IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Precise And Personalized Medicine: A Comprehensive Review

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Abstract

Precise and personalized medicine (PPM) is an advanced healthcare approach that focuses on designing treatment strategies based on an individual' s genetic makeup, biomarkers, lifestyle, disease characteristics, and environmental influences. With the rapid growth of genomic sequencing, proteomics, metabolomics, artificial intelligence (AI), and digital health technologies, PPM has become a practicalclinical reality. This review provides a comprehensive overview of the concepts, technological foundations, clinical applications, advantages, limitations, and future potential of precise and personalized medicine. Emphasis is placed on pharmacogenomics, biomarker-guided therapies, targeted drug delivery, machinelearning based prediction tools, and disease-specific implementation of personalized strategies. The review also highlights current research advancements, ethical considerations, and global challenges in adapting PPM into mainstream healthcare. Overall, precise and personalized medicine represents a transformative shift from generalized therapy to individualized care.

.**Keywords** Precision medicine, personalized therapy, pharmacogenomics, biomarkers, targeted therapy, genomics, AI in healthcare.

1. Introduction

The traditional model of healthcare relies on generalized treatment strategies where one drug or one dosage is prescribed for most patients. However, clinical evidence shows that individuals respond differently to the same therapy due to variations in genetics, metabolism, physiology, lifestyle, disease severity, and environmental exposure. These limitations have guided the evolution of a new approach known as precise and personalized medicine (PPM).PPM aims to deliver the right drug, at the right dose, to the right patient, at the right time by using genetic information, biomarkers, real-time diagnostics, and computational tools. This approach allows clinicians to predict disease risk, improve diagnosis accuracy, and select the most effective therapy while minimizing adverse effects.The increasing availability of high-throughput sequencing technologies, such as next-generation sequencing (NGS), and advanced computational methods has expanded the clinical application of precision medicine. Government-funded

initiatives like the U.S. Precision Medicine

Initiative (PMI) and European Personalized Medicine (EUPM) have also accelerated research, infrastructure development, and clinical adoption.This review discusses the conceptual framework, technological pillars, applications, current challenges, and future perspectives of precise and personalized medicine. It highlights how genomics, proteomics, metabolomics, bioinformatics, and artificial intelligence contribute to personalized healthcare.

Concept of Precision and Personalized MedicineAlthough the terms precision medicine and personalized medicine are often used together, they describe slightly different but interconnected approaches in modern healthcare. Both approaches aim to improve the accuracy and effectiveness of treatment, but they differ in scope, focus, and the type of patient data used.1. Treatment of inflammation, fever, pain, and digestive disorders

Precision Medicine

Precision medicine is a scientific and data-driven approach that classifies patients into subgroups based on molecular characteristics such as genetics, proteins, metabolites, disease biomarkers, and drug-response patterns.It does not create a treatment plan for each individual separately but identifies specific biological groups for which targeted therapies can be designed.

Key Features of Precision Medicine

Uses genomic variations, biomarkers, and molecular signatures .Helps in predicting disease progression Enables selection of targeted therapies Reduces trial-and-error prescribing

Examples

- HER2-positive breast cancer patients benefit from trastuzumabantimicrobial, and analgesic activity.
- EGFR mutation-positive lung cancer patients respond better to gefitinib
- BCR-ABL+ leukemia patients receive imatinib hey help promote regular bowel

movements and assist in blood sugar control.Leaves are also useful in jaundice, asthma, and in clearing mucus from the bronchial tubes [6].

Personalized Medicine

Personalized medicine is more patient-centered and integrates genomic data + lifestyle + environmental exposures + clinical history + personal preferences.This approach sees every patient as a unique case and tries to tailor prevention, diagnosis, and treatment accordingly.

Key Features of Personalized Medicine

Focus on the individual instead of subgroups

Treatment considers diet, habits, occupation, environment, stress, and genetics

Helps in optimizing dosing, minimizing side effects, and improving patient satisfaction

Examples

1. Adjusting insulin therapy based on diet, activity level, and glucose-monitoring data

2. Using wearable devices to personalize hypertension treatment

3. Designing diet plans based on genetic predisposition (nutrigenomics) Key Technologies Enabling Precise and

Personalized Medicine

Precise and personalized medicine (PPM) depends heavily on advanced technologies that allow physicians to understand the biological structure of diseases at a deeper level. These help detect genetic variations, technologies protein patterns, metabolic changes, lifestyle influences, and environmental factors.

The most important technologies contributing to PPM include genomics, transcriptomics ,proteomics, metabolomics, biomarker discovery, pharmacogenomics, bioinformatics, artificial

intelligence, and digital health tools. Genomic Genomics is the central pillar of precision

medicine. It involves the study of the entire

human genome and helps identify genetic

mutations responsible for disease risk, drug

response, and treatment resistance.

