcomes and advancing personalized medicine.

FUTURE PERSPECTIVES

The future of AI-based pharmacogenomics and precision medicine is predicted to be marked by more advanced computational technologies, a higher level of genomic integration, and highly personalized healthcare systems that can provide personalized therapeutic interventions in real time. The most promising part is the development of explainable artificial intelligence (XAI), which aims to enhance the clarity and comprehensibility of AI-based clinical decision-making. In contrast to the traditional black-box algorithms, explainable AI offers interpretable justifications of predictions and recommendations, which allows clinicians to assess treatment choices more efficiently and trust AI-assisted healthcare systems more.

The ability will help expedite the clinical use and regulatory approval of pharmacogenomic applications. Digitizing health technologies with genomic medicine is another significant development. Wearables, biosensors, mobile health, electronic health records and remote monitoring systems are producing continuous physiological and behavioral data which when combined with genomic data can result in comprehensive patient profiles [22]. These multidimensional datasets can be analyzed in real time by AI algorithms, making it possible to dynamically monitor disease progression, therapeutic response, and adverse drug reactions.

These strategies could help enable proactive healthcare measures and aid in accuracy treatment regimes that will constantly adjust to the needs of individual patients. The scalability and accessibility of pharmacogenomic services should also be enhanced with the help of advances in next-generation sequencing, cloud computing, multi-omics integration, and federated learning without sacrificing the privacy and security of data. In future years, the AI-based personalized therapy can go beyond standard pharmacogenomics and integrate genomic, transcriptomic, proteomic, metabolomic, environmental and lifestyle data into unified predictive algorithms.

Such systems will also facilitate very personalized treatment recommendations, better drug development procedures, and earlier risk of disease detection. Virtual patient simulators and digital twins, as well as autonomous clinical decision support platforms, can also help improve precision medicine by anticipating the outcomes of therapeutic interventions prior to treatment. Also, AI-aided drug discovery and repurposing approaches will decrease the costs of drug development and speed the launch of new targeted therapies [25–28].

The future of AI-driven pharmacogenomics and precision medicine is shown in Figure 4, with the intersection of explainable AI, digital health technologies, real-time genomic monitoring, advanced analytics, and personalized therapeutic systems. With further maturation of these innovations, they will likely have a significant impact on healthcare by making it less reactive and more predictive, preventive, and highly individualized, which will result in improved treatment efficacy, reduced adverse drug reactions, and overall better patient outcomes [29, 30].

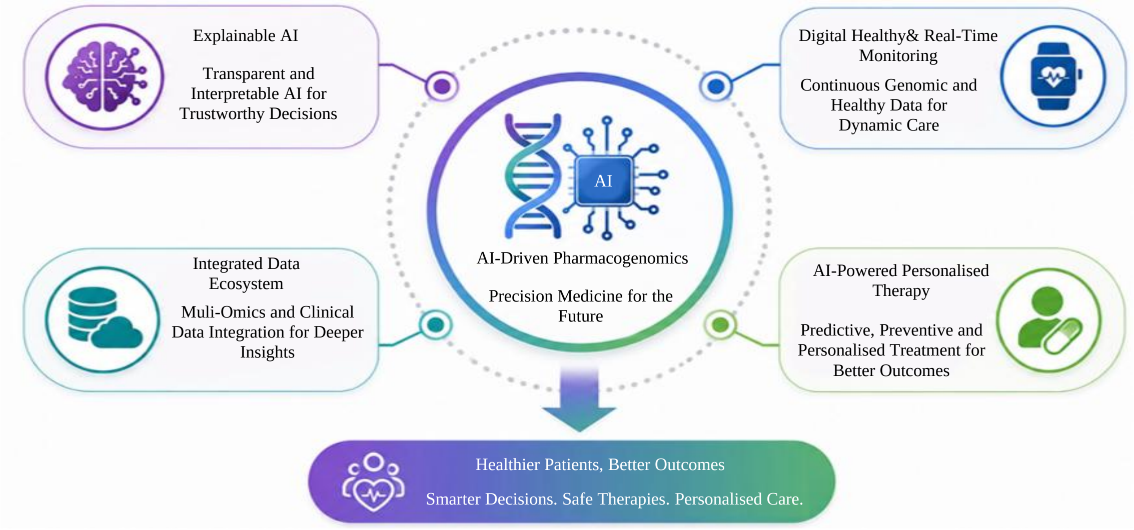

Figure 4. Future landscape of AI-driven pharmacogenomics and precision medicine.

