BIOMARKERS AS THERAPEUTIC TOOLS IN MEDICAL DIAGNOSTICS AND DISEASE MONITORING

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FOREWORD

Biomarkers have become a cornerstone in precision medicine, assisting clinicians globally in understanding, diagnosing, and monitoring diverse diseases with greater accuracy, thus revolutionizing patient care.

The book "Biomarkers as Therapeutic Tools in Medical Diagnostics and Disease Monitoring," edited by Dr. Vandana Gupta, Dr. Megha Verma, and Dr. Ajay K. Shukla, brings together pioneering research and recent developments in the field of biomarkers, offering an extensive overview of their theranostic value across various diseases. Each chapter in the book provides a critical insight into the biomarkers with diagnostic, prognostic, and therapeutic value in various disease conditions.

This book showcases the most recent advancements in biomarker-based diagnostics and their role in therapeutic decision-making for a wide range of diseases and conditions, including neurological disorders (Chapter 1), inflammatory diseases, including IBD (Chapter 2), and autoimmune diseases (Chapter 6). The inclusion of cancer stem cell biomarkers and biomarkers for personalized cancer treatment (Chapters 8 and 9) highlights the significance of precision medicine in oncology. In addition, the chapters on cardio-oncology (Chapter 7), and coronary artery disease (Chapter 5), provide an in-depth analysis of how biomarkers influence risk stratification and disease progression tracking.

Of particular interest are the discussions on progressive neurodegenerative biomarkers (Chapter 3) and activity-based diagnostics (Chapter 4). These emerging areas highlight the future directions of biomarker-based research and its potential for transforming healthcare systems worldwide.

This book is an excellent resource for researchers, physicians, and healthcare professionals who seek to understand ever-growing applications of biomarkers. It not only delves into the molecular basis of disease, but also provides practical insights into how biomarkers might be used for early detection, patient stratification, therapy monitoring, and precision medicine.

I extend my appreciation to the editor(s)/author(s) and contributors for their commitment to this important field. I am confident that this book will serve as a foundational reference, inspiring further research and innovation in biomarker-based diagnostics and therapeutics.

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PREFACE

In recent years, biomarkers have become essential tools for early disease detection, prognosis, and therapeutic interventions, causing a paradigm change in medical diagnostics and disease monitoring. Biomarker research is a rapidly growing discipline that offers novel methods in precision therapy, customized medicine, and real-time illness monitoring. Biomarkers have greater promise than ever as therapeutic tools because of the rapid developments in molecular biology, bioinformatics, and nanotechnology.

In order to provide a thorough overview of the most recent advancements in biomarker discovery, characterization, and clinical applications, this book, Biomarkers as Therapeutic Tools in Medical Diagnostics and Disease Monitoring, integrates knowledge from a variety of fields, including clinical research, pharmacology, molecular medicine, and bioengineering. It also examines the role of biomarkers in a number of diseases, such as cancer, cardiovascular disorders, neurodegenerative conditions, infectious diseases, and metabolic syndromes. The basic features of biomarkers, such as their classification, modes of action, validation methods, and regulatory issues, are covered in the book's chapters. Particular attention is paid to the function of biomarkers in targeted therapies, drug development, and personalized medicine. Recent developments in liquid biopsies, biosensors, and AI-powered biomarker analysis are also covered, emphasizing how they will affect healthcare in the future.

Researchers, physicians, biomedical scientists, and students interested in learning more about the use of biomarkers in illness management should read this book. We aim to contribute to the expanding body of knowledge that will influence precision medicine in the future by offering a thorough examination of biomarker-based diagnoses and treatments.

We would like to thank all of the researchers, collaborators, and medical professionals whose groundbreaking work has significantly enhanced this field. We sincerely hope that this book will be a useful tool for the clinical and academic communities, spurring additional advancements in biomarker-based treatments and diagnostics.

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CHAPTER 1

Blood-based Biomarkers for Neurological Disorder Diseases: Present Status and Potential Applications in a Changing Global Healthcare Environment

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Abstract: In the worldwide healthcare system, blood-based biomarkers for neurological illnesses have been recognized as important instruments for early diagnosis, disease monitoring, and individualized treatment. Currently, several research studies have reported robust assays of blood biomarkers for the identification of tau and beta-amyloid proteins for Alzheimer-type dementia. Neurofilament light polypeptide is linked to various conditions, including amyotrophic lateral sclerosis, and is used alongside inflammatory markers such as C-reactive protein and cytokines to assess neuroinflammation and underlying pathophysiologic processes. These biomarkers are intriguing, but they have issues related to standardization, sensitivity, and specificity. Blood-based biomarkers provide affordable, non-invasive diagnostic tools in the evolving healthcare landscape, particularly in resource-constrained countries where advanced imaging is less readily available. In the near future, blood-based biomarkers can be used for patient screening, tailored treatment, and remote care integration. Widespread acceptance, however, will depend on removing the present legislative and technological obstacles and guaranteeing consistent clinical utility. Blood-based biomarkers can be utilized for global management of neurological illnesses and have the potential to be used clinically. In this review, recent advancements and their fruitful implications, as discussed by neurologists, will be discussed.

Keywords: Alzheimer's disease, Beta-amyloid proteins, Blood-based biomarkers, Neuroinflammation.

INTRODUCTION

The term “neurodegeneration” refers to either the delayed process of apoptosis or immediate cell death through necrosis [1]. The primary characteristics of neurode-

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generation include problems with the cytoskeleton, inflammation, aberrant protein aggregation, loss of neurons, abnormal proteostasis, and abnormalities in DNA, RNA, and mitochondrial functions [2]. Neurodegenerative disorders (NDs) can be categorized on the basis of significant genetic abnormalities, prominent clinical characteristics, or the anatomical distribution of pathological alterations [3]. Two major risk factors for neurodegenerative illness include heredity and age variables, along with gender illiteracy, metabolic state, oxidative stress, diabetes, infections, brain trauma, inflammation, and environmental variables, among others [4]. Neuroinflammation is one of the most prevalent characteristics of neurodegenerative disorders. Chronic neuroinflammation causes microglia and astrocytes to release excessive amounts of reactive oxygen species (ROS) and pro-inflammatory cytokines, which results in alterations of synapses, reduced neuronal cell growth, and neuronal cell death.

