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Review

How artificial intelligence is revolutionizing precision medicine and drug discovery?

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Abstract

Traditionally, medical treatments have been developed using a standardized approach, where identical treatment protocols are administered to all patients with a particular disease or condition. Precision medicine represents a groundbreaking approach to healthcare that centers on customizing medical treatments and interventions to individual patients based on their unique environmental factors, lifestyles, and molecular profiles. This approach has been shown to enhance the success rates of clinical trials and expedite drug approvals. By harnessing vast amounts of data and sophisticated algorithms, artificial intelligence (AI) has the potential to transform precision medicine and drug discovery. AI can offer valuable insights into all facets of precision medicine, including expediting the development of new therapies, optimizing clinical trials, facilitating accurate diagnoses, guiding treatment decisions, and monitoring patients. In this review, we endeavor to explore the ways in which AI will impact the various aspects of precision medicine and drug discovery.

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1. Introduction

In recent years, precision medicine has created great expectations for improving the success rate of clinical trials by adjusting treatment choices to the features of patient subgroups based on genomic profiles, lifestyle, and environmental variables. The number of medical and healthcare application areas of precision medicine has rapidly expanded, with oncology at the forefront of its application (1). Furthermore, new studies on cardiovascular disease, type 2 diabetes, and neurodegenerative illnesses such as Alzheimer's disease have underlined the rising applications of precision medicine in the healthcare industry (2). Since the deep molecular characterization of the patients is one of the most crucial requirements for precision medicine, significant leaps were made by the rapid advancement of ‘omics’ technologies such as transcriptomics, epigenomics, and proteomics (3). Since all of these technologies are computer-based, advancements in computer sciences have paved the way for the successful incorporation of artificial intelligence (AI) with precision medicine. Taking advantage of high-performance computer capabilities, AI has the ability to harness a patient's complete molecular landscape, making it a vital tool for precision medicine (4). In addition to discovering the therapeutic targets and drugs and facilitating the procedure of clinical trials, AI can play a vital role in all aspects of precision medicine such as precise diagnosing of the disease and complete phenotyping of the patient, guiding clinical decisions and selection of the best treatment strategy, and following-up of the patients (5). In this overview, we will address the intricated nature of precision medicine and describe the AI-mediated solutions that have been developed to overcome these complications.

2. Precision medicine

Precision medicine is the customization of medical therapy to each patient's unique traits. Its primary objective is to divide patients into distinct subgroups based on differences in their disease prognosis or in their response to a given treatment, with the end goal of directing therapeutic interventions toward those patients who stand to gain from them while minimizing the financial burden and adverse effects of treatment for those patients who are not likely to reap any benefits from the treatment (6). For a precise medication, comprehensive molecular characteristics of a large cohort of patients should be collected through high-throughput omics technologies and then, these patients should be divided into distinct groups based on their molecular profiles (7). Subsequently, bioinformatics studies should be applied identify discriminatory biomarkers among different groups and specified compounds for each groups of patients should be designated (8). After extensive in vitro and in vivo evaluations, produced medications must fulfill the necessary standards for safety and efficacy before drug approval to being available on the market (9). At this stage, the most appropriate therapy plan can be chosen for the management of the condition following the completion of an integrated multi-omics assessment of a patient. **Figure 1** provides a brief overview of the steps involved in performing precision medicine.

3. Artificial Intelligence (AI)

Artificial intelligence (AI) is a technical discipline that focuses on the development and application of computer systems capable of performing tasks that normally require human intelligence. Problem-solving, learning, perception, thinking, decision-making, and language comprehension are examples of these tasks by leveraging advanced algorithms and computational power, AI aims to replicate and enhance human cognitive abilities (10). Machine learning and deep learning are two types of AI that have gained significant attention and popularity in recent years. Both approaches aim to enable machines to learn and make intelligent decisions without explicit programming (11).

