Review Article

Integrated precision medicine and artificial intelligence in healthcare

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Abstract

The current healthcare landscape is undergoing a transformative revolution driven by the synergistic integration of precision medicine, artificial intelligence and robotics. This convergence is fundamentally shifting the paradigm from standardized treatments to highly individualized patient care, promising unprecedented improvements in diagnostic accuracy, therapeutic efficacy, and operational efficiency. Artificial Intelligence enables the rapid analysis of massive, multimodal datasets, including genomics, proteomics, electronic health records and real-time physiological data from wearable sensors. Robot-assisted surgery offers surgeons enhanced competency, tremor filtration, and high-definition 3D visualization, leading to minimally invasive procedures and fewer complications and faster patient recovery. This review highlights the current state, transformative impact, and future trajectory of combining precision medicine with AI and robotics, emphasizing its potential to deliver safer, more efficient, and truly personalized healthcare for all.

Keywords: Artificial intelligence, biomarkers, biosensors, epigenomics, precision medicine, telemedicine.

Introduction

The field of medical treatment has undergone a profound paradigm shift in recent decades, driven by revolutionary advancements in diagnostic and therapeutic technologies. This evolution has fundamentally altered conventional medical practice, transitioning the focus from a standardized, "one-size-fits-all" model to a highly personalized approach to patient care. The continuous integration of digital technology across all levels of the healthcare advancement is the core catalyst for this transformation. This shift has enabled healthcare to advance at the individual patient level, supporting the realization of precision medicine. Artificial intelligence (AI) serves as a critical engine for this modern approach. AI systems are capable of analysing vast and diverse sets of medical data, including, Medical Imaging: X-rays, magnetic resonance imaging (MRI) scans, computer tomography (CT) scans, and ultrasounds; bio-signals: electrocardiogram (ECG), electroencephalogram (EEG), and electromyography (EMG); Clinical Data: Electronic health records (EHRs), vital signs, patient history, and laboratory results. This sophisticated data analysis empowers medical professionals to diagnose illnesses with greater efficiency and accuracy. Crucially, the automation of complex data processing reduces the workload on medical practitioners, allowing them to redirect their expertise and time towards direct patient engagement and care. Ultimately, AI-driven

data analysis is foundational to delivering precision medicine, enabling the prediction of outcomes, and accurately modelling the progression of diseases.[1] This review aids in decision-making and provides precise predictive outcomes, helping healthcare professionals make better-informed choices regarding patient care. It is useful in the Emergency Department for physicians to focus on difficult cases. It is also useful in rural medical settings where physicians are less available.

Precision medicine: The paradigm shift

"Precision medicine", previously referred to as personalised medicine, represents a revolutionary shift from traditional approaches toward truly individualized therapy. The rationale behind precision medicine is that, since no two individuals are the same, their healthcare should be tailored accordingly. Instead of treating diseases generically, precision medicine guides treatment decisions using an individual's genomic, environmental, and lifestyle information.[2] Thus, the treatment is no longer guided by the traditional model in which the physician is considered the sole authority, being evolved into a structured, integrated, and collaborative model (Figure 1). The goal of precision medicine is to provide a more precise approach for the prevention, diagnosis and treatment of disease.

The tools employed in precision medicine include AI, various *omics* technologies, environmental factors, and social determinants. Information derived from these sources is then integrated with preventive and population-level medical approaches. However, precision medicine primarily relies on data from EHRs, which incorporate clinical findings, outputs from biomarkers, laboratory test results, and radiological reports.[3] Analysing this vast amount of information requires machine-learning techniques that use complex decision pathways and algorithms to guide disease management.[4] Thus, the traditional "one-size-fits-all" approach is giving way to precision-based treatment strategies. Environmental, social, and behavioural factors also hold great significance in precision medicine, especially in the management of complex diseases, where treatment success depends heavily on addressing these determinants. Ultimately,

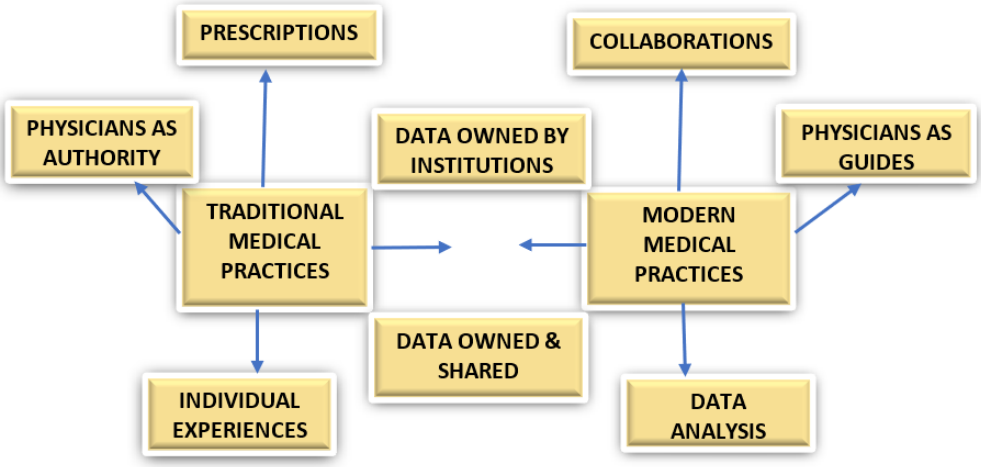

Figure 1: Comparison between traditional healthcare practices and modern healthcare practices

integrating precision approaches with preventive and public health strategies creates a comprehensive framework that is poised to transform the practice of medicine in the future.