It is difficult to diagnose neurodegenerative disorders due to unusual variations or the absence of symptoms in the early stages of the disease [5]. For the diagnosis of a “neurodegenerative” disease, brain tissue analysis is the most significant but not the sole routine clinical procedure, as it demands a brain biopsy, which is intrusive and not morally feasible for a standard clinical evaluation [6]. Clinical examination serves as the foundation for most diagnostic procedures. Recent research data indicates that functional imaging may be more specific for neurodegenerative diseases and helpful in the early detection of PD and dementia. Functional imaging is frequently employed to rule out alternative diagnoses [7]. Significant advancements have been achieved in the study of protein biomarkers for neurodegenerative disorders in recent years. Biomarkers may be essential to comprehending the pathophysiology of neurodegenerative disease since they represent physiological and pathological processes that occur in the nervous system (Figs. **1** and **2**). Protein biomarkers may be used as a diagnostic aid as well as for forecasting future cognitive decline in healthy persons, along with tracking of dementia progression in patients with cognitive impairments. Additionally, these biomarkers can be used as an evaluator of various stages of disease progression. Biomarkers act as therapeutic tools for the diagnosis and monitoring of disease, as their concentration changes in the brain's extracellular space, reflecting continuous metabolic changes during disease progression. The best source of biomarkers for NDs is cerebrospinal fluid (CSF) [8]. Nevertheless, the lumbar puncture method, which is used to obtain CSF, is extremely intrusive and fraught with adverse consequences such as nausea, headache, backache, and weariness. Due to the shortcomings of collecting CSF, there is an increasing requirement for collecting easily accessible diagnostic materials like blood or saliva. Assessing blood-based biomarkers is advantageous since blood collection is not overly intrusive, affordable, and easy. Various analytical methods have been developed for decades to quantify biomarkers in plasma. The enzyme-linked

immunosorbent assay (ELISA) is the most common method used for the analysis of CSF. However, significant methodological issues with plasma have been observed that adversely affect the performance of ELISA. Multiple analyte profiling (xMAP) is one of the leading technologies employed as a substitute for ELISA, as it allows for the analysis of a large number of samples simultaneously with a smaller sample volume. Analysis of biological markers using Mesoscale Discovery (MSD) and Electrochemiluminescence (ECL) is progressing, as it offers better sensitivity at lower sample concentrations compared to traditional ELISA and xMAP advanced technologies. For protein analysis, immunoprecipitation and mass spectrometry (IP-MS) techniques are likewise trustworthy. Quantitation has demonstrated strong outcomes for the presence of pTau and Aβ biomarkers in plasma. Research studies have revealed transcranial magnetic stimulation (TMS)-based techniques to be highly reliable and accurate for the estimation of plasma biomarkers, even though major accurate data is further required for validating the results [9]. To ascertain their diagnostic qualities, more prospective research studies are required. The recently developed technology, known as single molecule array (SIMOA), shows good diagnostic accuracy and enhanced sensitivity even when measuring at lower concentrations. The SIMOA technique depends on individual molecule arrays and the simultaneous enumeration of isolated capture microbeads.

From a therapeutic perspective, the most important methods for the quantitative estimation of blood biomarkers are completely automated processes, such as ECL and SIMOA [10]. The aim of this review is to present a summary of the latest research regarding the application of the most promising blood biomarkers in the management of common neurodegenerative diseases, including multiple sclerosis, Alzheimer's disease, Parkinson's disease, and Creutzfeldt-Jakob disease.

ALZHEIMER'S DISEASE

The most common cause of dementia is Alzheimer's disease (AD), which has significant societal and financial ramifications. According to Prince M *et al*., currently, there are an estimated 50 million dementia sufferers worldwide, which is expected to rise to over 80 million by 2030 [11]. Since aging is the primary risk factor for dementia, increased life expectancy contributes to the rising prevalence of the disease [12]. As a result, these disorders pose a significant and growing worldwide health burden [13]. Furthermore, accurate prognosis and illness monitoring are challenging and solely depend on gathering clinical data. Thus, the study of biomarkers will help in gathering information regarding the prevalence of disease. Biomarkers, which offer an objective measurement of pertinent pathophysiology *in vivo*, are now part of the diagnostic criteria for AD in current

CHAPTER 2

Therapeutic Interventions for Inflammatory Bowel Disease and Predictive Biomarkers of Therapeutic Response

Mohammad Akbar Siddiqui[1,*], Nidhi Agrawal[1], Sakshi Gupta[1], S. K. Lanjhiyana[1], Meenakshi Jaiswal[1] and **Vandana Gupta[2]**

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Abstract: This narrative review examines contemporary predictive biomarkers and therapeutic interventions in the management of Inflammatory Bowel Disease (IBD), including Crohn's disease (CD) and ulcerative colitis (UC). The literature was retrieved from databases including PubMed, Scopus, ScienceDirect, and Google Scholar using keywords such as "Inflammatory bowel disease," "biomarkers," and "therapeutic interventions," with inclusion criteria focusing on peer-reviewed human studies published till 2025. The review critically examines conventional and emerging treatments, including antibiotics, TNF inhibitors, probiotics, prebiotics, microbial replacement therapy, nutritional interventions, immunomodulators, and cell adhesion molecule inhibitors. It also synthesizes current findings on predictive biomarkers, including microbial profiles, genetic polymorphisms, hematological indicators, immune mediators, fecal markers, and anti-drug antibodies, that influence therapeutic response. Major trends indicate a growing emphasis on personalized medicine through biomarker-guided therapy. However, challenges such as clinical variability, biomarker accessibility, and standardization remain. This review underscores the need for integrated, biomarker-based approaches to enhance treatment efficacy and patient outcomes in IBD.

Keywords: Biomarkers, Ulcerative colitis, Crohn's disease, Gastrointestinal tract, Inflammatory bowel disease.

