© May 2026 | IJIRT | Volume 12 Issue 12 | ISSN: 2349-6002

Precision Medicine: Revolutionizing Personalized Treatment

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doi.org/10.64643/IJIRTV12I12-201377-459

***Abstract*—Personalizing treatment based on each patient's specific genetic markers, environmental, and clinical characteristics is the primary objective of precision medicine. It helps in identifying health risks and outcomes of individuals by considering all the above factors. It makes the use of technologies such as mass spectrometry for early diagnosis. Personalizing medicines based on individual genetic makeup and specific mutations has advanced the disease treatments. The more comprehensive definition of precision health is comprehensive treatment using specific, individualized methods. This is a unique approach that prioritizes the analysis of genetic changes that is necessary to achieve advance treatments. New technological developments indicate the importance of understanding the genetic, epigenetic, and gene expression characteristics for various diseases. Artificial intelligence facilitates the development of individualized treatment plans based on the enhanced diagnostic accuracy in bringing positive patient outcomes. The review paper is to present a comprehensive summary of precision medicine introduction and development considering its present implications and challenges.**

***Index Terms*—Precision Medicine, Early detection, Preventive medicine, Personalized Treatment, Artificial Intelligence, Big data.**

I. INTRODUCTION

In recent years, there has been a considerable evolution in precision medicine from the idea of individualized treatment based on genetic information to a broader approach that includes data-driven and predictive techniques [1, 2]. As a result of this, healthcare practices have shifted from being reactive to proactive, using machine learning and artificial intelligence to improve the results of patients [3]. Precision health is another extension of the idea that prioritizes individualized therapies and comprehensive care [4]. Currently used in different areas, with a focus on early, precise diagnosis and clinical tumor treatment employing advanced imaging technologies such as dual-modality photoacoustic-ultrasonic imaging [5]. These applications allow for the accurate identification of diseases as well as the development of individualized treatment plans based on functional and molecular data.

Precision medicine has evolved significantly in the last several years, moving beyond its original emphasis on personalized care based only on genetic data. As a result of this progression, an overall approach that combines predictive and data-driven methodology has emerged, transforming healthcare practices and patient outcomes [1]. Technological advances such as Machine Learning (ML) and Artificial Intelligence (AI) play a major role in facilitating the paradigm shift in healthcare from reactive to proactive. With the use of these technologies, healthcare professionals can now analyze enormous volumes of patient data, spot trends, and make better judgments. Clinicians can predict prospective health risks, intervene earlier, and more successfully personalize therapies to meet the needs of specific patients by applying these technologies [2]. This is a holistic approach to patient care, building upon the principles of precision medicine that considers a wider variety of elements influencing an individual's health in addition to specific therapies [3]. The goal of precision health is to present a more comprehensive picture of a person's health condition and possible risks by integrating multiple areas of their life, such as lifestyle, environment, and social determinants (Figure 1) by using advanced technologies like AI [4].