The cosmic to cellular journey of precision medicine

The Cosmic-to-Cellular (C–C) journey, in the context of precision medicine and holistic health, is an emerging philosophical and interdisciplinary perspective that explores how large-scale natural phenomena are related to microscopic biological processes. This viewpoint does not assert direct causation but considers how environmental factors such as light, temperature, and naturally occurring electromagnetic (EM) fields may influence human physiology through established biophysical mechanisms. It is perceived as an idea that links the "cosmic" environment directly to the "cellular" health.[5] While the suggested long-term interactions between the cosmic environment and cellular health remains hypothetical, research does show that EM fields can influence certain cellular functions under specific conditions *in vitro* or in controlled environments. For example, EM fields have been studied for their potential effects on cell proliferation, apoptosis, and tissue repair,[6] though these findings are context-dependent and not yet definitive for clinical practice. The C-C journey to health may be regarded as an aspiration to create a medical model that uses cellular-level precision medicine to diagnose and treat diseases in a holistic way that includes a person's genetics, environment, and lifestyle.

The “Cosmic” aspect aims to place cellular biology within a broader physical and universal context, drawing conceptual connections between physics, electromagnetism, and life processes. The universe is governed by fundamental physical laws, including Einstein’s mass energy equivalence ($E = mc^2$), which expresses the inherent relationship between matter and energy. They underscore that the energy transformations driving cellular processes operate within the same universal physical framework that governs all matter and energy. Since cellular processes and metabolic activities are energy-dependent, diseases can sometimes be detected or quantified through alterations in molecular energetics. Presently, using quantum-based strategies to correct diseases remain a theoretical idea rather than an established approach. Nevertheless, quantum-level insights continue to support the development of advanced diagnostic technologies and future therapeutic innovations.[7]

Application of Quantum theory and mechanics in medicine

Quantum medicine refers to emerging research that applies principles of quantum theory and quantum mechanics to better understand biological processes at the molecular and subatomic level; areas where classical physics offers limited explanatory power. Quantum theory describes the behaviour of matter and energy at the atomic and subatomic scales. Instead of describing particles with fixed paths, it uses wave functions, quantized energy levels, and probabilities to predict where particles might be and how they behave. Although the biological processes themselves are governed by large-scale quantum effects, most cellular functions are described by classical biochemical principles. However, its direct application to medicine occurs mainly through technologies derived from quantum principles.[7] For example, quantum physics enables medical imaging techniques such as MRI which relies on nuclear spin resonance, laser-based surgical tools, and semiconductor devices used in diagnostic equipment. Quantum chemistry also supports our

understanding of molecular interactions relevant to DNA damage, enzyme function, and protein structure. For example, at the molecular level, quantum chemistry helps explain phenomena such as electron transfer in cellular respiration, the photochemical reactions in DNA *viz.,* UV-induced mutagenesis, and the energetics governing protein folding and molecular binding interactions. [7,8]

Emerging fields such as quantum biology explore whether quantum effects like tunnelling and coherence play roles in specific biological events like enzyme catalysis or photosynthesis. Quantum tunnelling is particularly important in biology for reactions involving the transfer of light particles, primarily electrons and hydrogen (as protons, hydrogen atoms, or hydride ions).[8,9] It is a process where a particle, such as a proton or electron, can pass through an energy barrier even if it does not have enough classical energy to overcome it. This is being investigated in areas like enzyme catalysis and spontaneous mutations in DNA. A specific example is alcohol dehydrogenase which shows hydrogen tunnelling during its catalysis of alcohol oxidation.[10] Quantum coherence refers to the existence of a superposition of quantum states or a constant, phase-locked wave function that can lead to interference effects. This is primarily studied for its potential role in efficient energy transfer during photosynthesis. [8,11] While quantum biology has increasing empirical support in some biological processes (e.g., photosynthesis), proposals that quantum theory provides a direct explanation for mental states or the hard problem of consciousness are part of ongoing, often controversial, philosophical and theoretical debates, and are not considered established scientific facts.[12] In medicine, quantum-based technologies continue to advance diagnostics and treatment. Techniques derived from quantum physics have improved early disease detection, increased the precision of imaging systems, and contributed to research in neurological disorders. [7,13] These advances stem from quantum-enabled instrumentation and computational modelling, rather than from direct manipulation of quantum states in living systems.

Genomics versus epigenomics

Genotype-guided treatment is one of the most extensively researched applications of precision medicine in healthcare today, helping clinicians determine the appropriate dosage based on genotype information in the 23 pairs of chromosomes.[14] The human genome is composed of roughly 6 billion DNA base pairs that contain all the code needed to create a human being.