CONCLUSION

Artificial intelligence (AI) and pharmacogenomics are transforming the future of precision medicine by allowing extremely personalized therapeutic approaches, which depend on the genetic, molecular, and clinical traits of an individual. The conventional methods of treatment do not consider interindividual variability in drug response, which results in poor therapeutic choices and higher risk of adverse drug reactions. Combining pharmacogenomics with the latest AI tools, such as machine learning, deep learning, natural language processing, and big data analytics, offers potent solutions to the analysis of complex biomedical data and the generation of clinically actionable information. Pharmacogenomics using AI has shown a great promise in terms of drug response prediction, genetic variants, ideal drug selection and dosage, and reduced treatment-related toxicity. The range of diverse clinical applications in oncology, cardiovascular diseases, neurological and psychiatric conditions, and rare genetic disorders have pointed to the usefulness of such an approach in enhancing patient outcomes and contributing to evidence-based personalized care. The most recent innovations in genomic sequencing, integration of multi-omics, digital health technology, and AI-based decision-support systems have only increased the pace at which the shift to precision healthcare is happening. Even in the light of these positive changes, the issues of data privacy, transparency of the algorithm, regulatory approval, clinical implementation, and fair access are crucial factors to consider. The multidisciplinary approaches involving healthcare professionals, researchers, policymakers and technology developers will be needed to create strong ethical, technical and regulatory frameworks to address these issues. The clinical utility and accessibility of personalized medicine will be improved further in future through explainable AI, real-time genomic monitoring, digital health ecosystems and predictive therapeutic modeling. With the ongoing development of computational capabilities and the growing integration of genomic information into everyday healthcare, AI-based pharmacogenomics will probably become a key aspect of the medical decision-making process. To sum up, the convergence of artificial intelligence and pharmacogenomics is a paradigm shift in the contemporary field of medicine that provides unparalleled possibilities to increase the precision of therapeutic interventions, patient safety, and healthcare outcomes and opens the door to a more predictive, preventive, and personalized future of healthcare.

REFERENCES

1. Wake DT, Smith DM, Kazi S, Dunnenberger HM. Pharmacogenomic clinical decision support: A review, how-to guide, and future vision. Clin Pharmacol Ther. 2022;112(1):44–57.
2. Zhou Y, Park Y, Lauschke VM. Substrate-specificity of pharmacogenomic variability–clinical relevance and emerging predictive strategies. Expert Opin Drug Metab Toxicol. 2026;22(3):201–15.
3. Zack M, Stupichev DN, Moore AJ, Slobodchikov ID, Sokolov DG, Trifonov IF, et al. Artificial intelligence and multi-omics in pharmacogenomics: A new era of precision medicine. Mayo Clin Proc Digit Health. 2025;3(3):100246.