Key aspects:

• Detects single-nucleotide polymorphisms (SNPs)

• Identifies disease-causing mutations

• Supports selection of targeted therapy

• Enables whole genome sequencing (WGS) & whole exome sequencing (WES)

Applications:

BRCA1/BRCA2 mutation testing → breast cancer risk predictionKRAS mutation → colon cancer treatment selectionHLA-B screening → prevents hypersensitivity to abacavir

Transcriptomics

Transcriptomics studies RNA molecules to understand gene expression patterns.This helps determine which genes are active or inactive during disease progression.

Importance:

• Useful in cancer classification

• Helps in predicting tumor aggressiveness

• Supports development of RNA-based

therapies (e.g., mRNA vaccines)

Proteomics

Proteomics involves the study of proteins, their interactions, structures, and biological functions. Detects disease-specific protein biomarkersHelps in monitoring treatment response Identifies protein targets for drug development

Examples:

HER2 overexpression → breast cancer therapy

PSA levels → prostate cancer screening

Metabolomics

Metabolomics evaluates small molecules

(metabolites) present in blood, urine, or tissues.

Uses:

Detects metabolic disorders Supports personalized diet planningHelps understand drug metabolism

Example:

Metformin response influenced by AMPK pathway metabolites

Biomarker-Based Technologies

Biomarkers are measurable indicators of biological conditions.

Types of biomarkers used in PPM:

Genetic biomarkers (mutations)Protein biomarkers (PSA, troponin)Metabolic biomarkersImaging biomarkers (PET, CT)

Applications:

- Diagnosis
- Prognosis
- Monitoring therapy response
- Predicting drug effectiveness
- Pharmacogenomics Pharmacogenomics studies how genetic variations affect drug metabolism and drug response.

Key importance:

Avoids adverse drug reactionsHelps select correct drug & doseImproves treatment success

Examples:

• CYP2C19 variants affect clopidogrel response

• CYP2D6 variants affect antidepressant metabolism

• TPMT testing before mercaptopurine therapy

Bioinformatics

Bioinformatics integrates biological data (genomic, proteomic, metabolomic) using computational tools.

Uses:

• Analyzing large genomic datasets

• Predicting drug targets

• Disease prediction models

Artificial Intelligence (AI) & Machine

LearningAI plays a major role in interpreting complex biological data.

Applications:

- Predicting disease risk (AI-based risk calculators)
- Image-based diagnosis (radiomics)
- Personalized drug recommendations
- Virtual clinical trial simulationsj

WORKFLOW OF PERSONALIZED MEDICINE

The workflow of personalized medicine involves a systematic process, beginning from patient assessment to personalized treatment selection. Each step uses advanced technologies, clinical data, and molecular analysis to create an individualized therapeutic plan [2,4].

1. Patient Assessment and Clinical Evaluation

The first step is a detailed clinical evaluation of the patient, including:medical history,lifestyle factors, family history,environmental exposure,previous treatment outcomes.This baseline information helps identify risk factors and provides context for further molecular testing

[3].

2. Collection of Biological Samples

Biological samples such as blood, saliva, tumor tissue, or buccal swabs are collected for molecular analysis.These samples contain DNA, RNA, proteins, and metabolites needed for genetic profiling and biomarker testing [1].

3. **Molecular and Genomic Testing**

The collected samples undergo tests such as: Whole Genome Sequencing (WGS) Whole Exome Sequencing (WES)Targeted gene panels Biomarker analysis These tests help detect gene mutations, protein expression patterns, and molecular abnormalities that are associated with disease progression or drug response [5,7].

4 Data Analysis and Interpretation

Advanced bioinformatics and AI tools analyze large-scale genomic and clinical datasets to identify:disease pathways,drug–gene interactions,mutation-driven drug resistance,therapeutic targets [8].AI-based analytics are particularly useful in interpreting complex cancer genomics and predicting therapy response in Indian patients [9].

5. Development of Personalized Treatment Plan

Based on molecular analysis, a customized treatment plan is developed. This includes:targeted therapy selection,immunotherapy options,dosage optimization,drug delivery modifications,lifestyle recommendations.

6 .Clinical Decision Support System (CDSS)

Integration CDSS tools help doctors interpret genomic reports and offer suggestions on:optimal drug choices,dose adjustments,potential adverse drug reactions,drug–drug interactions [3].They bridge the gap between genomic testing and actual clinical practice.

7. Monitoring and Follow-up

After treatment initiation, patients are monitored through:biomarker tracking,therapeutic drug monitoring,imaging tests,symptom assessment. Continuous monitoring helps evaluate treatment success and identify the need for modifications [10].

8 .Feedback and Data Storage for Future Use

Patient data is stored securely for future analysis and to contribute to large-scale precision medicine databases.These databases support research, population studies, and improved clinical protocols [4].