Personalized medicine customize treatment based on individual patient data, such as genomic and biochemical information due to individual variations. Advances in technologies like DNA sequencing and proteomics have highlighted the need for this approach. Future challenges include enhancing the efficiency of patient characterization and developing effective personalized treatments, although universally effective drugs may still be sought; yet remain difficult to achieve. For patients with lung or breast cancer, genomic profiling of malignancies can inform customized treatment regimens. Incorporating precision medicine into healthcare can lead to more accurate diagnoses, enable the early identification of 'at-risk patients' before symptoms appear, and provide individualized treatment plans that balance effectiveness and safety.[15] Another application includes assessment of potential responses to new drugs, predicting disease prognosis. Epigenomic-guided treatment utilises the study of how environmental factors affect gene expression, without altering the underlying

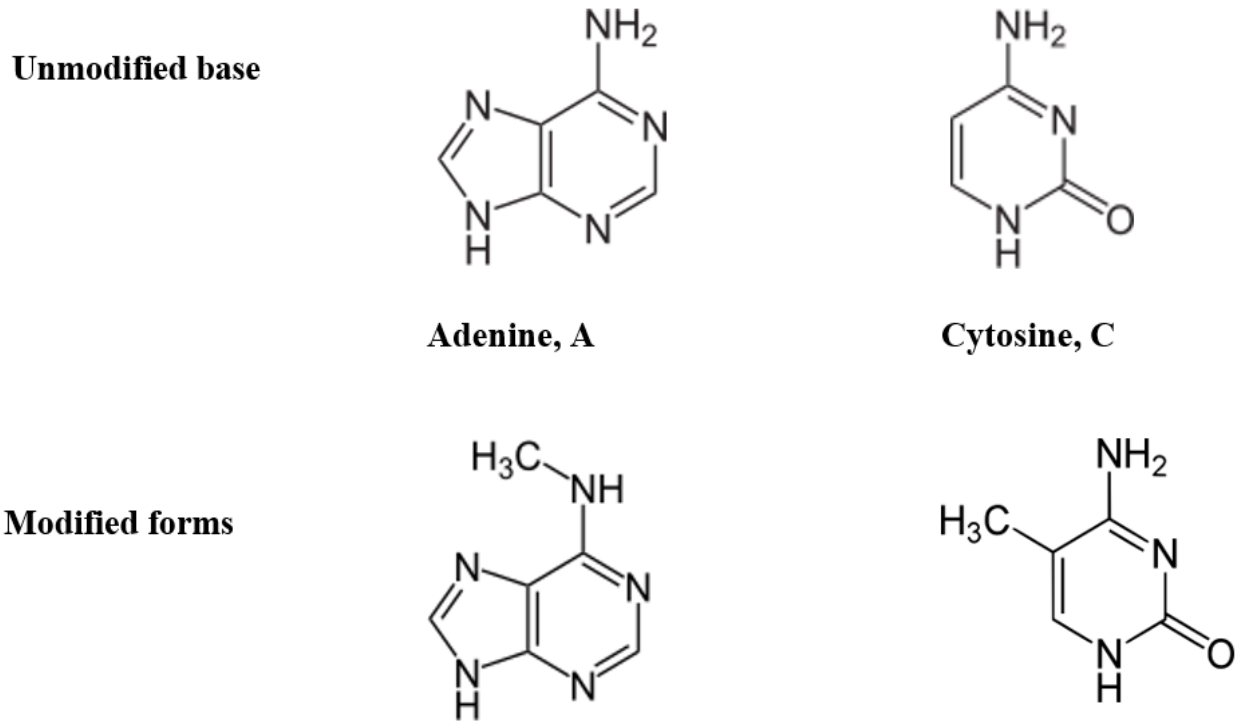

Figure 2: Unmodified and methylated forms of adenine and cytosine

DNA sequence, to develop targeted therapies. Epigenomics examines the non-coding regions and modifications therein that control gene expression without manipulating the DNA sequence itself. These include the following methods: DNA methylation, Histone modifications, and Lifestyle-based genetic modifications.[16]

DNA methylation

DNA methylation is a biological process by which methyl groups are added to the DNA molecule. It is a normal and vital epigenetic function in eukaryotic organisms that generally acts to switch off or repress gene function. Methylation can change the activity of a DNA segment without changing the sequence. When located in a gene promoter, DNA methylation typically acts to repress gene transcription. In mammals, DNA methylation is essential for normal development and is associated with a few key processes including genomic imprinting, X-chromosome inactivation, and repression of transposable elements. It also has significant impacts on aging and carcinogenesis.[17] The nucleobases on which natural, enzymatic DNA methylation takes place are adenine and cytosine (Figure 2). The modified bases are N6-methyladenine, 5-methylcytosine.