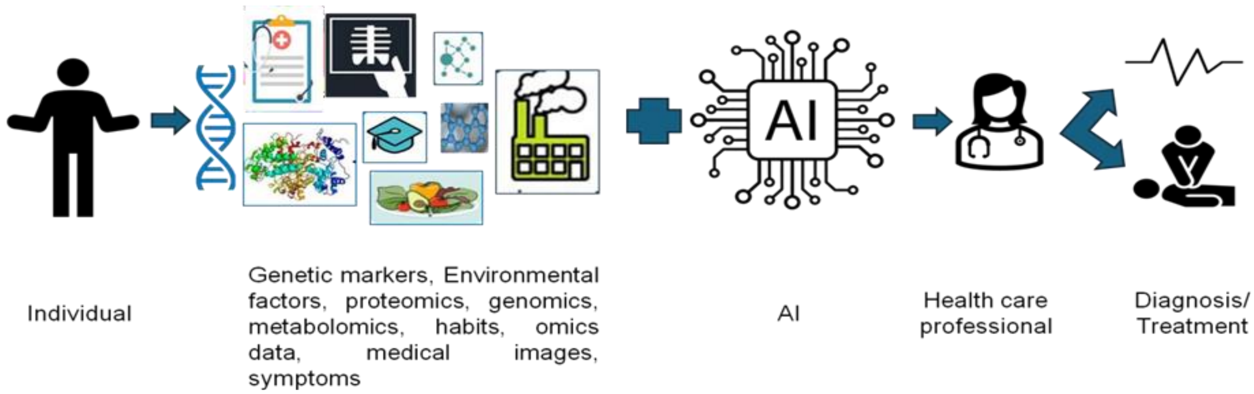

Figure 1. Overview of personalised medicine

Early and precise diagnosis of cancer is one of the most potential applications of precision health in the medical industry. Advanced imaging methods such as dual-modality photoacoustic-ultrasonic imaging techniques reveal previously inaccessible knowledge by visualizing the body's chemical functions and anatomical structures. The use of these advanced imaging modalities has significantly boosted the ability to identify and analyse cancers with remarkable accuracy. By integrating both functional and molecular data the clinicians can identify diseases at an earlier stage [5]. Besides, the availability of this comprehensive data enables personalized treatment programs that account for each patient's unique features.

A significant advancement in science and technology is evident in the integration of artificial intelligence analytics, modern imaging technologies, and precision medicine. These integrations efforts provide possibilities for more precise diagnosis, personalized treatment plans, and better patient outcomes. As these fields continue to evolve and intersect, the potential for further advances in patient care and healthcare delivery remains substantial.

II. EVOLUTION OF PRECISION MEDICINE

To maximize efficacy and minimize adverse responses, this system is intended to deliver the right medical intervention to the right person at the right time [1]. Precision medicine is a part of the broader health framework, which focuses on providing comprehensive care to the patients by individualized approaches [2]. Achieving this requires a comprehensive strategy that interprets the causative effects of genetic modifications and considers how individual level of genetic events interacts in a non-linear manner [4]. As technology advances, patient-specific treatment plans based on unique biological characteristics such as genetic changes and cancer-signalling pathways are becoming more prevalent [6].

During the initial implementation, the precision medicine treatments are based on the drug response of the individual and the population averages responses [7]. But the present approaches are based on the integration of the advanced approaches such as genomics, proteomics and omics data [8]. Emergence of the pharmacogenomics has revolutionised to understand the response of genes towards the drugs, highlighting the importance of genetic variations [9]. Completion of the human genome project has paved the way for integrating high-throughput sequencing technologies helped the researchers to study about various biomarkers directly associated with various diseases [10]. The present precision medicine methods Integrates a wide range of various advanced approaches such as omics, advanced imaging technologies, big data analytics and Artificial Intelligence (Figure 2) (Table 1).

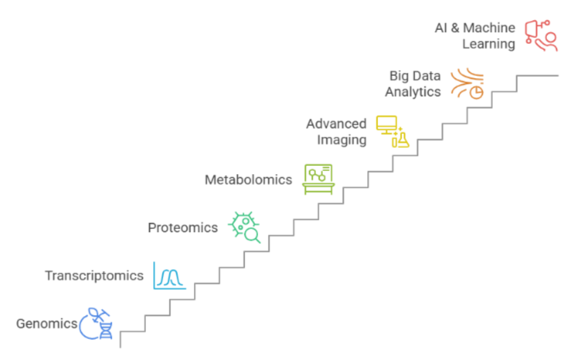

Figure 2. Advancements in personalised medicine

Table 1. Key Technology in Precision medicine

Technology	Application	References
Artificial Intelligence (AI)	Diagnostics (e.g., imaging analysis), treatment planning, biomarker discovery, drug discovery	[12], [13], [16], [20]
Genomics	Identifying disease mutations and subtypes	[10], [20]
Proteomics	Blood biomarker discovery, disease monitoring	[24]
Imaging	Early tumor detection (e.g., photoacoustic-ultrasonic imaging)	[45]
Liquid Biopsy	Detecting circulating tumor DNA (ctDNA)	[44]
CRISPR-Cas	Genome editing for therapy	[25]