Machine learning is an AI subfield that focuses on the creation of algorithms and models that allow computers to learn and make predictions or decisions without being explicitly programmed. It entails analyzing and interpreting large amounts of data using statistical techniques and computational

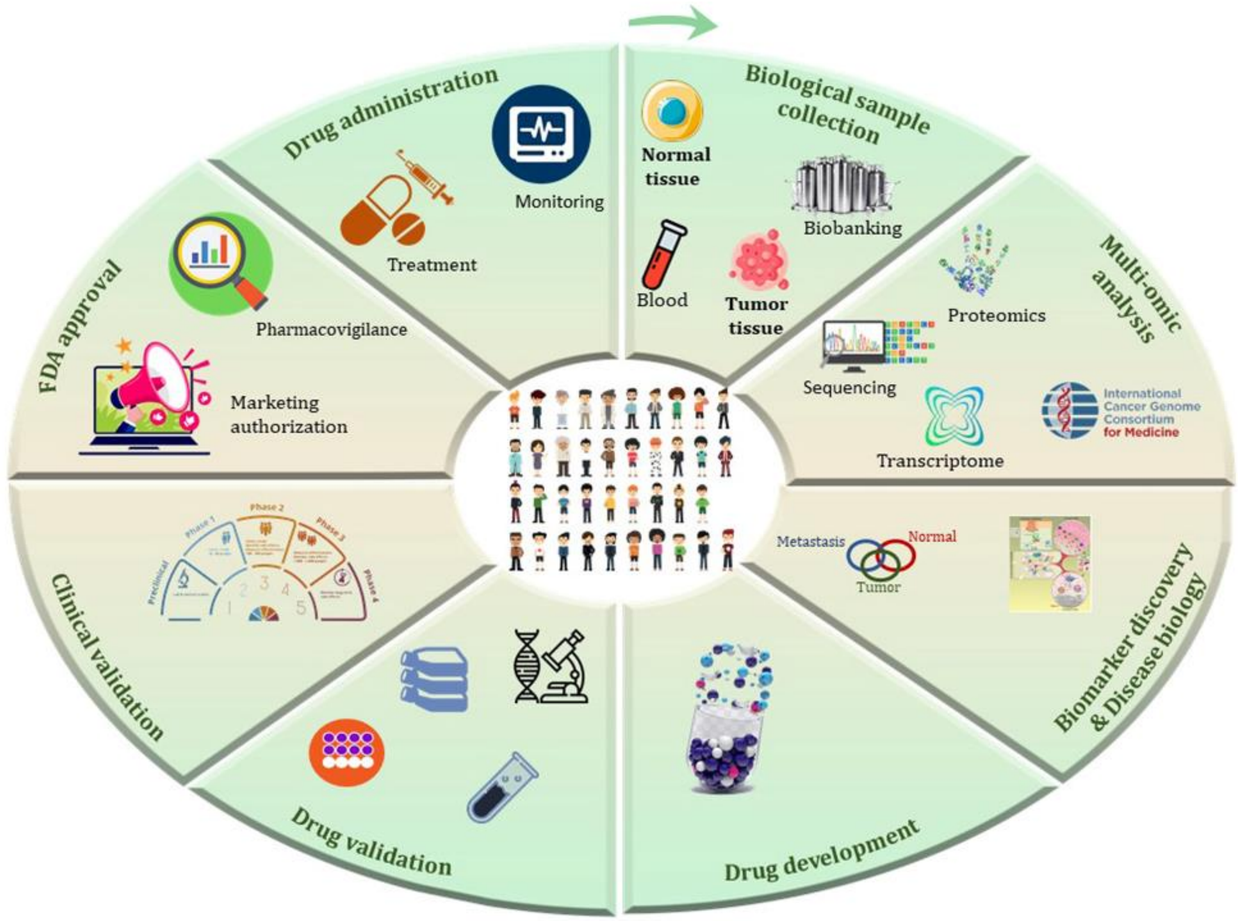

Figure 1. A schematic representation of the procedure of precision medicine. For performing precise treatment, first we should designate a precise drug for patients or a group of patients. it is necessary to gather detailed molecular information from a large group of patients using high-throughput omics technologies. This data can then be used to classify the patients into different groups based on their molecular profiles. Following this, bioinformatics studies can be conducted to identify biomarkers that differentiate between these groups. After confirming the safety and effectiveness of the drug through laboratory and clinical studies, and finally FDA approval, it is possible to choose the best drug for each patient based on the exact diagnosis of the disease, patient profile, and drug effectiveness.