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INTRODUCTION

IBD is a persistent, chronic, relapsing inflammatory condition of the gastrointestinal (GI) system. This condition is marked by non-infectious chronic inflammation that primarily impacts the lining of the GI tract, leading to ongoing structural and functional damage, which necessitates indefinite treatment [1]. IBD is divided into two primary forms, determined by distinct pathological characteristics and clinical manifestations: Ulcerative Colitis (UC), which mainly affects the mucosa of the bowel in an unbroken sequence, and Crohn's disease (CD), which can affect the various segments throughout the GI tract, indicating that these subgroups represent unique illnesses requiring specific treatment approaches. Both CD and UC have several subtypes. For UC, subtypes are classified based on the area affected: proctitis (confined to the rectum), proctosigmoiditis (extending to the sigmoid colon), distal ulcerative colitis (beyond the sigmoid colon), and pancolitis (affecting the entire colon up to the cecum). On the contrary, CD is classified by phenotype, comprising inflammatory, structuring, or penetrating forms [2]. Both CD and UC are extremely variable and complicated, further complicating their clinical management and treatment strategies. The chronic, progressive, and relapsing nature of the disorder has a significant impact on the patient's quality of life due to immunological dysregulation and the associated inflammatory dysfunction [3].

Current treatments for IBD work by inhibiting pro-inflammatory cytokines and blocking leukocyte migration through the inhibition of sphingosine-1-phosphate receptors and integrins. These treatments aim to achieve clinical and endoscopic remission, decrease the incidence of complications and surgery, and enhance patients' quality of life. Although colonoscopy is still the best method for determining the level of disease activity, it is risky, expensive, and invasive. As a result, non-invasive biomarkers are increasingly used to monitor disease activity, treatment response, and relapse. According to the National Institute of Health, biomarkers are measurable indicators of normal or pathological processes or responses to treatment [4].

Biomarkers can be sampled from various sources, *i.e*., serum, stool, urine, and tissue. Although the quantity of biomarkers accessible to physicians has expanded in recent years, notably due to advancements in metabolomics, genomics, and proteomics, not all biomarkers are practical or obtainable for clinicians in routine practice [5]. The ideal biomarker should be non-invasive for patient comfort, extremely sensitive and specific, represent the underlying disease process, respond to treatment, and help with prognosis. It should also be affordable. Additionally, biomarkers that are easily accessible, have fast turnaround times, and depend on trustworthy testing techniques are valued by clinicians [6].

METHODS

This narrative review was conducted by searching relevant scientific literature in databases including PubMed, Scopus, ScienceDirect, and Google Scholar using keywords such as "inflammatory bowel disease," "C-reactive protein," "biomarkers," "calprotectin," "therapeutic response," and "Crohn's disease." The inclusion criteria comprised peer-reviewed articles published up until 2025 that focused on human studies, therapeutic strategies, and predictive biomarkers in IBD. Key findings were synthesized thematically and critically reviewed.

Predictive Biomarkers of IBD and Their Influence on Response to Therapy

Biomarkers play a crucial role in the diagnosis and management of IBD by assessing inflammation levels (Table **1**) present in blood or stool samples. Among the frequently utilized biomarkers are:

Gut Microbiota as Markers

Although the exact etiology of IBD is still unidentified, it is well known that changes in the microbiota contribute to the development of IBD. The complicated relationship between gut microbial ecology and immune cells may impact disease severity and sensitivity to intestinal inflammation (Fig. **1**), as well as immune treatment in IBD patients. Elevated levels of Bifidobacterium, Clostridium colinum, Eubacterium rectale, uncultured Clostridiales, and Vibrio, together with reduced levels of Streptococcus mitis, have been linked to a more favorable response to anti-TNF medication in individuals with IBD. In contrast, individuals with reduced gut microbial dysbiosis or increased fibrostenotic illness and a diminished prevalence of Faecalibacterium prausnitzii demonstrated a worse response rate to anti-TNF therapy and frequently required surgical intervention for disease management [7]. Additionally, a higher presence of butyrate-producing species (such as *Roseburia inulinivorans* and *Burkholderiales*) and branched-chain amino acid synthesis has been shown to predict remission and clinical response to Vedolizumab effectively. However, due to the variability of changes across different populations and the lack of statistical power in research, defining microbial biomarkers for responsiveness to biological treatments remains challenging. On the other hand, bacteria that produce short-chain fatty acids, such as those from the *Lachnospiraceae* and *Ruminococcaceae* families, have been linked to primary non-responders to anti-TNF-α therapies [8].

Researchers have also examined how the balance between two dominant gut microbial groups, Prevotella and Bacteroides, affects patients' response to anti-TNF therapy. High Prevotella levels compared to Bacteroides have been linked to a more favorable response to biological treatments. Recent research by Caenepeel

CHAPTER 3

Neuro-inflammatory Biomarkers

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Abstract: This narrative review explores Parkinson's disease (PD), a progressive neurodegenerative condition that significantly affects motor function and is associated with significant neuroinflammatory processes. Activated microglia and astrocytes, along with the release of inflammatory mediators, trigger neuroinflammation, a crucial factor in the onset and progression of Parkinson's disease. Neuroinflammatory response biomarkers are important tools for understanding these pathways because they allow early diagnosis, tracking of disease progression, and judging how well a treatment is working. They are very important because they reveal factors like cytokines (TNF-α, IL-1β, and IL-6), markers of microglial activation (TSPO), signs of oxidative stress (nitric oxide and malondialdehyde), and complement system proteins (C3 and C4). Examining these biomarkers in cerebrospinal fluid and blood, along with modern imaging methods, simplifies the monitoring of inflammation levels in Parkinson's patients. This helps doctors determine the severity of the disease and identify areas for future treatment focus. Even though there are issues with biomarker specificity and repeatability, neuroinflammatory biomarker research is making progress. This can lead to better diagnosis, more personalized treatment plans, and a better understanding of how Parkinson's disease works at its core. This review synthesizes current knowledge on the categorization, functions, and prospective clinical applications of these biomarkers, concluding that they are crucial for enhancing diagnostic accuracy, enabling personalized treatment plans, and deepening the fundamental understanding of Parkinson's disease pathology.

Keywords: Alpha-synuclein, Antioxidants, Biomarkers, Brain imaging, Cellular modifications, Cerebrospinal fluid, Chemokines, Cytokines, Genetic markers, Molecular markers.

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INTRODUCTION

Parkinson's disease (PD) is the predominant movement condition and the second most prevalent neurodegenerative disorder. It is a neurological condition rapidly increasing globally in terms of prevalence, disability, and mortality. In 2016, it was predicted that 6.1 million individuals globally had Parkinson's disease, compared to 2.5 million in 1990, with predictions indicating this figure will exceed 12 million by 2040 [1]. It induces motor dysfunctions, including bradykinesia, resting tremors, stiffness, and postural instability, while also impacting autonomic processes and cognitive abilities [2].