The abnormal DNA methylation landscape in cancer is characterized by a widespread loss of methylation, which can lead to chromosomal instability or oncogene activation. Meanwhile, site- specific increases in methylation may silence vital tumour suppressor genes. The goal of targeted DNA methylation therapy is to reverse these patterns, thereby restoring normal gene function and improving the effectiveness of other treatments. If genes responsible for maintaining healthy heart structure or keeping blood vessels flexible become hyper methylated, they get silenced. This can lead to maladaptive cardiac remodelling, fibrosis, and reduced contractility seen in heart failure. Conversely, following hypomethylation, a condition in which the methylation patterns

are lost, the genes that promote inflammation or cell proliferation may become overactive, hastening plaque buildup in atherosclerosis.[18] DNA methylation acts as a crucial intermediary, translating the impact of your environment and lifestyle (like diet, stress, and toxins) into specific changes in gene activity within the cells. These epigenetic alterations can either silence protective genes or activate harmful ones, directly influencing the development and progression of diseases like heart disease. As methylation is reversible, it presents a target for future diagnostic biomarkers and therapies.[19]

Histone modifications

The packaging of DNA begins with the fundamental double-stranded DNA helix, which has a width of 2 nanometres (nm).[20] This DNA wraps around a cluster of histones (specifically a histone octamer) to form nucleosomes. Each nucleosome core involves the DNA coiling, approximately 1.65 times around the octamer, creating the initial level of chromatin organization. These chromatosomes pack together to generate the 30 nm chromatin fibre, representing a more condensed form of chromatin. The 30 nm fibre undergoes additional folding, organizing into 300 nm loop domains which provide another level of compaction. These loops organise genes within the nucleus. The 300 nm loops compress to 250 nm which are tightly coiled and folded into a dense chromatid structure. This final level of packaging produces the characteristic 1400 nm thick chromatid seen during cell division.[21]

Histones are essential, highly basic proteins that act as spools around which DNA wraps. Their functional significance is twofold: they provide the necessary compaction to fit the genome within the nucleus, and through chemical Post-Translational Modifications (PTMs) like acetylation and methylation, they actively regulate gene expression, a mechanism central to normal cellular function. Dysregulation of nucleosomes or their modifications is strongly implicated in several diseases, particularly cancer and various developmental disorders, as such errors disrupt the precise control over which genes are accessible and active. Histone modifications are covalent post-translational changes that occur on the histone proteins responsible for packaging DNA into chromatin. These modifications are a key component of epigenetic regulation. They influence gene activity by changing the physical properties of chromatin, either making it more accessible for transcription or more condensed or repressed. [21]

Lifestyle-based genetic modification

Epigenetic lifestyle modifications influence gene expression in individuals through external factors by switching ‘on or off’ the genes involved. Some of the external factors include diet and nutrition, physical activity, psychological stress and pollutants.[22]

Diet and Nutrition: Specific nutrients (like folate, B vitamins, or polyphenols) can act as co- factors for the enzymes that perform DNA methylation or histone modification. So balanced healthy diet is important for normal gene regulation.

Physical Activity: Exercise can induce epigenetic changes that are beneficial for metabolism and inflammation.

Psychological Stress: Stress, especially chronic or early-life stress (adverse childhood experiences), has been shown to significantly impact epigenetic effects.

Toxins and Pollutants: Exposure to tobacco smoke, heavy metals such as arsenic, and air pollution can alter epigenetic patterns. For example, prolonged exposure to black carbon and SO_4 particles is found to be associated with hypomethylation of two types of repetitive elements [23] Similarly, exposure to

certain drugs or industrial chemicals can disturb the gene function.

The genetic orchestra and cellular communication

The concepts of the "genetic orchestra" and cellular communication are central to precision medicine, moving it beyond traditional healthcare practices. This framework recognizes that thousands of genes, proteins and signalling pathways work together in a complex system of cellular function. The piezoelectric properties of DNA's crystal structure enable it to convert mechanical pressure into electrical signals, creating a communication network that extends from the nucleus to surrounding cells.[24] Thirty-seven trillion cells communicating through electrical signals highlights the incredible complexity of our biological systems. In this analogy, disease can be seen as a discord note in the biological orchestra, and precision medicine aims to restore harmony by understanding the underlying molecular miscommunication. While the genetic orchestra dictates what a cell can do, cellular communication governs how cells coordinate this activity in real-time. Cells communicate over various distances using signal molecules (ligands) like hormones, neurotransmitters, or growth factors that bind to specific receptors on other cells, initiating a signal transduction cascade.[25]

Biomarkers in cancer

AI can detect cancer at molecular level. Cancer biomarkers are biological molecules, such as genes, proteins, or other substances, that are found in tissues, blood, or other body fluids, that provide essential diagnostic and prognostic information about a person's cancer, providing crucial information about the status and progression of malignancy. These markers are essential to the practice of precision medicine because they reveal a tumour's unique biological characteristics and molecular drivers, which vary significantly between patients, even those with the same cancer type. It replaces the traditional treatment with high accuracy for early detection and intervention. Treatment strategies relying on biomarker data may help to effectively combat cancer associated conditions such as uncontrolled proliferation, genomic instability, immune evasion, and the development of metastasis to adjacent organs. OncoMark is an AI-based computational tool developed by Indian researchers to decode cancer at the molecular level.[26] It can guide clinicians toward highly personalized and targeted therapies that directly inhibit cancer specific molecular pathways.