APPLICATIONS OF PRECISE & PERSONALIZED MEDICINE

Personalized medicine has transformed the management of several diseases by enabling targeted, effective, and safer therapy. Its application is most prominent in oncology, cardiology, neurology, infectious diseases, and pharmacotherapy optimization [11].

1. Oncology (Cancer Treatment)

Cancer is the leading field where precision medicine has shown revolutionary results. Tumors are genetically diverse, and targeted therapies are chosen based on specific molecular alterations.Genomic tumor profiling helps identify these mutations and guide therapy selection. Indian cancer centers now routinely use NextGeneration Sequencing (NGS) to design personalized treatment plans [13].

2. Cardiovascular Disorders

Personalized medicine predicts drug response for commonly used cardiac drugs like clopidogrel,

statins, and beta-blockers based on gene variations.
For instance:
• CYP2C19 polymorphisms affect clopidogrel activation.
• SLCO1B1 gene variants increase statininduced myopathy risk [14]

3.Diabetes and Metabolic Diseases

Type-2 diabetes patients respond differently to metformin, sulfonylureas, and insulin because of genetic variability.Precision medicine helps:identify insulin resistance pathways,predict drug response,tailor diet and lifestyle plans based on metabolic profiles [15].India, being the "diabetes capital", benefits significantly from metabolomics-based precision therapy [16].

4.Neurological Disorders

Genomic profiling assists in understanding diseases such as Alzheimer's, Parkinson's, epilepsy, and autism.Genetic testing identifies pharmacoresistant epilepsy mutations, guiding anti-epileptic selection [17].

5.Infectious Diseases

During COVID-19, host-genomic studies helped explain why some individuals developed severe infection while others remained mild [18].PCRbased and genomic sequencing met personalize antibiotic selection in tuberculosis, reducing drug resistance.

LIMITATIONS & CHALLENGES OF PERSONALIZED MEDICINE

Despite its advantages, personalized medicine faces several challenges, particularly in developing countries like India.

1.High Cost & Limited Accessibility

Genomic sequencing, AI-based analysis, and targeted therapies remain expensive.High treatment cost limits access, especially in rural and semi-urban India [19].

2.Lack of Skilled Workforce

India faces a shortage of trained professionals in genomics, molecular biology, and bioinformatics.This slows down the adoption of precision diagnostics [20].

3. Ethical and Privacy Concerns

Large genomic datasets raise concerns regarding patient privacy,data misuse,insurance discrimination,consent issues [21].Proper regulatory guidelines are needed for genomic data protection.

4. Infrastructure Limitations

Most Indian hospitals lack advanced:NGS machines,bioinformatics software,molecular pathology labs.This creates regional inequalities in precision therapy availability [22].

5. Limited Awareness Among Patients & Clinicians

Many patients are unaware of genomic testing benefits, while clinicians face difficulty interpreting complex genetic reports [23].

FUTURE PROSPECTS & EMERGING TRENDS

Personalized medicine is rapidly evolving due to technological advances.AI and Big Data Expansion AI models will soon predict:disease onset,drug response,treatment failure,relapse probability [24].
These tools will automate genomic interpretation for faster and cheaper analysis.

Gene Editing (CRISPR Technology)

CRISPR-based therapies have shown promise in correcting genetic defects responsible for blood disorders, cancers, and rare diseases [25].

Personalized Vaccines

Cancer vaccines created from the patient's own tumor neoantigens are under development and expected to become a major therapy platform [26].

Integration with Wearable Technologies

Wearable sensors monitor glucose, ECG, oxygen saturation, stress markers, and sleep patterns.These real-time data streams will personalize treatment adjustments automatically [27].
India's ProspectsInitiatives like "Genome India Project" aim to map genetic variations across Indian populations.This dataset will transform pharmacogenomics and disease-risk prediction for Indian patients [28]

CONCLUSION

Precise and personalized medicine represents a transformative advancement in modern healthcare. By integrating genomics, biomarkers, AI-driven analytics, and clinical decision-support systems, it enables the delivery of individualized therapies that are more effective and safer than conventional approaches. Personalized medicine shifts healthcare from a traditional trial-and-error model to a predictive, preventive, and patientcentered system.Its applications are expanding across oncology, cardiology, neurology, infectious diseases, and metabolic disorders. The integration of pharmacogenomics helps reduce drug toxicity and optimizes therapeutic outcomes. Despite rapid growth, several challenges remain in terms of affordability, skilled workforce, ethical concerns, and infrastructure gaps, particularly in developing nations like India.Future trends—including AI integration, CRISPR-based therapeutics, personalized vaccines, and the Genome India Project—promise to make precision medicine more accessible and clinically useful. With improved awareness, policy strengthening, and advancement in molecular technologies, precise and personalized medicine is expected to become an essential component of global healthcare in the coming decades.

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