Several neurological symptoms are associated with Parkinson's disease. These symptoms include the death of neurons in the substantia nigra, which leads to a lack of dopaminergic activity in the striatum, and the accumulation of α-synuclein in neurons. Parkinson's disease (PD) is caused by a number of distinct processes and dysfunctions in pathways, including oxidative stress, mitochondrial dysfunction, cellular calcium imbalance, neuroinflammation, and abnormalities in other neurotransmitter pathways. The majority of attempts that were made to reduce intracellular or extracellular alpha-synuclein levels or its aggregation as a disease-modifying therapy for Parkinson's disease in these clinically defined cohorts have been unsuccessful. Over the past few years, the defective biological mechanisms that are responsible for neurodegeneration in Parkinson's disease have been identified. This has enabled the development of potentially innovative biologically-based illness definitions and disease-modifying strategies that are specific to the unique disease biology of each individual. Both human patients with Parkinson's disease and animal models of the condition exhibit activation of glial cells, infiltration of T cells, and inflammatory responses that persist for an extended period of time. The degeneration of dopaminergic neurons is significantly influenced by the aforementioned factors. This suggests that there is the potential for the development of medicines for Parkinson's disease that target inflammatory processes [3, 4].

There are more proinflammatory substances in the brain, such as cytokines, chemokines, prostaglandins, complement cascade proteins, and reactive oxygen and nitrogen species (ROS/RNS) (Table **1**). These substances are known to cause inflammation. This can damage the blood-brain barrier (BBB) and make it easier for the adaptive immune system to play a role in the development of the disease. The review of the literature suggests that we can change the blood-brain barrier permeability of peripheral macrophages and blood leukocytes within the brain parenchyma to better control brain homeostasis and neuronal injury [5].

Table 1. Various categories of neuroinflammatory biomarkers with their source and type.

S. No.	Category	Biomarker	Source	Type	Description	References
1	Cytokines	Interleukin-1β (IL-1β)	Blood, CSF, brain tissue	Pro-inflammatory cytokine	Elevated in serum and CSF in PD; associated with microglial activation.	[6]
		Tumor Necrosis Factor-α (TNF-α)		Pro-inflammatory cytokine	Promotes neurodegeneration; higher levels in PD brains and CSF.	[7]
		Interleukin-6 (IL-6)		Mixed pro/anti-inflammatory	Increased in serum and CSF; linked to inflammation in PD.	[8]
2	Chemokines	Monocyte Chemoattractant Protein-1 (MCP-1)	CSF, blood	Pro-inflammatory chemokine	Attracts monocytes/microglia to the CNS; elevated in the CSF of PD patients.	[9]
		CCL2, CCL5, CXCL12	Plasma and serum	Peripheral immune activation	peripheral immune biomarker elevation	[10]
3	Immune Cells	Microglial markers (*e.g.*, Iba1, HLA-DR)	Brain imaging	Glial activation markers	Elevated in post-mortem PD brains, signifying neuroinflammation.	[11]
		T-cell subsets (CD4+, CD8+)	CSF, blood	Peripheral immune activation	Altered T-cell ratios and CNS infiltration in PD progression.	[12]
4	Oxidative Stress	8-Hydroxy-2-deoxyguanosine (8-OHdG)	Blood, urine	DNA oxidative stress marker	Elevated in CSF and serum; reflects oxidative damage in PD.	[13]
		Malondialdehyde (MDA), nitrotyrosine	Blood	Lipid peroxidation marker	Elevated in plasma and CSF; indicates oxidative damage related to inflammation.	[14]
5	Glial Markers	Glial Fibrillary Acidic Protein (GFAP)	CSF, blood	Astrocytic activation marker	Elevated in serum and CSF; indicates astrocyte reactivity.	[15]
		S100 Calcium-Binding Protein B (S100B)	CSF, blood	Astrocytic activation marker	Elevated in plasma and CSF; linked to neurotoxicity in PD.	[16]
6	Peripheral Markers	High-Sensitivity C-reactive Protein (hsCRP)	Blood	Systemic inflammation marker	Found in higher levels in serum, linked to systemic inflammation in PD.	[17]
7	Complement System	C1q, C3, C4	CSF, brain tissue	Protein markers	Dysregulation associated with neuroinflammatory responses.	[18]

CHAPTER 4

Activity-based Diagnostic: A New Approach to the Identification and Tracking of Disease

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Abstract: Several diseases can lead to life-threatening conditions, but their intermittent nature and vague symptoms often make diagnosis challenging. Therefore, activity-based diagnosis is an approach that simplifies the diagnostic process and improves accuracy. This narrative review examines the current scenario of activity-based diagnostic methods in infectious and non-infectious diseases, using various databases, including Google Scholar, PubMed, Web of Science, and Scopus (2000-2024). Clinical studies and review articles were included, with emphasis on technological advances and validation studies. The activity-based diagnosis has several advantages over traditional methods, like enhancing specificity, sensitivity, and detection time. The innovations include fluorescent probes, colorimetric detection systems, nanosensors, and the integration of artificial intelligence. Further clinical trial data show favorable results in cancer screening, as well asthe detection of infectious and chronic diseases, as this approach enhances targeted therapy and diagnosis.

Keywords: Activity-based diagnostics, Assay, Disease, Enzyme, Probes, Sensors.

INTRODUCTION

The human body consists of several functional biomarkers, like proteins, nucleic acids, lipids, enzymes, *etc*. These biological markers are helpful for performing clinical diagnosis (diagnostic biomarkers), monitoring disease progression (prognostic biomarkers), predicting treatment outcomes (predictive biomarkers), assessing safety-toxicity, and research purposes. Diagnostic methods, such as imaging, screening, blood tests, *etc*., have been utilized to detect disease at an

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early stage, but they lack specificity and require substantial investment in expensive infrastructure and the expertise of specialized personnel to interpret the results [1]. Day by day, the occurrence of different diseases increases, which raises the demand for accurate and fast diagnostic approaches that contribute significantly to the field of medical diagnostics [2]. Activity-based diagnostics is one of them, which identifies disease well before symptoms appear. This method enables early intervention, which can greatly change the course of the disease and enhance survival rates [3]. In Table **1,** we summarize the advantages of activity-based diagnostics over traditional diagnostic methods [4].