Biosensors

A biosensor typically consists of two main components: A bioreceptor (such as an enzyme, antibody, or DNA sequence) that specifically recognizes the target analyte and a transducer that converts this biorecognition event into a measurable mechanical, optical, or electrochemical signal. Early wearables primarily functioned as physical sensors, recording parameters such as heart rate, steps walked, and calories expended to monitor general performance and health. Over time, these devices evolved from tracking athletic activity, addressing broader healthcare needs, including diabetes management and remote monitoring for geriatric patients. More recently, wearable biosensors have been developed that incorporate biological recognition elements—such as enzymes, antibodies, cell receptors, and even cellular organelles—to detect a variety of biomarkers.[27] These advanced devices can measure analytes noninvasively through biofluids like sweat, saliva, or interstitial fluid. Wearable biosensors offer several advantages such as low energy consumption, high specificity, portability, affordability,

rapid response, and flexibility for comfortable long-term use. Non-invasive designs also enhance user-friendliness, reduce infection risk, and minimize the need for invasive procedures. Some of the fascinating devices include contact lens-based tear monitoring, an emerging non-invasive technology where a contact lens is designed to act as a biosensor to analyse the composition of the tear fluid,[28] colorimetric wearables that assess sweat as an alternative biomarker for measuring blood glucose levels and electronic nose sensors that analyse volatile organic compounds (VOC) in breath samples for non-invasive detection of neurological disorders.[29] Oncological biomarkers like proto-oncogenes and oncogenes have revolutionized cancer detection and treatment selection. Key advances include liquid biopsy approaches, such as blood-based assays that detect cancer-associated biomarkers including circulating tumour DNA (ctDNA)[30] and circulating tumour cells (CTCs). These technologies enable non-invasive monitoring of tumour evolution, treatment response, and minimal residual disease detection with sensitivity approaching 0.01% mutant allele frequency. Multi-gene assays (e.g., FoundationOne, Guardant360) identify actionable mutations in genes including EGFR, ALK, KRAS, BRAF, and HER2, directing targeted therapy selection.[31] Tumour Mutational Burden (TMB) serves as a predictive biomarker for immunotherapy response across multiple cancer types.

Quantum medicine explores the use of advanced biosensors to assess health and detect diseases.[27] These quantum-enhanced biosensors employ techniques such as brain imaging,[32] single-cell spectroscopy,[33] and non-invasive biochemical monitoring. Single-cell spectroscopy allows the analysis of molecular changes at the level of individual cells, supporting early disease detection and enabling more personalized treatment strategies. Similarly, quantum-based brain imaging techniques can help estimate neuronal activity and monitor neurotransmitter dynamics with high sensitivity. State-of-the-art imaging systems and advanced biosensors can identify subtle alterations in metabolic substrates associated with neurological conditions such as Alzheimer's disease, Parkinson's disease, and multiple sclerosis.[34] This facilitates earlier detection and can guide the selection of targeted therapeutic interventions. In addition, genetically encoded biosensors allow real-time observation of intracellular signalling pathways and neurotransmitter activity, significantly advancing research and clinical applications in neuroscience.[35]

AI-powered cardiac monitoring

Artificial intelligence (AI) enhances the interpretability and diagnostic utility of imaging modalities such as cardiac magnetic resonance imaging, echocardiography, computed tomography, and electrocardiography. It strengthens the performance of both screening and confirmatory tests and generates advanced insights through the integration of high-capacity computing and analytical frameworks. In doing so, AI enables systems to learn, adapt, and support clinical decision-making through augmented intelligence. Furthermore, AI facilitates the automation of several critical medical processes, including diagnosis, risk stratification, and clinical management, thereby reducing the workload of healthcare professionals and lowering the likelihood of diagnostic or procedural errors.[36]

AI-powered cardiac monitoring is an emerging technique in preventive cardiology, aligned with the principles of precision medicine, to continuously assess heart function. "CardioSense" is a medical AI company focused on combating preventable cardiovascular disease through a platform

that combines multimodal wearable technology with AI.[37] It is recognised as the first wearable to simultaneously capture three high-fidelity physiological signals that include:

1. ECG: Measures the heart's electrical activity (rhythm).
2. Photoplethysmogram (PPG): Measures changes in blood volume (pulse).
3. Seismocardiogram (SCG): Measures subtle vibrations on the chest wall caused by the heart's mechanical contraction and blood movement.

CardioSense provides comprehensive, non-invasive cardiac assessments from the hospital to the home, offering visibility into the heart's electrical activity, mechanical function, and hemodynamics. Basically, "CardioSense" is aiming to move beyond traditional rhythm monitoring by leveraging advanced sensor fusion (ECG+PPG+SCG) and AI to provide non-invasive, continuous hemodynamic and mechanical insights for proactive, precision cardiac care, particularly for conditions like heart failure. Other AI-based approaches are also being developed to predict and monitor various cardiac conditions.[37]

ECG monitoring - *Continuous heart rhythm analysis*

The purpose of this is to detect abnormalities in the heart's rhythm, known as arrhythmias, atrial fibrillation and ventricular tachycardia. Continuous monitoring is crucial for catching transient or asymptomatic events.