algorithms, allowing machines to identify patterns, extract insights, and improve their performance over time (12). Machine learning algorithms can be broadly categorized into supervised learning, unsupervised learning, and reinforcement learning (13). The algorithm is trained on labeled data in supervised learning, where each example is associated with a known output or target variable. Based on this training data, the algorithm learns to map inputs to outputs, allowing it to make predictions on new, previously unseen data (14). Unsupervised learning, on the other hand, works with unlabeled data to discover hidden patterns or structures. It entails grouping similar data points together or discovering relationships between different variables (15). Reinforcement learning is a type of machine learning in which an agent learns to interact with its environment in order to maximize its cumulative reward by performing actions that result in positive outcomes. This type of learning is frequently used in robotics and gaming scenarios (16). Deep learning is a subset of machine learning that has gained significant attention and popularity in recent years due to its superior performance in various domains. Unlike traditional machine learning algorithms, which rely on handcrafted features and explicit rules, deep learning models are capable of automatically learning hierarchical representations from raw data (17). This ability to extract complex features and patterns from large amounts of data makes deep learning particularly powerful in tasks such as image and speech recognition, natural language processing, and even drug discovery (18-20). Deep learning has previously been utilized to identify various antiviral compounds, such as antiviral peptides and small drug-like compounds that have the potential to hinder the activity of HIV-1 (21). Deep learning models, such as artificial neural networks, consist of multiple layers of interconnected nodes that mimic the structure and functioning of the human brain. By leveraging these deep architectures, deep learning algorithms can effectively capture intricate relationships and dependencies within the data, leading to more accurate predictions and better generalization capabilities (22). Additionally, deep learning models are highly scalable and can handle massive amounts of data, making them suitable for big data applications (23). The success of deep learning can be attributed to its ability to automatically learn relevant features from the data, eliminating the need for manual feature engineering, which can be time-consuming and error-prone (24). Moreover, deep learning models can continuously improve their performance through a process called training, where they adjust their internal parameters based on feedback signals provided by labeled data This iterative training process allows deep learning models to adapt to changing environments and improve their accuracy over time (16). Overall, the superiority of deep learning lies in its ability to handle complex and high-dimensional data, learn hierarchical representations, scale effectively with big data, and continuously improve through training. In recent years, AI techniques, such as machine learning and deep learning, have the potential to analyze vast amounts of data and extract meaningful insights that can aid in diagnosis, treatment selection, and patient monitoring (25). In particular, AI has revolutionized the field of biomedicine and healthcare, playing a crucial role in early drug discovery and enabling precision medicine (26).

4. Artificial intelligence in precision medicine

AI has become a significant asset in the field of precision medicine, bringing about a transformative impact on healthcare delivery. By leveraging AI techniques such as machine learning and deep learning, healthcare professionals can analyze vast quantities of data and uncover valuable insights that can greatly assist in the areas of diagnosis, treatment selection, and patient monitoring (27). Indeed, Traditional medical approaches often rely on generalized treatment guidelines that may not fully account for these individual differences. However, with the integration of AI technologies into precision medicine, healthcare providers can now harness the power of data-driven analysis to develop personalized treatment strategies (28, 29). AI techniques, such as machine learning and deep learning, have the potential to analyze vast amounts of data and extract meaningful insights that can aid in not only discovering the therapeutic targets and drugs (30) and clinical trials optimization (31), but also in accurate diagnosis, selection of the best treatment strategy, and patient monitoring (32).

Here in we review the role of AI in different steps of precision medicine.

4.1. Discovering the therapeutic targets and drugs

The approval process for a novel drug entering the market costs a ranging from $314 million to $2.8 billion. In addition, research and regulatory procedures require approximately 12 years before a drug is approved for sale (33, 34). Despite the high cost, the pharmaceutical industry and academic research centers continue to look for and develop innovative medicines for patients (35). The drug discovery process typically begins with the identification of potential targets, followed by the development of a specific compound, preclinical testing for safety and efficacy, clinical phases, and regulatory approval (36). Based on statics, only five compounds out of every 5,000 that undergo pre-clinical testing are evaluated in human trials, and only one of these five is approved for therapeutic purposes (34). The fundamental weakness of traditional drug development pipelines that reduces the effectiveness of discovered compounds is that patient heterogeneity is neglected in the evaluation of treatment response (9).

By revolutionizing the drug discovery process, AI plays a critical role in discovering therapeutic targets and drugs. By leveraging large-scale data analysis, predictive modeling, and machine learning algorithms, AI has the potential to significantly improve and accelerate this process (37). Target identification and validation, which is a critical step in developing new drugs, is one of the primary applications of AI in drug discovery (38). AI algorithms can analyze massive amounts of biological data, such as genomics, proteomics, and metabolomics data, to identify potential targets linked to specific diseases or conditions. AI can uncover hidden patterns and relationships that would not be apparent using traditional methods by integrating multiple data sources and applying advanced computational techniques (39). Once possible targets have been identified, AI can assist in confirming their relevance and efficacy. This includes looking at things like target expression levels, functional assays, genetic correlations, and clinical relevance (40). By combining experimental data with computational models, AI algorithms can prioritize targets based on their likelihood of success and reduce the number of false positives (41).