III. ARTIFICIAL INTELLIGENCE IN PRECISION MEDICINE

By facilitating individualized treatment plans, increasing diagnostic accuracy, and better patient outcomes, artificial intelligence is transforming healthcare. Machine learning algorithms that use Artificial Intelligence (AI) in diagnostic techniques have proven effective in identifying diseases including skin and breast cancer. AI has revolutionized the field of digital pathology by facilitating rapid and accurate diagnostic processes using medical images [11]. AI's ability to examine large datasets from large-scale medical testing has streamlined the process of personalizing medications to meet the specific needs of each patient [12]. In drug discovery, disease diagnosis, treatment optimization, and outcome, AI has played a significant role in the growth of precision medicine [13]. Promising outcomes were reported when personalized medicine is integrated with AI in treating the conditions like diabetes and cancer, demonstrating how AI has the power to improve health outcomes [14]. Big data plays a crucial role in developing method related to personalized medicine by enabling the analysis of large and complex datasets. It supports the identification of phenotypic-genotype relationships and is made possible by the integration of machine learning techniques with multi-omics data [15]. Big data analytics is being used in precision medicine for disease classification, biomarker discovery, and personalized treatment decisions based on patient data.

Table 2. AI in Precision Medicine

Feature	Description	References
Diagnostic Accuracy	AI surpasses human performance in image-based diagnoses	[16], [17]
Rapid Pathology Analysis	Quick analysis of slides and scans at low cost	[19]
Drug Discovery	Design novel compounds, predict efficacy/safety	[13], [14]
Predictive Analytics	Risk stratification using genomic and lifestyle data	[15], [22]
Genomic Data Interpretation	Identification of gene-pathway interactions	[20]

AI has the ability to analyse the vast amounts of complex data within short span of time in making decision about individualized treatment. Some of the advantages of integrating AI in the precision medicine are (Table 2):

1. Diagnostic Accuracy:

Deep learning models of AI will help in analysing the medical images (CT scans, MRIs, histopathological slides etc.) with an accurate accuracy, often surpassing the human capabilities in the identification of diseases [16].

For examples the lung or skin cancers can be detected at early stages with high sensitivity [17].

These technologies will also help for the identification of biomarkers from the medical images that will help for early treatment response [18].

Besides, the above applications, AI will also help in the pathological slides analysis in less time and at low cost as manual review takes time and high costs [19].

2. Drug discovery:

AI will not help in the identification of new drug candidates but also helps for designing novel compounds and predict their efficacy and safety. This will help to understand the individual molecular profile and customise the personalised therapies to the patients.

Genomic data analysis will help for the identification of the dysregulated genes and pathways for a specific disease [20].

The other application of the genetic analysis is that it will help in understand how the drug will respond in a specific individual. Hence, accordingly the healthcare professionals can suggest the dosages in precision medicine [21].

All the technology integration can only be validated after providing evidence from the clinical trials, making everyone benefit of precision medicine.

3. Treatment Optimization and risk predictions:

The treatment in the precision medicine can be suggested by taking into account of various kinds of data such as genomic data, clinical data, lifestyle factors, existing disorders etc. [22]. This data integration will bring effective results by minimising the patient risk for some adverse effects.

Some of the examples of the treatment optimisations are:

Cancer patients will respond to immunotherapy and give positive outcomes.

The patients who will be more prone to the diabetes, cardiovascular diseases, Alzhemier's diseases can be identified by taking into account of various factors using various AI algorithms and can be suggested for diet and physical activity modifications to minimise the risk of disease.