H-R variability - *Detecting stress, emotional states, and cardiac function*

This refers to Heart Rate Variability (HRV), specifically searching for any variation in time between consecutive R-peaks (the main spike in an ECG complex, representing ventricular depolarization). The time between two successive R-peaks is the R-R interval.[38] HRV reflects the net outcome of the effects between the sympathetic ("fight-or-flight") and parasympathetic ("rest-and-digest") autonomic nervous systems, that regulate heart rate. HRV is often associated with increased stress, anxiety, or emotional strain. It is a known independent predictor of increased mortality in patients with conditions like heart failure or post-myocardial infarction.

Entropy analysis - *Measuring cellular disorder and dysfunction*

Entropy analysis, in this context, is a non-linear analysis technique applied to the R-R interval time series (HRV). Entropy is a measure of randomness or complexity in a signal. A healthy, complex, and dynamic system exhibits higher entropy. Loss of entropy or complexity in signals leads to "disorder", indicating that the system is becoming more rigid, or dysfunctional. It is used to discriminate between different cardiac states (e.g., normal rhythm vs. life-threatening arrhythmias like Ventricular Fibrillation) or different disease states (e.g., healthy vs. heart failure).

Early detection - *Identifying sudden cardiac death (SCD) risk before symptoms appear*

The ultimate goal of identifying SCD risk, before symptoms appear, is achieved by combining the above analyses, often with machine learning/AI Research. The complex HRV features (including non-linear metrics like entropy) analysed from continuous ECG data can be used to build predictive models. These models aim to quantify an individual's SCD risk index, minutes or hours before a fatal event, allowing for potential pre-emptive intervention.

In summary, a state-of-the-art cardiac monitoring system that uses advanced signal processing such as entropy analysis on beat-to-beat timing data (R-R Variability) derived from continuous ECG readings can help

predict critical events before they manifest.

Precision medicine in the context of integrative healthcare

The integration of allopathy, ayurveda and homeopathy is a novel idea for the best holistic method of treatment.[39] Allopathic medicines are developed on scientific principles and methodology. It is evidence based to identify the active principle for treatment after many years of laboratory research work and trial experiments on animals and finally clinical trials on volunteering patients. It provides quick and targeted symptom relief. Ayurveda focuses on balanced, holistic treatment emphasizing prevention, lifestyle modifications like diet and long-term healing. Its principles are inherently centred on individual's constitution or personalization. Homeopathy offers highly individualized treatment plans based on the principles of "like cures like" (*similia similibus curentur*). It uses ultra diluted active principle for treatment and has a cellular to vascular approach.[40]

Over the next decade, the development of precision integrative medicine is expected to accelerate, combining molecular diagnostics with validated traditional medical practices. Policy support will be essential for the creation of AI-driven platforms that integrate modern biomedical data with traditional medicine knowledge systems to enable personalized integrative care. Equally important is the establishment of robust regulatory frameworks to ensure evidence-based, safe, and standardized integration of traditional and precision medicine approaches. Such a policy-driven approach can harness traditional medical knowledge while applying rigorous scientific standards to improve individualized health outcomes. A comprehensive framework is envisaged that integrates multiple domains: genomic, proteomic, and metabolomic profiling (molecular precision); rigorous, evidence-based evaluation of complementary therapies (traditional medicine validation); personalized nutrition, physical activity, and stress-management strategies (lifestyle genomics); customization of meditation, yoga, and mindfulness practices based on stress-response genetics and neuroimaging (mind–body precision); and the integration of gut microbiome analysis with traditional dietary principles to enable personalized nutritional therapy (microbiome integration).[41] Collectively, this integrative approach respects the wisdom of traditional healing systems while applying rigorous scientific methodology to optimize individual patient outcomes. It can also accommodate homoeopathy. Although the molecular mechanisms underlying homoeopathic systems remain debated, precision medicine tools may be used to explore individualized treatment responses by analysing enzyme function, neurochemical changes, immunological reactions, and metabolic alterations with the aim of investigating potential regulatory effects of ultra-dilute preparations.[40]

Omega fatty acids and cellular health

Omega fatty acids are considered crucial for cellular health. Omega-3 polyunsaturated fatty acids (PUFAs), particularly docosahexaenoic acid (DHA), can increase membrane fluidity by preventing lipid bilayer from packing tightly due to the presence of the kinks produced by double bonds. Proper membrane fluidity is vital as it affects the rotation and diffusion of proteins and other biomolecules within the membrane, which in turn affects cell function. Cells can employ compensatory mechanisms, like increasing saturated lipids, to counteract the fluidizing effect of incorporated PUFAs and maintain membrane biophysical properties. Omega-3 fatty acids, especially eicosapentaenoic acid (EPA) and

DHA, support heart health by reducing inflammation in blood vessels, helping to lower triglyceride levels, and potentially improving blood pressure. Some studies suggest that they may reduce the risk of cardiovascular disease (CVD) and death from CVD, and help prevent blood clots.[42] However, evidence on preventing heart attacks or strokes specifically from supplements is mixed. Omega-3 PUFAs (EPA and DHA) are structural components of neuronal membranes, influencing their function through membrane properties and also act as precursors for signalling molecules. They are linked to an improved state of mental health, potentially by modulating the gut-brain axis, reducing inflammation, and regulating the stress response (HPA axis). Some research indicates that omega-3 long-chain polyunsaturated fatty acids (LC-PUFAs) may improve sleep quality, specifically showing a significant improvement in sleep efficiency in some trials. Omega-3s contribute to overall cellular integrity and evidence suggests that they may lower the risk of certain cancers, such as colorectal cancer.[43] Their structural role in membrane further supports this protective effect.