Another critical role for AI in drug discovery is in the design and optimization of small molecules. Because of their ability to interact with specific targets in the body, small molecules are frequently used as drugs. However, designing small molecules with desired properties is a complex task that necessitates taking into account numerous factors such as target specificity, bioavailability, toxicity, and pharmacokinetics (42, 43). Virtual screening and de novo drug design are two AI-based approaches that can significantly speed up the process of identifying potential drug candidates. The process of using computational models to screen large databases of compounds for those that are likely to bind to a specific target is known as virtual screening. This method aids in narrowing the search space and prioritizing compounds for additional experimental testing. De novo drug design takes a more innovative approach, generating entirely new molecules with desired properties using AI algorithms. AI can propose novel chemical structures that have a higher likelihood of being effective drugs by leveraging deep learning models and generative algorithms. This method has the potential to uncover new chemical entities that would not have been discovered using conventional methods (44).

AI is also important in drug repurposing, which involves discovering new therapeutic applications for existing drugs. Because existing drugs have already been tested for safety, repurposing them can significantly reduce the time and cost associated with drug development (45). Large-scale datasets, such as electronic health records, clinical trial data, and molecular databases, can be analyzed by AI algorithms to identify potential repurposing opportunities based on shared mechanisms of action or disease similarities (46). Furthermore, AI can aid in predicting the safety and toxicity profiles of potential drug candidates. By analyzing chemical structures and their relationships to known toxic compounds, AI algorithms can provide insights into potential adverse effects early in the drug discovery process. This helps researchers prioritize compounds with lower toxicity risks and reduces the likelihood of late-stage failures (47). In summary, AI has emerged as a powerful tool in discovering therapeutic targets and drugs. By leveraging large-scale data analysis, predictive modeling, and machine learning algorithms, AI can accelerate target identification and validation, aid in small molecule design and optimization, facilitate drug repurposing efforts, and predict safety profiles. These advancements have the potential to revolutionize the field of drug discovery by reducing costs, shortening development timelines, and increasing the success rate of bringing new therapies to market.

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4.2. Clinical trial optimization

AI has been playing a significant role in optimizing clinical trials, revolutionizing the way research is conducted and accelerating the development of new treatments (48). Researchers and pharmaceutical companies can streamline various aspects of clinical trials, such as patient recruitment, trial design, and data analysis, by leveraging AI technologies. This method improves clinical trial efficiency and increases the likelihood of identifying effective drugs (49). Furthermore, AI algorithms can analyze historical clinical trial data to identify patterns and predict the outcomes of future trials (50). Here in, we will discuss several key areas where AI can bring about transformative changes in the field of clinical trials.

4.2.1. Patient Recruitment

One of the major challenges in clinical trials is finding suitable participants within a specific timeframe. Suboptimal patient selection and recruiting techniques, combined with an inability to effectively monitor and coach patients during clinical trials, are two of the primary causes of high trial failure rates (51). The third phase of clinical trials incurs a significant portion, namely 60%, of the overall expenses associated with advancing a drug through all trial phases. This is due to the requirement of enrolling the largest patient cohorts during this phase. The occurrence of a 32% failure rate in Phase III trials, attributed to patient recruitment issues, highlights a critical inadequacy in contemporary clinical trial design. Specifically, trials with the greatest patient demand are particularly susceptible to inefficiencies in patient recruitment techniques (51). AI algorithms can analyze large datasets from electronic health records (EHRs), medical literature, and other sources to identify potential candidates who meet the trial criteria. By automating this process, AI can significantly reduce the time and cost associated with patient recruitment (52). For instance, AI-powered platforms like Deep 6 AI use natural language processing (NLP) techniques to mine unstructured EHR data and match patients with appropriate clinical trials (53).