Table 1. Advantages of activity-based diagnostics over traditional methods.

Aspect	Activity-based Diagnostics	Traditional Diagnosis Methods
Sensitivity	High sensitivity due to specific enzyme activity detection.	Variable sensitivity, often lower, depending on the method used [4].
Specificity	High specificity by targeting disease-specific enzymatic activity.	Specificity varies; it can be lower due to cross-reactivity [4].
Turnaround Time	Faster results as they directly measure enzymatic activity.	Slower, especially for methods like culture-based diagnostics [4].
Instrumentation	It can be integrated with advanced imaging and molecular techniques.	Often require specialized equipment and trained personnel [4].
Cost	Potentially lower in the long run due to faster and more accurate diagnostics.	This can be higher due to repeated testing and longer processing times [4].
Application Range	Effective for a wide range of diseases, including infectious and non-communicable diseases.	Limited by the method's specificity and sensitivity [4].
Non-Invasiveness	Often non-invasive, using biomarkers from bodily fluids.	It can be invasive, requiring tissue samples or other invasive procedures [4].
Adaptability	Highly adaptable to new diseases and conditions.	Less adaptable, often requiring new protocols for different diseases [4].

Activity-based diagnostics is a novel method that uses enzyme activity to quantify biomarkers for noticing and tracking both infectious and non-communicable diseases. In other words, it belongs to the class of chemical probes that control the dysfunction of metabolic signatures and produce observable signals, especially in targeted tissues of disease, as shown in Fig. (**1**) [5]. The basis of activity-based diagnostics originates from the understanding of enzymes and their importance in several disease conditions, which provides the direction for discovering a method utilizing enzymes for diagnosis. Activity-based probes were developed in the 1990s, which significantly changed the field of diagnostics. Chemical probes were discovered that showed interaction with the enzyme's active form and helped researchers to quantify enzyme activity in biological samples. This approach led

to the discovery of another method of diagnosis. Clinical applications of activity-based diagnosis (ABDx) began in the 2000s, when investigators found the threshold of ABDx for the rapid detection of different diseases [6]. This chapter examines the different technological techniques used in activity-based diagnosis, which include probe systems, detection techniques, etc, and also highlights the value of ABDx in treating many diseases, showcasing the latest discovery that enhances its effectiveness. Besides, a critical comparison of several approaches is provided to evaluate their strengths and limitations. Finally, it looks ahead to future directions and summarizes major insights and conclusions.

Method: This narrative review was conducted through a literature search of peer-reviewed studies on ABDx methods and novel probe technologies, using keywords such as "activity-based diagnostics," "biochemical activity detection," and "enzyme-based diagnosis," combined with similar terms for biomarkers. Data were obtained from various databases, including PubMed, Web of Science, Scopus, and Google Scholar.

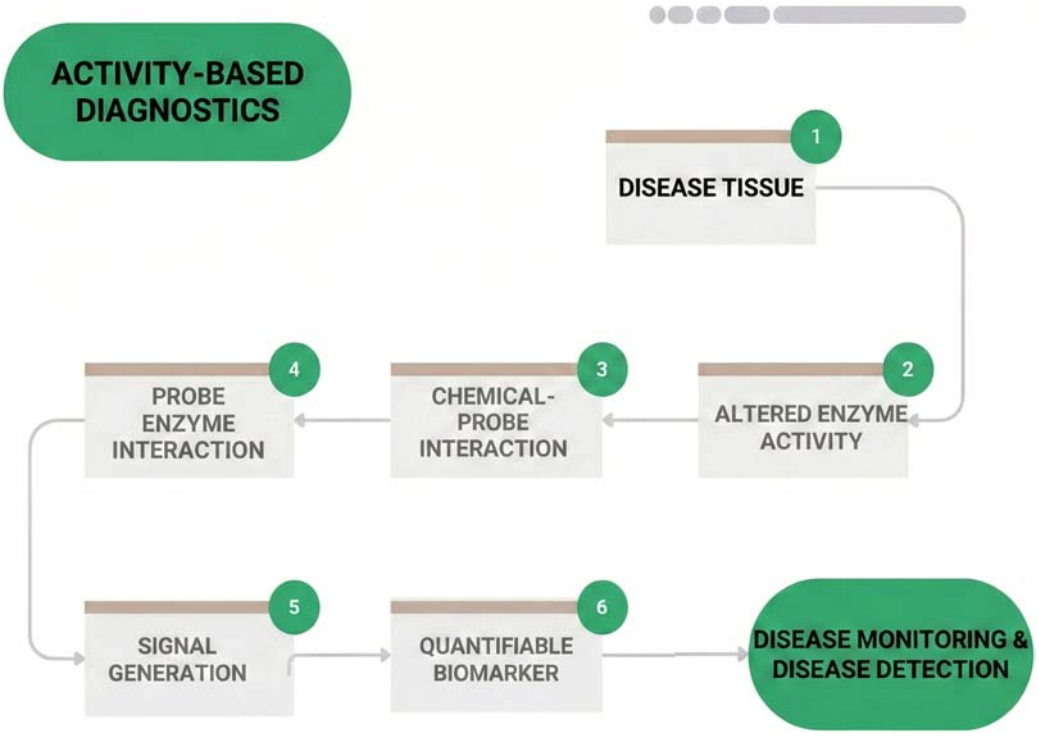

Fig. (1). Represented principles and mechanisms of activity-based diagnostics.