The future: AI-enhanced biohacking

AI-enhanced biohacking is the integration of AI with personal health optimization practices to achieve unprecedented levels of self-improvement. It involves feeding complex, high-volume personal data sourced from wearables, genomics, and biomarker testing into machine learning algorithms.[44] This powerful analytical capability allows biohackers to move past generalized health advice and generate hyper-personalized, adaptive strategies for fitness, nutrition, and cognitive function, thereby rapidly accelerating the path towards peak performance and enhanced longevity. The combination of ayurvedic principles with AI technology represents an exciting frontier in personalized medicine, where ancient knowledge meets cutting-edge technology to optimize human health at the cellular level. This holistic approach to healthcare - linking genetics, AI, and precision medicine under the theme "Don't Miss a Beat" - truly represents the future of medicine where technology serves human wellbeing while honouring traditional healing wisdom.[45]

Telemedicine

Distance healthcare, includes services provided through audio and video technology, extending healthcare services to remote areas, especially during pandemics, and improving overall healthcare access. Telemedicine enables healthcare providers to offer services, consultations and patient monitoring without being physically present, thereby increasing accessibility.[46]

Robots

Robots have the potential to completely transform the medical field (Figure 3). The growing integration of robotics in medicine is driven by advancements in computing power and miniaturization. AI-medical robots are increasingly recognized for their employment in surgery, particularly for the

Figure 3: Robot used in Hridayalaya Cardiology and Robotic Research Centre

precise manipulation of surgical instruments through small incisions, guided by computers and software. These systems provide a precise, controlled surgical field, visualized in three dimensions through high-definition, magnified imaging. The main advantages of robot- assisted surgery for patients include fewer incisions, less blood loss, and quicker recovery, similar to the benefits of laparoscopic surgery. Robotics also hold promise for replacing traditional endoscopy. Small robots can be directed to precise areas to perform tasks such as obtaining a biopsy or cauterizing a bleeding vessel. Microrobots could be used to enter blood vessels to deliver medication or radiation therapy to a targeted area. Additionally, robotic endoscopic capsules that can be swallowed may patrol the digestive system, collect data and transmit diagnostic information back to the operator.[47]

Multi-omics

A wide array of molecular research fields with the suffix "-omics"—including genomics, epigenomics, proteomics, transcriptomics, metabolomics, and microbiomics—play pivotal roles in advancing precision medicine. Among these, metabolomics and genomics deserve special mention.[36]

Metabolomics involves the study of specific metabolites for diagnostic purposes. For instance, a metabolic transition occurs in the failing myocardium. Hence, metabolic profiles of patients with systolic heart failure can be assessed by examining serum and breath samples for clinical purposes such as diagnosis and prognosis. Extensive databases of metabolites are now available, many of which are implicated in heart failure. For example, metabolite clusters such as factor 4 (branched-chain amino acid metabolites) and factor 9 (urea-cycle metabolites) can aid in the diagnosis of coronary artery disease (CAD).[48] Elevated levels of branched-chain amino acids (BCAAs)—including leucine, isoleucine, and valine—themselves have been implicated in CAD, often reflecting metabolic impairments such as insulin resistance and abnormal protein metabolism. Acylcarnitines, which are byproducts of mitochondrial fatty acid oxidation, serve as markers of dysregulated mitochondrial metabolism and are associated with CAD, heart failure, and insulin resistance.[49] Cholesterol and lipids (such as triglycerides and phospholipids), fatty acids, glucose, and ketone-related metabolites are also considered important metabolic risk factors.[49] Pharmaco-omics is another important discipline that contributes to the development of drugs tailored to the needs of particular subpopulations; such drugs are not prescribed to non-responders, thereby preventing unwanted adverse effects and making treatment more cost-effective.[36]

Advances in genomics have also contributed significantly to the diagnosis and treatment of genetic diseases, including myocardial infarction (MI). DNA sequencing and gene identification have enabled the development of new therapeutic agents. For instance, the identification of genes such as CNR2, DPP4, GLP1R, SLC5A1, HTR2C, and MCHR1 may facilitate the development of drugs for type 2 diabetes or obesity without increasing cardiovascular risk. Similarly, dual antiplatelet therapy (DAPT) is routinely used to reduce the risk of thrombosis or MI. However, patients with loss-of-function CYP2C19 mutations have a higher likelihood of ischemic events when treated with standard DAPT. In such cases, a genotype-guided P2Y12 inhibitor, such as ticagrelor, is recommended as an alternative.[50]

The term "multi-omics" refers to a research approach that combines several "omics" data sets from various fields of study. This integrative analysis is crucial because biological functions are not governed by any

single type of molecule in isolation; instead, they result from complex, dynamic interactions across all these molecular levels. By combining these diverse datasets, researchers gain a far more holistic understanding of cellular processes, the progression of diseases, and the overall health state of the patient.[51] The ultimate goal is to bridge the gap between a patient's genetic code and the observable traits, or phenotype. This comprehensive molecular profiling is foundational to advancing both fundamental biological research and the implementation of precision medicine.