4.2.2. Trial Design

AI can also aid in the optimization of clinical trial design to ensure enhanced efficiency and effectiveness. Conventional trial designs frequently adopt a uniform approach, resulting in suboptimal outcomes. By employing AI, researchers can employ machine learning algorithms to scrutinize diverse factors, including patient characteristics, disease progression patterns, and treatment responses, to identify optimal trial designs (54). This approach enables personalized medicine by tailoring trials to specific patient populations or subgroups (55). It has been officially announced that the first fully AI-generated drug, INS018_055, has commenced clinical trials in humans. The drug is being developed by Insilico Medicine, a Hong-Kong based company, and has progressed to phase 2 trials for the treatment of idiopathic pulmonary fibrosis, a chronic respiratory disease characterized by lung scarring and breathing difficulties. The company employs cutting-edge AI systems that integrate biology, chemistry, and clinical trial analysis, utilizing deep generative models, reinforcement learning, transformers, and other advanced machine learning techniques. These platforms are utilized for the discovery of novel targets and the generation of molecular structures with desired properties (30).

4.2.3. Data Analysis

It has been officially declared that the initial completely AI-generated medication has commenced clinical trials in human subjects. The process of clinical trials necessitates the precise and efficient analysis of extensive and intricate data. AI methodologies, including machine learning and deep learning, can be employed to extract valuable insights from these datasets. By training algorithms on historical trial data, AI models can predict patient outcomes, identify potential safety issues, and optimize treatment protocols. This empowers researchers to make informed decisions during the trial process and enhance patient care (50, 56). Additionally, AI can automate the process of adverse event detection and reporting, enhancing patient safety and reducing the burden on trial investigators (57). Studies have demonstrated that deep learning techniques utilizing neural fingerprints can not only anticipate unfavorable drug reactions with an AUC of approximately 0.85, but also recognize the related molecular sub-structures. These algorithms possess the capability to provide evidence-based guidance for the development of safer pharmaceuticals. Comparable methodologies can be employed to forecast drug-drug interactions for untested drug combinations (58, 59).

4.2.4. Real-world Evidence

AI technologies have the capability to utilize authentic data from sources such as electronic health records (EHRs), claims databases, and social media to produce real-world evidence (RWE). RWE offers valuable insights into the efficacy of treatments, safety profiles, and patient outcomes beyond the confines of controlled clinical trial settings (60, 61). RWE and randomized controlled trials (RCTs) are both significant sources of information for assessing the efficacy and safety of medical interventions. Nevertheless, each possesses distinct advantages and drawbacks, and it is crucial to take into account the circumstances in which the evidence is being employed. Indeed, Both RWE and RCT evidences hold significant importance in informing decision-making (62). It is advisable to consider multiple sources of evidence while evaluating the effectiveness and safety of an intervention. Through the analysis of RWE using AI algorithms, researchers can complement conventional clinical trial data with real-world observations to enhance trial design and provide guidance for regulatory decisions (60, 61).

4.2.5. Drug Repurposing

AI has the capability to identify potential novel applications for pre-existing drugs through computational analysis of vast biomedical data (63). By scrutinizing molecular structures, genetic profiles, and disease pathways, AI algorithms can discern drugs that may exhibit therapeutic effects in diverse indications (64). Fang et al. introduced an integrated, network-based AI methodology that expeditiously translates Genome-wide association studies (GWAS) findings and multi-omics data into genotype-informed drug repositioning in Alzheimer's disease (65). Another notable example is the use of AI-based drug repositioning in the fight against COVID-19. Beck and colleagues have devised a hybrid model that combines Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN) called Molecule Transformer-Drug Target Interaction. The purpose of this model is to predict the efficacy of commercially available antiviral drugs against SARS-CoV-2. Through computational analysis, the authors have identified several known antiviral drugs, including atazanavir, remdesivir, efavirenz, ritonavir, and dolutegravir, that have the potential to treat SARS-CoV-2 infection (66). This methodology can expedite the drug development process by repurposing pre-existing drugs for novel treatments, thereby curtailing the expenses and time associated with conventional drug discovery techniques.

4.3. Diagnosing of the disease

Accurate diagnosis serves as the bedrock of precision medicine, as it enables healthcare professionals to identify the specific disease or condition afflicting a patient and determine the most appropriate treatment plan. Based on research conducted by Johns Hopkins University, approximately 40,500 patients lose their lives in intensive care units annually in the United States due to diagnostic errors. The study found that around 65% of these cases were influenced by system-related factors, including deficiencies in processes, teamwork, and communication (67). The advent of AI technologies, such as machine learning and deep learning algorithms, has revolutionized the field of medical diagnosis by enhancing accuracy, efficiency, and speed (68). These technologies empower computers to analyze vast amounts of medical data, including patient records, medical images, genomic data, and scientific literature. By leveraging this wealth of information, AI systems can assist healthcare professionals in making more precise diagnoses (69, 70).