4. Multi-Omics Data analysis:

The biological data is huge, highly dimensional and unstructured which constitutes all types of data such as genomics, transcriptomics, images, medical records etc. [23]. A comprehensive understanding of this requires advanced technologies which will help to understand the differences in the genetic makeup and the molecular interactions of the individual patients suffering with specific disease.

While AI holds immense promise for advancing precision medicine, it is important to address challenges such as data privacy, algorithm bias, and the need for rigorous validation before these technologies can be widely implemented in clinical practice.

Technology has had a significant impact on precision medicine as it integrates data science, analytics, and biomedicine. Advanced computing systems like artificial intelligence and machine learning, virtual reality, robotics, wearable sensors, and nanotechnologies, are very essential in the field of personalized healthcare. Proteomics has simplified the blood marker analysis for disease diagnosis as well as in therapy monitoring. The process of analyzing large amounts of healthcare data has been made easier by the integration of AI, particularly deep learning [24]. Moreover, therapeutic gene therapy has been transformed by genome editing technologies like CRISPR-Cas, which enable precise alterations to correct genetic mutations and introduce therapeutic changes [25].

IV. ROLE OF PRECISION MEDICINE IN DIFFERENT DISEASES DIAGNOSIS AND TREATMENT

Precision medicine is being applied to a wide range of diseases, including cancer, diabetes, and pneumonia, by tailoring treatments to individual patient characteristics.

PNEUMONIA

Effective integration of precision medicine in the management of pneumonia management faces critical challenges like low-complexity computational solutions for the molecular data analysis, high cost, and ethical concerns and data security [26]. Precision medicine approaches have been used to manage COVID-19, demonstrating how genomic and other omics data can be used in personalized treatment approaches [27]. Despite the above challenges, it offers opportunities to enhance outcomes for pneumonia patients by predicting responses and tailoring interventions based on genomic variants and molecular interpretations [28].

Precision medicine have significant implication in providing diagnosis and treatment of lung disorders like pneumonia by:

1. Pathogen identification:

The traditional diagnostic methods will rely on the culture-based methods for the identification of the pathogens. This will cost and take some time for the identification of organism. This process can be fastened by integrating metagenomics analysis in precision medicine by targeted antibiotic or antiviral therapy.

2. Disease severity prediction:
Biomarkers will help in the prediction of high-risk patients who are more prone to pneumonia. The most common example is genetic changes associated with the pneumonia in some patients will likely results in acute respiratory distress syndrome (ARDS) [29]. Hence based on the genetic changes some of the healthcare professionals will recommend corticosteroids or immunomodulatory agents as a part of tailored therapy.

3. Host response and tailored treatment:
Gene expression analysis will be used to identify the immune response of individual for a treatment. Anti-inflammatory therapies can be recommended for the individuals with overactive immune responses.
It was understood from the above, that precision medicine holds a promise in pneumonia care but there exists limitations of costs and validations. Some studies have provided evidence that host gene expression profiling will help in distinguishing between different kinds of pneumonia (such as bacterial and viral), helping the healthcare professional to take decision about the treatment.

CANCER
Over the past ten years, there is significant advancement in the cancer treatment, particularly in the individualization of cancer therapy for patients based on specific genetic mutations [30]. This method, which has started in the Human Genome Project, targets abnormal oncogenic proteins which are the cause of tumour growth and provides individualized therapy. For certain patients' groups, treatment selection is optimized using biomarker assessments and next-generation sequencing, leading to improved clinical results. Other malignancies including head and neck cancer are now being treated by using precision medicine in addition to non-small cell lung cancer. The integration of AI and machine learning in tumour characterization offers promising avenues for advancing the use of precision medicine, despite obstacles such as treatment resistance.