Patient selection, implementation, and risk stratification protocols in precision medicine

The identification of candidates for precision medicine interventions follows a multi-tiered screening approach that balances clinical efficacy with economic feasibility. However, establishing common criteria for patient selection remains challenging due to the inherent complexity involved. Current protocols incorporate family history assessment alongside validated genetic risk tools, such as polygenic risk scores for cardiovascular disease and cancer predisposition. Population-based screening programmes prioritise high-risk groups; for example, BRCA1/2 testing is recommended for individuals with a strong family history of breast or ovarian cancer. Furthermore, algorithmic risk prediction models further refine selection by integrating electronic health records, lifestyle variables, and preliminary biomarker data.[4] Presymptomatic disease detection is facilitated by routine health surveillance and emerging liquid biopsy technologies. [27-29]

Healthcare costs rise with both age and disease burden. A major driver of escalating expenditure is the growing prevalence of chronic and multiple long-term conditions, largely linked to lifestyle changes and population ageing. Globally, an estimated 33% of adults live with multiple long-term diseases, a figure that rises to nearly 75% in developed countries.[52] Age is a critical determinant of cost: in the United States, annual healthcare expenditure for individuals over 65 years is approximately 2.5–5 times higher than that for younger age groups, depending on comorbidity profiles. Escalating pharmaceutical costs contributes to healthcare inflation, with the US drug budget projected to grow at an average annual rate of 6.1% between 2020 and 2027. The adoption of new and often expensive medical technologies also adds to overall costs.[52]

Conversely, improved access to large-scale, high-quality multi-omics patient data, advances in data analytics, and systematic drug repurposing have ushered in an era of more affordable and precise personalised medicine. These approaches have the potential to reduce overall healthcare expenditure by identifying the most effective therapies for individual patients, improving outcomes while minimising unnecessary treatments.[51] In the context of rising drug prices and increasing pressure on healthcare budgets, such strategies may prove critical to the future sustainability of healthcare systems.[52] In short, the economic sustainability of precision medicine depends on judicious implementation. Initial screening using cost-effective targeted genomic panels has become more affordable, with costs reduced by nearly 50% in several centres in India. Cost reduction could be achieved by prioritising conditions in which precision interventions offer clear cost benefits, such as avoiding ineffective chemotherapies and preventing adverse drug reactions. Increasingly, precision diagnostics are covered by insurance when these tests directly guide clinical decisions, as in the case of Oncotype DX in breast cancer and

pharmacogenomic testing in psychiatric treatment. It is a relief to patients that the cost of whole-genome sequencing has declined substantially (by approximately 50%) in recent years, facilitating the wider application of precision medicine. Population-level screening programmes for actionable genetic conditions, such as familial hypercholesterolaemia, are also found to be cost-effective, through early intervention. Likewise, Machine learning algorithms reduce interpretation costs and enable automation of routine analyses.[36,44]

Future of healthcare

The future of healthcare is individualized and driven by advancements in nanotechnology, IT, and genetics. Advances in anaesthesia and minimally invasive surgical practices are expected to decrease inpatient volumes while increasing outpatient examinations and treatments. Advances in oncogenomics and cancer pharmacogenomics, driven by next-generation sequencing technology, are anticipated to personalize cancer screening and diagnosis.[53] AI systems will shift healthcare from traditional models to cost-effective, data-driven disease management strategies, furthering immunomics and drug discovery for better preventive strategies. Wearable healthcare and Internet of Medical Therapy (IoMT) devices equipped with biosensors and transducers promise continuous health monitoring and reduced hospital visits. [27-29] Collectively, such wearables can support telemedicine and telehealth by enabling continuous monitoring while serving as platforms for secure health data generation and storage.

The surge of innovations, encompassing AI, telemedicine, precision medicine, and big data analytics (BDAs), has revolutionized the healthcare sector.[54] The transformative potential of these advancements becomes evident as we gaze into the future of healthcare. The healthcare sector holds tremendous promise, driven by the convergence of state-of-the-art technologies, data-driven methodologies, and a dedicated commitment to mitigating healthcare disparities. This synergy between healthcare and technology presents exciting possibilities, paving the way for personalized treatments that account for individual variations and enhanced patient outcomes. Moreover, this technological evolution has the potential to establish a more accessible healthcare system, dismantling barriers and delivering quality medical services to diverse populations, including those residing in underserved areas.[54]

Conclusion

As we move into the next decade, collaborative endeavours between healthcare and technology are poised to redefine our approach to wellness. The journey towards a promising future requires active engagement, innovation, and careful navigation of ethical considerations within the healthcare sector. By embracing these principles, stakeholders in the healthcare ecosystem can collectively contribute to a landscape that is not only technologically advanced and efficient but also profoundly centred on the well-being of individuals and communities. This transformative trajectory holds the potential to create a healthcare environment that is responsive to the evolving needs of society and dedicated to fostering optimal health outcomes for all.

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