CHAPTER 5

Biomarkers for Determining the Outcome, Severity, and Effectiveness of Treatment for Coronary Artery Disease

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Abstract: Coronary artery disease (CAD) remains one of the major causes of morbidity and mortality in the world. The importance of developing advanced diagnostic, prognostic, and therapeutic monitoring tools cannot be overemphasized. Biomarkers have emerged as invaluable resources for tracking disease outcomes, assessing severity, and evaluating treatment efficacy. This review will explore the landscape of biomarkers for CAD, focusing on their role in providing precision medicine approaches for this complex condition. Biomarkers, such as Troponin I (TnI) and C-reactive protein (CRP), have been established in identifying myocardial damage and inflammation, respectively, which correlate with the severity of coronary atherosclerosis and high-risk plaque characteristics. In parallel, new biomarkers based on transcriptomics, such as circulating microRNAs (*e.g.*, miR-126, miR-223, miR-19), may open new avenues for early detection and risk stratification. These RNA molecules are linked to the molecular basis of CAD, which is the connection between endothelial dysfunction and inflammatory cascades with adverse cardiovascular events. Quantitative imaging biomarkers include coronary artery calcium scores (CACS) and the features of high-risk plaque (HRP) found by coronary computed tomography angiography (CCTA). They provide a real-time assessment of the plaque burden and vulnerability. Increasing evidence is emerging with the incorporation of biomarker profiles and imaging tools for improved risk stratification and, consequently, individualized treatment pathways. Such biomarkers include Growth Differentiation Factor-15 (GDF-15) and soluble ST2, which are potential candidates for predicting the disease's progression and the response to pharmacological interventions. Recent advances in the omics technologies, namely genomics, proteomics, and metabolomics,

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have expanded the range of CAD biomarkers with the potential to identify patient-specific therapeutic targets. However, significant challenges remain in translating such discoveries into clinical practice because of variability in biomarker expression, lack of standardization, and large-scale validation studies.

Keywords: Adhesion molecule, Apolipoprotein B, C-reactive protein, Cardiac troponins, Circulating microRNAs, Coronary artery disease, Endothelial dysfunction, Endothelin-1, Exosomes, Molecular biomarker.

INTRODUCTION

Coronary artery disease, also referred to as ischemic heart disease, is a chronic condition characterized by the narrowing or blockage of coronary arteries, which supply oxygen-rich blood to the heart muscle, known as the myocardium. The main cause of CAD is atherosclerosis, which involves the build-up of fatty deposits, inflammatory cells, and fibrous tissue within the arterial walls. Biomarkers, including diagnostic (indicating disease presence), prognostic (predicting outcome), and predictive (guiding treatment response) types, are critical for CAD management. This paper is structured as follows: Section 1 outlines risk factors and pathophysiology; Section 2 introduces biomarker categories; Section 3 details biomarkers for tracking outcomes; Section 4 covers biomarkers for severity assessment; Section 5 discusses biomarkers for treatment effectiveness; and Section 6 addresses limitations and future directions. In CAD, there is reduced blood flow to the heart muscle; the symptoms involve chest pain, commonly referred to as angina, breathlessness, and sometimes heart attack or heart failure [1, 2].

RISK FACTOR IN CAD

The development of CAD is multifactorial and includes genetic predisposition, environmental factors, and lifestyle influences. Key risk factors include [1, 3 - 7]:

Non-Modifiable Factors

Age

The risk for CAD increases with age due to natural changes in blood vessels and plaque accumulation.

Gender

Men are generally at higher risk earlier in life, though postmenopausal women face an elevated risk due to declining estrogen levels.

Genetics

A positive family history for CAD significantly increases the risk, as there is genetic susceptibility to diseases like dyslipidemia or hypertension.

Modifiable Risk Factors

Dyslipidemia

Elevated LDL-C contributes to the development of plaque, and reduced HDL-C reduces the elimination of excess lipid from blood vessels.

Hypertension

Long-term elevation of blood pressure can lead to endothelial damage and predispose an area to the formation of plaques.

Smoking

Tobacco smoking accelerates atherosclerosis by promoting inflammation and oxidative stress, damaging the vascular endothelium.

Diabetes

High blood sugar damages blood vessels, promoting atherosclerosis and increasing CAD risk.

Obesity

Excess body fat exacerbates other risk factors, such as hypertension, insulin resistance, and dyslipidemia.

Sedentary Lifestyle

A lack of physical activity increases the likelihood of weight gain and poor cardiovascular health.

Dietary habits include saturated fats, trans fats, and processed sugars, all of which lead to an increase in lipid deposition within the arterial wall.

Additional Contributing Factors

Chronic Stress

Chronic stress results in an elevated level of catecholamines, thereby promoting increased blood pressure, tachycardia, and inflammation, which in turn worsens

CHAPTER 6

Biomarkers for Monitoring Therapeutic Effectiveness in Common Autoimmune Diseases

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Abstract: Autoimmune disease is a condition in which the immune system mistakenly damages healthy cells in the human body. There are different types of autoimmune diseases, including systemic lupus erythematosus (SLE), rheumatoid arthritis, Sjögren's syndrome, Type-I diabetes, autoimmune hepatitis, multiple sclerosis (MS), myasthenia gravis, *etc*. Biomarkers are used to determine disability progression, monitor ongoing disease activity, and measure treatment response. Thus, these biomarkers are required to decide the therapy for the treatment of autoimmune diseases. Different types of biomarkers, such as diagnostic biomarkers, prognostic biomarkers, predictive biomarkers, monitoring biomarkers, emerging biomarkers, *etc*., are used in the diagnosis and treatment of different autoimmune diseases. The ideal biomarker can act as a diagnostic tool and monitoring method to determine the efficacy of therapeutic agents. This chapter encompasses the types of autoimmune diseases and the classification of biomarkers in autoimmune diseases. It also includes applications of biomarkers in autoimmune diseases, as well as challenges and future prospects in biomarker research for autoimmune diseases. Furthermore, the integration of biomarker-based strategies into clinical practice is explored, emphasizing their utility in improving therapeutic outcomes and reducing adverse effects. This review highlights the importance of biomarker research in advancing the understanding and management of autoimmune diseases.

Keywords: : Autoimmune diseases, Biomarkers, Diagnosis, Rheumatoid arthritis.

INTRODUCTION

Autoimmune diseases are a diverse group of disorders characterized by the immune system's aberrant attack on the body's own tissues, leading to chronic inflammation and tissue damage.

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These diseases, including rheumatoid arthritis (RA), systemic lupus erythematosus (SLE), multiple sclerosis (MS), and type 1 diabetes (T1D), impose a significant burden on global health due to their prevalence, complexity, and impact on quality of life. Monitoring disease progression and assessing therapeutic effectiveness are pivotal for improving patient outcomes; however, these tasks remain challenging due to the heterogeneity and fluctuating nature of autoimmune diseases [1].

Biomarkers play a crucial role in addressing these challenges. By providing quantifiable indicators of biological processes, disease activity, and treatment response, biomarkers enhance diagnostic precision and enable personalized therapeutic approaches [2]. They help bridge the gap between clinical observations and underlying molecular mechanisms, offering deeper insights into disease pathology [3].