4. Liang L, Hu J, Sun G, Hong N, Wu G, He Y, et al. Artificial intelligence-based pharmacovigilance in the setting of limited resources. Drug Saf. 2022;45(5):511–9.
5. Foote HP, Cohen-Wolkowiez M, Lindsell CJ, Hornik CP. Applying artificial intelligence in pediatric clinical trials: Potential impacts and obstacles. J Pediatr Pharmacol Ther. 2024;29(3):336–40.
6. Ibekwe PM, Akintayo EA, Okuku CN, Muhammed I, Jeje FM, Oseghale O, et al. Decoding tumor heterogeneity through multi omics: Insights into cancer evolution, microenvironment and therapy resistance. J Cancer Tumor Int. 2025;15(3):91–112.
7. Zhou Y, Peng S, Wang H, Cai X, Wang Q. Review of personalized medicine and pharmacogenomics of anti-cancer compounds and natural products. Genes (Basel). 2024;15(4):468.
8. Haga SB. Artificial intelligence, medications, pharmacogenomics, and ethics. Pharmacogenomics. 2024;25(14–15):611–22.
9. Patel YA, Narkhede K, Prajapati A, Narkhede S, Luhar S. AI-Driven Pharmacogenomics: The Future of Personalized Medicine. Asian J Pharm Technol. 2025;15(1):51–6.
10. Showbharnikhaa S, Vijayalakshmi MK, Akshaya T. Unlocking the genetic code: Pharmacogenomics and the potential of personalized medicine. J Pharma Insights Res. 2024;2(1):50–5.
11. Santos P, Nazaré I. The doctor and patient of tomorrow: Exploring the intersection of artificial intelligence, preventive medicine, and ethical challenges in future healthcare. Front Digit Health. 2025;7:1588479.
12. Das DC, Akter MS. AI-Powered Multimodal Diagnostics in Modern Healthcare: A Shift Toward Integrative Intelligence. Asia Pac J Med Innov. 2025;2(3):47–57.
13. Uddin MJ, Gholap AD, Khan T, Proma AY, Masud S, Choonara YE, et al. The Integration of Nanotechnology, Artificial Intelligence (AI), Machine Learning (ML) and 3D-Bioprinting Approaches for Personalized COVID-19 Treatment. J Biomed Nanotechnol. 2024;20(12):1759–90.
14. Srivastav AK, Mishra MK, Lillard JW Jr, Singh R. Transforming pharmacogenomics and CRISPR gene editing with the power of artificial intelligence for precision medicine. Pharmaceutics. 2025;17(5):555.
15. Dhieb D, Mustafa D, Hassiba M, Alasmar M, Elsayed MH, Musa A, et al. Harnessing Pharmacomultiomics for precision medicine in diabetes: A comprehensive review. Biomedicines. 2025;13(2):447.
16. Velumani D, Rega C. Applications of Artificial Intelligence and Pharmacogenomics in Cardiovascular and Cancer Treatment. J Pharma Insights Res. 2025;3(3):200–9.
17. Dogiparthi LK, Bukke SP, Thalluri C, Thalamanchi B, Vidya KP, Sree GN, et al. The role of genomics and proteomics in drug discovery and its application in pharmacy. Discov Appl Sci. 2025;7(6):552.
18. Baxtiyorovna DG, Gulmira E, Sayfievna AM, Kamalovich NS. Next-Generation Precision Medicine: Integrating Artificial Intelligence, Genomics, and Real-World Clinical Data for Disease Prediction and Personalized Therapy Optimization. Int J Spec Educ. 2026;41(5 Suppl):330–47.
19. Carini C, Seyhan AA. Tribulations and future opportunities for artificial intelligence in precision medicine. J Transl Med. 2024;22(1):411.
20. Taherdoost H, Ghofrani A. AI's role in revolutionizing personalized medicine by reshaping pharmacogenomics and drug therapy. Intell Pharm. 2024;2(5):643–50.
21. Das DC, Akter MS. AI-Powered Multimodal Diagnostics in Modern Healthcare: A Shift Toward Integrative Intelligence. Asia Pac J Med Innov. 2025;2(3):47–57.
22. Murugan M, Yuan B, Venner E, Ballantyne CM, Robinson KM, Coons JC, et al. Empowering personalized pharmacogenomics with generative AI solutions. J Am Med Inform Assoc. 2024;31(6):1356–66.
23. Rahman MH, Aunni SA, Ahmed B, Rahman MM, Shabuj MM, Das DC, et al. Artificial intelligence for improved diagnosis and treatment of bacterial infections. Microb Bioact. 2024;7(1):1–8.
24. Baptista D, Correia J, Pereira B, Rocha M. Evaluating molecular representations in machine learning models for drug response prediction and interpretability. J Integr Bioinform. 2022;19(3):20220006.
25. Adam G, Rampášek L, Safikhani Z, Smirnov P, Haibe-Kains B, Goldenberg A. Machine learning approaches to drug response prediction: Challenges and recent progress. NPJ Precis Oncol. 2020;4(1):19.
26. Baptista D, Ferreira PG, Rocha M. Deep learning for drug response prediction in cancer. Brief Bioinform. 2021;22(1):360–79.

27. Zhu Y, Ouyang Z, Chen W, Feng R, Chen DZ, Cao J, et al. TGSA: Protein-protein association-based twin graph neural networks for drug response prediction with similarity augmentation. Bioinformatics. 2022;38(2):461–8.
28. Nguyen T, Nguyen GT, Nguyen T, Le DH. Graph convolutional networks for drug response prediction. IEEE/ACM Trans Comput Biol Bioinform. 2022;19(1):146–54.
29. Liu H, Peng W, Dai W, Lin J, Fu X, Liu L, et al. Improving anti-cancer drug response prediction using multi-task learning on graph convolutional networks. Methods. 2024;222:41–50.
30. Chen J, Zhang L. A survey and systematic assessment of computational methods for drug response prediction. Brief Bioinform. 2021;22(1):232–46.