Precision medicine in cancer treatment will help to identify the target specific molecular abnormalities that will further can be analysed for the treatment [31]. Some of the most important applications of precision medicine are:

1. Tumor Profiling:
Tumor profiling will help for the identification of mutations, gene fusions and others and this helps to take correct treatment decisions [32]. Some researchers have worked on the application of the precision medicine on the patients suffering with non-small cell lung cancer (NSCLC) caused because of mutations in EGFR gene can be given treatment by using EGFR tyrosine kinase inhibitors (TKIs) [33]. Overexpression of HER2 proteins will lead to breast cancer and targeted therapies like trastuzumab will help the patient.

2. Targeted therapies:
Targeted therapies at molecular levels will be more effective and less toxic in comparison to the existing therapies like chemotherapy where the healthy cells will also be damaged in addition to cancer cells. Immunotherapy is a kind of targeted therapy which can be used in precision medicine to harness the patient immune system to fight cancer [34]. Ex: Checkpoint inhibitors can be used in some cases to minimise the cancer cells attack.

3. Liquid Biopsies:
Circulating tumor DNA (ctDNA) can be identified by using liquid biopsy will help to analyse the treatment response, early diagnosis and mutations that occurs in the tumor [35]. Hence, based on the final results, personalised vaccine can be recommended. Some of the researchers are working on the development of personalised medicine to melanoma.
Discovery of the Philadelphia chromosome has paved way to treat chronic myeloid leukemia (CML) with the help of imatinib as a targeted therapy and enhance the survival rates of the patients. BRCA1 and BRCA2 gene mutations led to the development of the PARP inhibitors to treat both breast cancer as well as ovarian cancer patients.

DIABETES
Diabetes treatment strategies have become more unique by using this method, which adapts treatment

based on patient features such as genetic markers, environmental factors, behavioural traits, and demographic data [36,37]. This method considers patient-specific aspects such as habits and socioeconomic conditions in addition to scientific data on genotype, phenotype, and biomarkers to choose appropriate therapies [37]. Advances in understanding of genetics, Pathophysiology, and insulin administration have been made as individualized approaches in the treatment of type 1 diabetes. These methods include prognosis, prevention, treatment, and diagnosis. Integration of genome profiling with the in vitro human cell models such as human pluripotent stem cells, researchers can develop individual patient based diabetic-specific cells that can cure diabetes. This approach enables in developing highly personalized therapeutic strategies for diabetes.
Some of the applications of precision medicine in diagnosing and treating the diabetes patients are:

1. Diabetes subtyping: Many researchers have identified various subgroups based on the genetic makeup of the individual, metabolic functioning and clinical characteristics. The response of the patient will vary from one person to other and there will be difference in the complications. Precision medicine plays a crucial role in providing the tailored treatment based on the disease subgroups. Because some patients' immune respond to metformin while some responds to sulfonylureas or other medications which are GLP-1 receptors agonists.
2. Precision medicine have a crucial role in diagnosis of monogenic diabetes a rare condition which is caused because of the gene mutations. In this condition the patient will not respond to the medication and specific therapies needs to be recommended.
3. Precision medicine helps for the early intervention by suggesting the lifestyle modifications to prevent the disease or to delay the disease. Individuals with genetic risk score are suggested lifestyle intervention such as weight loss, diet modifications (low-carbohydrate diet) and physical activity.

Some researchers have reported that *TCF7L2* gene variations results in the risk of developing type2 diabetes as an early preventive measure.

Precision Medicine in Early Detection

Precision medicine aids in the early detection of diseases because it predicts health outcomes and risks by combining clinical, environmental, and genetic data [38, 37]. The focus on Family Health History as an essential resource that helps in early identification of individuals who may be susceptible to various medical disorders is an important component of precision medicine [40,41]. When it comes to respiratory diseases, advanced methods like mass spectrometry-based proteomics are required for early diagnosis because early symptoms are frequently nonspecific and can lead to a delayed clinical diagnosis [42].