The rapid advancements in technologies such as genomics, proteomics, and bioinformatics have further propelled biomarker discovery, making it possible to identify novel indicators with high sensitivity and specificity [4]. In this chapter, the roles of biomarkers in monitoring and evaluating therapeutic effectiveness in common autoimmune diseases have been explored. This chapter also describes their classification, highlights key biomarkers for specific diseases, and discusses emerging technologies driving biomarker discovery. Furthermore, we address the challenges and future directions in biomarker research to provide a comprehensive understanding of this rapidly evolving field.

TYPES OF AUTOIMMUNE DISEASES

Autoimmune diseases encompass a wide range of disorders, each with unique pathophysiology, clinical manifestations, and therapeutic challenges [5]. Understanding the different types of autoimmune diseases helps contextualize the role of biomarkers and their application in clinical practice.

Systemic Autoimmune Diseases

Systemic autoimmune diseases affect multiple organs and tissues, leading to widespread inflammation and damage. Examples include:

- ***Systemic Lupus Erythematosus (SLE)*****:** A prototypic systemic autoimmune disease characterized by the presence of autoantibodies like ANA and anti-dsDNA, affecting the skin, joints, kidneys, and central nervous system [6].

- ***Rheumatoid Arthritis (RA)*:** Although primarily affecting the joints, RA can also involve extra-articular manifestations like vasculitis, interstitial lung disease, and cardiovascular complications [7].
- ***Sjögren's Syndrome*:** It is characterized by dry eyes and mouth due to lymphocytic infiltration of exocrine glands; it can also affect other organs, leading to systemic complications [8].

Organ-specific Autoimmune Diseases

Organ-specific autoimmune diseases primarily target a single organ or tissue. Key examples include:

- ***Type 1 Diabetes (T1D)*:** Caused by immune-mediated destruction of pancreatic beta cells, leading to insulin deficiency [9].
- ***Hashimoto's Thyroiditis and Graves' Disease*:** Affecting the thyroid gland, these conditions result in hypothyroidism and hyperthyroidism, respectively [10].
- ***Autoimmune Hepatitis*:** It involves chronic liver inflammation caused by an immune response against hepatic antigens [11].

Neurological Autoimmune Diseases

Neurological autoimmune diseases involve the central or peripheral nervous system and are often associated with debilitating symptoms:

- ***Multiple Sclerosis (MS)*:** Characterized by immune-mediated demyelination and neurodegeneration, leading to sensory, motor, and cognitive impairments [12].
- ***Myasthenia Gravis*:** A disorder caused by autoantibodies targeting acetylcholine receptors, leading to muscle weakness [13].
- ***Neuromyelitis Optica Spectrum Disorder (NMOSD)*:** A rare condition involving optic neuritis and transverse myelitis, often associated with antibodies against aquaporin-4 [14].

Gastrointestinal Autoimmune Diseases

These diseases primarily affect the gastrointestinal tract and are often associated with systemic inflammation:

- ***Celiac Disease*:** Triggered by gluten ingestion in genetically predisposed individuals, leading to intestinal damage and malabsorption [15].
- ***Inflammatory Bowel Disease (IBD)*:** It includes Crohn's disease and ulcerative colitis, characterized by chronic inflammation of the gastrointestinal tract [16].

CHAPTER 7

Current Developments in Serum Biomarkers for Cardio-oncology Risk Stratification and Patient Management

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Abstract: Cardio-oncology is at the intersection of cardiology and oncology, focusing on an emerging dual mandate of optimizing outcomes in cancer therapies and minimizing associated cardiovascular toxicity. The cardiovascular consequences of cancer treatment include anthracyclines, trastuzumab, and checkpoint inhibitors, covering the spectrum of asymptomatic myocardial injury through overt heart failure and arrhythmias. These complications have a great impact on the quality of life and survival of cancer patients, and thus, early identification and proactive management are necessary. Robust serum biomarkers have become indispensable tools for risk stratification, early diagnosis, and therapeutic monitoring, providing a non-invasive and cost-effective approach to patient management. Traditional biomarkers, such as cardiac troponins and natriuretic peptides, remain the mainstay for detecting myocardial injury and cardiac dysfunction. Troponins are very sensitive and specific markers of acute and cumulative cardiotoxic effects of therapies. Natriuretic peptides, including B-type natriuretic peptide (BNP) and N-terminal proBNP (NT-proBNP), are important for the diagnosis and monitoring of heart failure. However, these biomarkers are often unable to detect subclinical cardiotoxicity or to fully capture the complex pathophysiological mechanisms underlying cancer therapy-induced cardiac injury. In doing so, emergent biomarkers have expanded the horizon of cardio-oncology beyond the earlier simplistic diagnostic and prognostic limitations. Galectin-3 and soluble ST2, with their potential roles in fibrosis and myocardial stress, indicate early stages of cardiac remodeling. GDF-15, one of the related inflammation biomarkers, has become more useful in its ability to forecast adverse cardiovascular consequences in cancer patients undergoing cardiotoxic treatments. In addition, circulating microRNAs (miRNAs), small non-coding RNAs, have emerged as highly specific and sensitive indicators of myocardial

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stress and injury. Among these, miR-126, miR-208, and miR-34a are notably interesting as they play roles in detecting subclinical cardiotoxicity and provide insight into disease progression. Advances in proteomics, metabolomics, and multi-biomarker panel technologies have further helped to enhance serum biomarkers. High-throughput omics platforms also help in the discovery of previously uncharacterized biomarkers and clarify the molecular mechanisms of cardiotoxicity.

Keywords: B-type natriuretic peptide, Cardiac biomarker, Cardiac troponins, Cardio-oncology, Cardiotoxicity, Cytokines, Tyrosine kinase inhibitor.