One of the primary ways in which AI contributes to accurate diagnosis is through image recognition and analysis. Medical imaging techniques, such as X-rays, CT scans, MRI scans, and histopathology slides, generate large volumes of visual data that require expert interpretation (71). AI algorithms can be trained on massive datasets to recognize patterns and anomalies in these images, helping radiologists and pathologists detect diseases with higher accuracy. For instance, AI-powered systems have demonstrated remarkable performance in detecting various types of cancer, including breast cancer, lung cancer, and skin cancer (72). Coudray et al. have devised a deep-learning model for the automated analysis of tumor slides, utilizing publicly accessible whole-slide images from The Cancer Genome Atlas (TCGA). The efficacy of the deep learning models was found to be on par with that of individual pathologists. The authors assert that deep-learning models can aid pathologists in identifying cancer subtypes or gene mutations in any form of cancer, resulting in significant savings in time and expenses (73). In addition to image analysis, AI can also analyze other types of medical data to aid in diagnosis. Electronic health records (EHRs) contain a wealth of patient information, such as medical history, laboratory test results, medication records, and demographic data.

an AI program was created to predict the occurrence of diabetes mellitus (DM) with a 95% accuracy rate, utilizing routine health checkup records (74). Additionally, an algorithm for managing cardiac arrest in emergency situations was developed by analyzing EHR data, specifically blood pressure, pulse rate, respiration rate, and body temperature (75). By analyzing large-scale datasets such as EHR, genomic data, and imaging studies from diverse patient populations, AI systems can uncover hidden patterns that may not be apparent to human clinicians alone (76).

4.4. Guiding Clinical Decisions

The incorporation of AI into the healthcare industry has the potential to revolutionize the decision-making process for treatment, leading to more personalized and effective patient care. For instance, AI models can be trained on large datasets of labeled images to identify subtle patterns and markers that may not be easily detectable by human radiologists. This can aid in early disease detection, accurate diagnosis, and selection of appropriate treatment options (65, 77). By analyzing genomic data, AI algorithms can identify genetic variants associated with specific diseases or drug responses, enabling healthcare providers to select the most effective treatment strategy for each patient, minimizing adverse effects and optimizing outcomes. The Imaging in FOCUS initiative has recently been introduced to address the inappropriate use of diagnostic imaging by utilizing AI to track appropriate use criteria. A study involving 55 participating sites has shown that the proportion of inappropriate cases decreased from 10% to 5% after implementing the radionuclide imaging performance improvement module. These preliminary findings suggest that self-directed quality improvement software and interactive collaboration among physicians can significantly reduce the proportion of tests that do not meet appropriate use criteria (78).

Furthermore, AI algorithms can analyze diverse types of data, including genomic information, clinical trial data, electronic health records, scientific literature, and even real-world data from wearable devices, to identify potential drug targets, predict the efficacy of different compounds, and optimize treatment strategies. AI-based systems can also predict how a drug molecule interacts with its target molecule at a molecular level, simulating their interaction and predicting the binding affinity between them. This information helps researchers assess the likelihood of a drug being effective against its intended target (79). AI platforms in conjunction with the vast databases available, have the capability to establish links between multiple compounds and numerous targets and off-targets. Bayesian classifiers and SEA algorithms can be utilized to determine the connections between the pharmacological profiles of drugs and their potential targets (80).

By integrating various factors such as molecular properties, physiological parameters, and patient-specific data, AI can predict how a drug will behave in the human body, crucial for determining optimal dosing regimens and assessing the potential efficacy of a drug (81). For example, the IDentif.AI-x platform, which is a clinically actionable AI tool, was employed to expeditiously identify and rank the most effective combination therapies for COVID-19 (82). Zhu and colleagues have developed a machine learning model that can assist healthcare professionals in adjusting medication dosages for patients in order to mitigate the occurrence of adverse reactions (83). **Figure 2** provides a comprehensive overview of the various facets of precision medicine and drug discovery that can be facilitated through the utilization of AI.