Table 3: Precision Medicine in Early Detection

Method	Application	References
Genetic Analysis	Predict cancer, heart disease, Alzheimer's; BRCA mutations	[43]
Biomarker Detection	Liquid biopsy for tumor DNA	[44]
Imaging Technologies	Photoacoustic imaging for early tumor detection	[45]
Family History Screening	Assess inherited disease risks	[40], [41]
Predictive AI Models	Targeted screening (e.g., PSA + genetic markers for prostate cancer)	[46]

Disease diagnosis and treatment by using precision medicine constitutes several key assessments (Table 3):

1. Genetic analysis:

Precision medicine among High-risk individuals with higher genetic predisposition for various diseases like cancer, heart disease, Alzheimer's disease etc. will help for early detection and can be suggested for lifestyle modification as a preventive measure. For example, women diagnosed BRCA1 and BRCA2 mutations are highly recommended for frequent screening because there is a chance of prediction of breast and ovarian cancers [43].

2. Biomarker analysis:

Molecular markers or biomarkers are very essential in detecting the disease prior to the appearance of symptoms. One of the most common examples is liquid biopsies will detect the tumour DNA in blood which can be used as a preventive measure for detecting the cancer or its recurrence [44].

3. Imaging techniques:
Molecular imaging techniques and functional imaging techniques are very sensitive and helps for the identification of changes across various organs or tissues for early disease diagnosis [45]. One of the most common examples is the usage of photoacoustic-ultrasonic imaging helps for the identification of early tumours.

4. Family history:
Family history plays a crucial role in the identification of various diseases which will be inherited. This will help to understand the genetic makeup for the personalized screening recommendations.

5. Predictive analysis:
Predictive analysis will help for the targeted screening of high-risk individuals by using various machine learning algorithms by taking into account of various factors such as genetic data, health records, lifestyle information etc. Some of the studies have provided the evidence that the prostate-specific antigen (PSA) screening along with the genetic factor analysis aided for the early detection of the prostate cancer in some men [46]. Some other studies also provided the evidence that colonoscopy screening along with family history, genetic markers helped in the diagnosis of colorectal cancer and treatments.
Hence, it is clear that the framework of various technological advancements such as proteomics, genomics, imaging, biomarkers etc. will provide sensitive and accurate results in the precision medicine.

V. CHALLENGES

This method faces several challenges that need to be addressed for its effective implementation. Challenges include ethical concerns related to values, privacy, and justice [47], technical difficulties and informatics challenges in single-cell sequencing technology, the complex genetic landscape of haematological malignancies limits precise diagnosis and treatment decisions [47,48]. Broader structural factors affecting equitable access to benefits, the underrepresentation of some populations in precision medicine cohorts, and the considerable histopathologic and molecular heterogeneity in diseases like bladder cancer, indicates a deeper understanding to improve classification and treatment strategies [48]. In order to fully utilize precision medicine potential in providing individualized and effective healthcare interventions, it is essential to address these challenges (Figure 3).

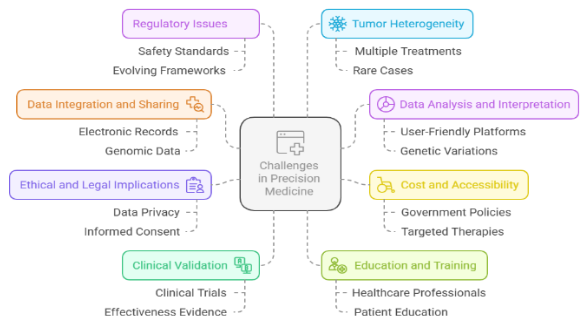

Figure 3. Challenges in Precision Medicine

Table 4. Challenges in Implementing Precision Medicine

Challenge	Description	References
Data Integration	Difficulty combining genomics, imaging, EHR data	[49]
Cost and Accessibility	High sequencing and therapy costs limiting equitable access	[50], [51]
Ethical and Legal Concerns	Data privacy, genetic discrimination	[52]
Clinical Validation	Need for trials to prove efficacy	[53]
Education & Training	Healthcare providers need genomic data interpretation training	[54]
Regulatory Frameworks	Need for clear policies due to complex technologies	[55]
Tumor Heterogeneity	Variability in mutations requiring multi-target therapies	[48]