4.5. Follow-up of the patients

The follow-up of patients is a crucial aspect of precision medicine, as it involves the monitoring and evaluation of the effectiveness of treatments and interventions over time (84). AI technologies play a significant role in enhancing the efficiency, accuracy, and personalization of care by automating data analysis, providing predictive analytics, enabling remote monitoring and telemedicine, leveraging natural language processing techniques, offering decision support systems, and enhancing patient engagement and education. AI technologies can enhance patient engagement and education during the follow-up process, providing patients with personalized information about their condition, treatment plan, and self-management strategies, and empowering them with knowledge and resources to improve patient outcomes and satisfaction (85, 86). Intelligent conversational agents, commonly referred to as "chatbots," have demonstrated their potential as effective tools for engaging and educating patients directly (87). AI algorithms can analyze vast amounts of patient data, including electronic health records (EHRs), medical imaging results, laboratory test results, and wearable device data, to identify patterns, trends, and anomalies that may not be easily detectable by human clinicians. This helps in the early detection of complications or treatment failures, allowing for timely intervention (88, 89). AI models can leverage machine learning techniques to predict patient outcomes based on historical data, enabling clinicians to identify patients who are at higher risk of developing complications or relapses, and providing proactive interventions (90, 91). It has been reported that AI possesses the capability to substitute 50%-70% of customary follow-up clinical consultations with virtual engagements and remote monitoring (92). AI-powered remote monitoring systems enable continuous tracking of patients' health status outside traditional healthcare settings, while telemedicine platforms integrated with AI technologies allow for virtual consultations between patients and healthcare providers, reducing the need for in-person visits (93, 94). Bugajski et al. developed an instance of an artificial neural network which has demonstrated significant efficacy in forecasting self-management in patients with chronic obstructive pulmonary disease (COPD) by comprehending and documenting patient symptoms. The precision of this model was determined to be 93.8% (95).

5. Future perspective and obstacles

The prospective outlook regarding the utilization of AI in precision medicine and drug discovery is exceedingly auspicious. The progression of AI algorithms, computational potency, and data accessibility is anticipated to transform these domains. The refinement of machine learning and deep learning models will persist, facilitating more precise prognostications, superior patient risk stratification, and improved treatment optimization (5, 96). The synergistic partnerships between AI and other advanced technologies, including robotics, nanotechnology, and quantum computing, have the potential to unveil novel opportunities for precise drug administration, expedited experimentation, and customized therapeutic interventions (97).

While the application of AI in precision medicine and drug discovery holds immense potential, there are several obstacles that need to be overcome for its successful implementation. For instance, AI algorithms are heavily dependent on datasets of high

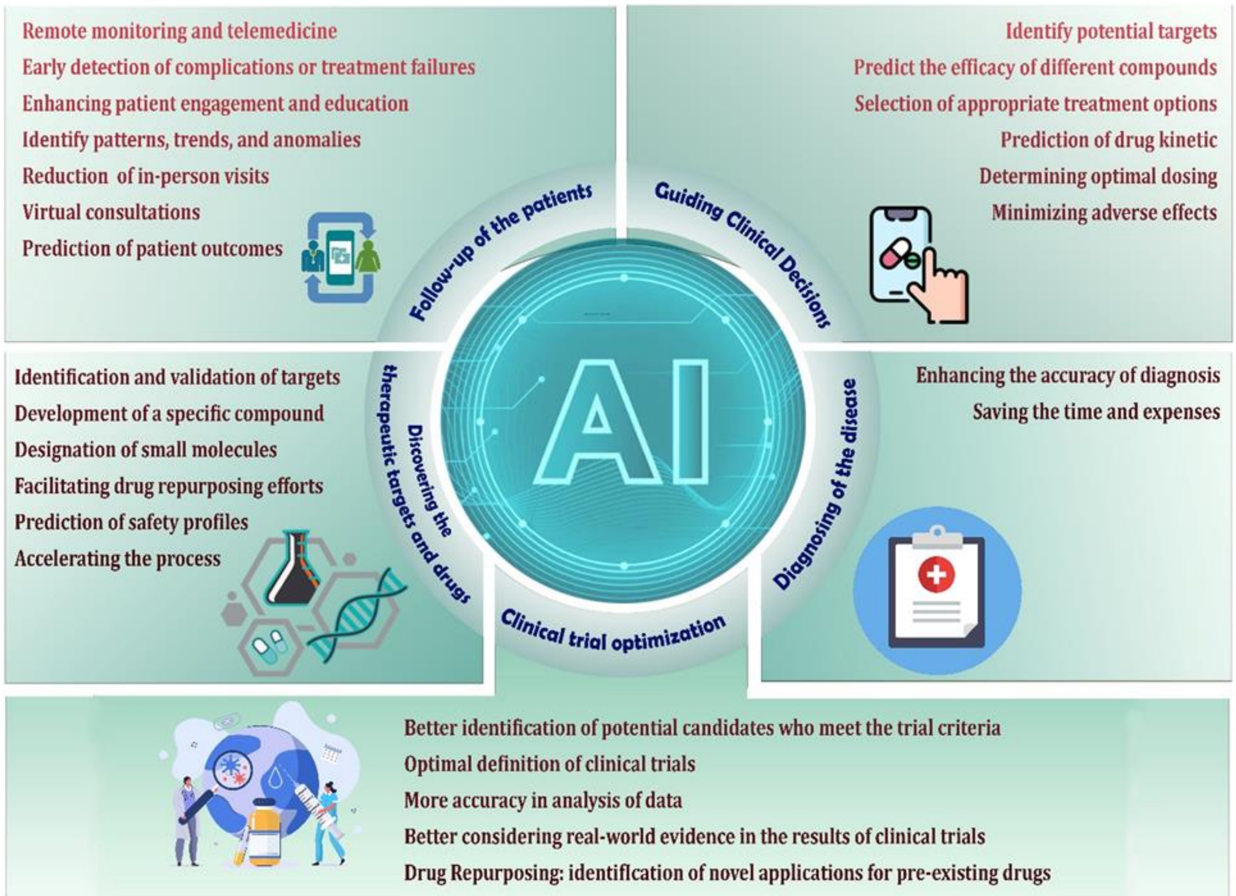

Figure 2. Advantages of using artificial intelligence in different aspects of precision medicine.

quality and diversity for both training and validation purposes. Nevertheless, in the fields of precision medicine and drug discovery, obtaining comprehensive and well-annotated datasets can prove to be a challenging task. This is due to the fact that data may be dispersed across various healthcare systems, stored in formats that are incompatible with one another, or subject to privacy and security restrictions. The limited availability of data, as well as the potential biases present in the collected data, can have a significant impact on the performance and generalizability of AI models (98, 99) . Moreover, the lack of standardized data structures and protocols poses a significant challenge in aggregating and harmonizing diverse datasets, making it difficult to leverage the full potential of AI (100).

Ethical and legal considerations pose significant challenges in the development and deployment of AI systems. For example, there are concerns about the potential impact of AI on employment and the workforce and there is a possibility of job displacement or significant changes in the nature of work (101) . moreover, protecting patient privacy while ensuring data availability for research and development is a delicate balance. Additionally, the interpretability and transparency of AI algorithms are essential to build trust among healthcare professionals, regulators, and patients (102). On the other hand, the integration of AI technologies into established clinical workflows and the attainment of approval from healthcare professionals can prove to be a challenging endeavor. Clinicians may possess a limited understanding of AI concepts and may harbor reservations regarding the dependence on AI-generated recommendations. The establishment of trust, the provision of explicable AI models, and the demonstration of the clinical efficacy and supplementary value of AI tools are imperative for their efficacious assimilation (103, 104). The resolution of these impediments necessitates the cooperation of various stakeholders, such as researchers, clinicians, policymakers, and technology developers. It is imperative to undertake endeavors aimed at enhancing data sharing, standardizing data structures, formulating ethical guidelines, and constructing sturdy validation and regulatory frameworks to fully realize the potential of AI in the domains of precision medicine and drug discovery.

6. Conclusion

In conclusion, the utilization of AI in precision medicine and drug discovery holds significant implications and promising future prospects. These include the advancement of more sophisticated machine learning algorithms, the integration of multimodal data sources (such as wearable devices and real-time monitoring), and the amalgamation of AI with other emerging technologies such as robotics and nanotechnology. Through sustained research and collaboration between scientists, healthcare professionals, and technology experts, AI has the potential to revolutionize precision medicine and drug discovery, resulting in more efficacious treatments, improved patient outcomes, and a paradigm shift in healthcare delivery. However, it is imperative to acknowledge that AI should not supplant human expertise and judgment in the selection of treatment strategies. Rather, it should be regarded as a potent tool that complements and enhances the decision-making process. Healthcare professionals should utilize AI-generated recommendations as a valuable source of information but ultimately make the final treatment decisions based on their clinical experience, patient preferences, and ethical considerations.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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