Some of significant challenges that needs to be addressed for effective implementation of the precision medicine are (Table 4):

1. Data integration and sharing:
As in healthcare there exists various kinds of the data such as electronic records, genomic data, imaging data etc. integrating all these data is very complex. Hence making data standardizations along with certain standard data sharing guidelines will help in providing a comprehensive health assessment to the patient for quick recovery [49].

2. Data Analysis and Interpretation:
The data generated will be highly complex and needs a user-friendly platforms and algorithms which will help in analysing data to extract meaningful insights. But still there is a limitation because some of the tools or algorithms will not clearly identify the genetic variations and biomarkers, extensive research is recommended for effective implementation [50].

3. Cost and Accessibility:
Huge costs associated with genomic sequencing, imagining techniques and the targeted therapies will limit the accessibility of personalised medicine for some patients in underserved patients [50,51]. This can be addressed by effective integration of personalised medicine with some of the government policies.

4. Ethical and Legal Implications:
Protecting the data privacy and taking informed consent will prevent the genetic discriminations and helps in ensuring the equity of benefits of precision medicine among the populations [52].

5. Clinical Validation:
All the personalised medicine approaches need to be validated with proper clinical evidence to understand the effectiveness of the approach [53]. Hence clinical trials need to be incorporated before starting with personalised approach for effective justification about the process. This not only builds trust among patients but also validates the approach.

6. Education and Training:
The healthcare professionals need to be trained in using various tools for understanding the genomic information and make decision about the treatment [54]. Besides, it is also very important to educate the patients about the benefits and limitations of the precision medicine.

7. Regulatory Issues:
Precision medicine is continuously evolving and complex which integrates various tools and algorithms [55]. Hence a clear regulatory framework is needed to ensure the safety of the patient.

8. Tumour Heterogeneity
Different mutations among different patients will lead to different cancer in the same patient itself (some rare cases). In this situation, more than one treatment is needed for treating the patient.
These are some of the limitations which needs to be addressed by a concerted effort from researchers, clinicians, policymakers and patients.

VI. CONCLUSION

By integrating genetic, environmental, and clinical data, precision medicine aims to provide individualized treatments with the goal of identifying health risks and outcomes. By combining a range of data sources and advanced technologies, it facilitates the early disease detection, which is effective in customizing treatment plans. Artificial intelligence (AI) plays a pivotal role in advancing personalized medicine by improving patient outcomes, diagnosing diseases and facilitating individualized treatment plans. A more comprehensive approach that incorporates predictive and data-informed methods has replaced personalized treatment solely based on genetic data, resulted in improved patient outcomes. Combining AI with personalized medicine to treat diseases like diabetes and cancer showed promising results, with the possibility of AI to improve health outcomes. By individualizing treatment plans based on each patient's own genetic and molecular profile, precision medicine is transforming the healthcare industry and enhancing the effectiveness of medical interventions.
In conclusion, the integration of precision medicine and advanced imaging technologies, combined with a more comprehensive data-driven approach, marks a significant turning point in healthcare. This strategy enhances our ability to diagnose and treat diseases

accurately, paving the way towards a future where personalized medicine becomes the norm. In order to understand the huge potential of the precision medicine it is very important to address the key challenges such as data integration, cost, ethical concern, data security and need more research on clinical validations. The above limitations can be overcome by effective collaboration between collaborations with various stakeholders, doing in depth research and providing equal benefits to all the patients. Technology advancements enhances the understanding of the disease at molecular level, making precision medicine as one of the promising technologies in healthcare to improve the lives of millions of people.

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