INTRODUCTION

Cardio-oncology is an emerging interdisciplinary field focused on understanding and mitigating the cardiovascular complications associated with cancer and its treatments. The intricate relationship between cancer and cardiovascular health arises from shared risk factors, overlapping pathophysiological mechanisms, and the cardiotoxic effects of various cancer therapies such as chemotherapy, radiotherapy, and immunotherapy. Advances in cancer treatments have significantly improved patient survival rates, but they have also highlighted the importance of addressing long-term cardiovascular health in cancer survivors. Biomarkers, including diagnostic (indicating disease presence), prognostic (predicting outcome), and predictive (guiding treatment response) types, are critical for cardio-oncology management. This paper is structured as follows: Section 1 outlines risk factors associated with cardio-oncology; Section 2 details risk stratification and monitoring strategies; Section 3 explores the correlation between cancer, cardiotoxicity, and serum biomarkers; Section 4 discusses the need for biomarkers; and Section 5 reviews established and emerging serum biomarkers, with future prospects outlined in Section 6. Cardiotoxicity manifests in different forms, including left ventricular dysfunction, arrhythmias, hypertension, and vascular complications, which pose a challenge for both oncologists and cardiologists. Therefore, it is important to have collaborative approaches that integrate cardiovascular risk assessment, early detection of cardiotoxicity, and personalized management strategies for optimizing patient outcomes. This convergence of oncology and cardiology underscores the need for dedicated research to develop biomarkers, imaging modalities, and therapeutic strategies for risk stratification and patient management in cardio-oncology [1, 2].

RISK FACTOR ASSOCIATED WITH CARDIO-ONCOLOGY

Since many cancer treatments have the potential to produce cardiotoxicity (Table **1**), the subject of cardio-oncology is quickly developing and addresses the confluence of cardiovascular diseases (CVD) and cancer therapy. Concern over cardiovascular problems that occur during or after cancer therapy has grown as a

result of improvements in oncology treatments that have increased cancer patient survival rates. Heart failure (HF), arrhythmias, hypertension, thromboembolism, myocardial ischemia, and left ventricular dysfunction are some of the symptoms of cardiotoxicity. Finding risk factors for cardiovascular disease (CVD) linked to cancer therapy is crucial for patient stratification, treatment plan optimization, and preventing irreparable heart damage [2 - 6].

Table 1. Direct and indirect cardiotoxic effects of chemotherapeutic drug classes.

Class of Drug	Examples	Mechanism of Cardiotoxicity	Clinical Effects
Anthracyclines	Doxorubicin, Epirubicin	Oxidative stress, mitochondrial damage, and cardiomyocyte apoptosis	Heart failure, arrhythmias, LV dysfunction
Alkylating Agents	Cyclophosphamide, Ifosfamide	Endothelial injury, direct myocardial toxicity	Myocarditis, HF
HER2 Inhibitors	Trastuzumab, Lapatinib	Inhibition of cardioprotective HER2 signaling	LV dysfunction, HF
Tyrosine Kinase Inhibitors (TKIs)	Sunitinib, Imatinib	Endothelial dysfunction, hypertension	Hypertension, LV dysfunction
Immune Checkpoint Inhibitors (ICIs)	Pembrolizumab, Nivolumab	Autoimmune myocarditis	Myocarditis, arrhythmias

Risk Factors Associated With Patients

Gender and Age

Due to endothelial dysfunction, pre-existing comorbidities, and decreased cardiac reserve, older patients (≥65 years) are more vulnerable to chemotherapy-induced cardiotoxicity. Left ventricular dysfunction is more likely to occur in female patients, especially those on HER2-targeted treatments (such as trastuzumab).

Young cancer survivors are susceptible to heart failure and cardiomyopathy for the rest of their lives, particularly if they were treated with anthracyclines or chest radiation.

Pre-existing CVD

In patients with preexisting cardiovascular disease (CVD), cardiotoxic cancer treatments further increase the risk of cardiac complications, especially in those with a history of hypertension, coronary artery disease, heart failure, or arrhythmias. Obesity and diabetes increase the risk of vascular damage from chemotherapy by exacerbating circulatory stress.

CHAPTER 8

An Adaptable Prospective Biomarker and Therapeutic Target for Diverse Cancer Types

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Abstract: Highly heterogeneous and complex, cancer displays distinct molecular and cellular characteristics in various tumor types. Despite incredible achievements in oncology, there is currently no universal diagnostic or therapeutic target. Biomarkers represent biologically significant molecules that serve as indicators of a disease's presence, progression, or response to treatment, which are essential for early detection, prognosis, and precision therapy selection. An ideal biomarker should be adaptable, allowing its application in different types of cancers while maintaining specificity and sensitivity at the highest degree. This review will present the state of adaptable biomarkers and their relevance to unified strategies in diagnostic and treatment settings among various types of malignancies. Molecular pathways that have a high alteration frequency in cancer include the TP53, PI3K/AKT/mTOR, and RAS-RAF-MEK pathways, which offer a basis for adaptable biomarkers and therapeutic targets. These pathways serve critical roles in cell proliferation, survival, metabolism, and evasion of the immune response, making them candidates for broad-spectrum cancer therapeutics. In addition, newly established biomarkers of the TME, such as immune checkpoint proteins (PD-1, PD-L1, and CTLA-4), metabolic markers (LDH and glutaminase), and the stromal elements, have been identified as a part of tumour progression and response. Advances in liquid biopsy technology have further made it possible to detect circulating tumor DNA (ctDNA), exosomal microRNAs, and tumor-educated platelets, which enable real-time monitoring of disease dynamics and treatment efficacy. Despite the promise of adaptable biomarkers, several challenges persist, including tumor heterogeneity, resistance mechanisms, and economic barriers to widespread implementation. Addressing these challenges requires a multi-omics approach, integrating genomics, transcriptomics, proteomics, and metabolomics to refine biomarker-driven therapeutic strategies. In this review, a comprehensive account is

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given for the current scenario regarding adaptable biomarkers, therapeutic implications, and the potential directions ahead in personalized cancer care.

Keywords: Biomarkers, BRAF, Cancer, Circulating tumor DNA, DNA methylation, EGFR, Epigenetic biomarker, Homologous recombination therapy, Immunological biomarker, KRAS.

INTRODUCTION

Cancer represents an unnatural process characterized by the continuous growth of cells (Fig. **1**) and induced genetic instability. These cells spread beyond the organ in which they originate to invade distant organs. For this reason, cancer remains among the leading causes of morbidity and death at present, with estimates indicating 19.3 million new cases and nearly 10 million deaths in 2020 alone [1]. It is challenging to overcome the heterogeneity of the disease, which is associated with genetic mutations, epigenetic alterations, metabolic reprogramming, and interactions with the tumor microenvironment. Although remarkable progress has been made in the early detection of cancer, targeted therapy, and immunotherapy, the disease remains one of the biggest burdens on the global health care system, which requires further investigation into universal biomarkers and therapeutic strategies [2].

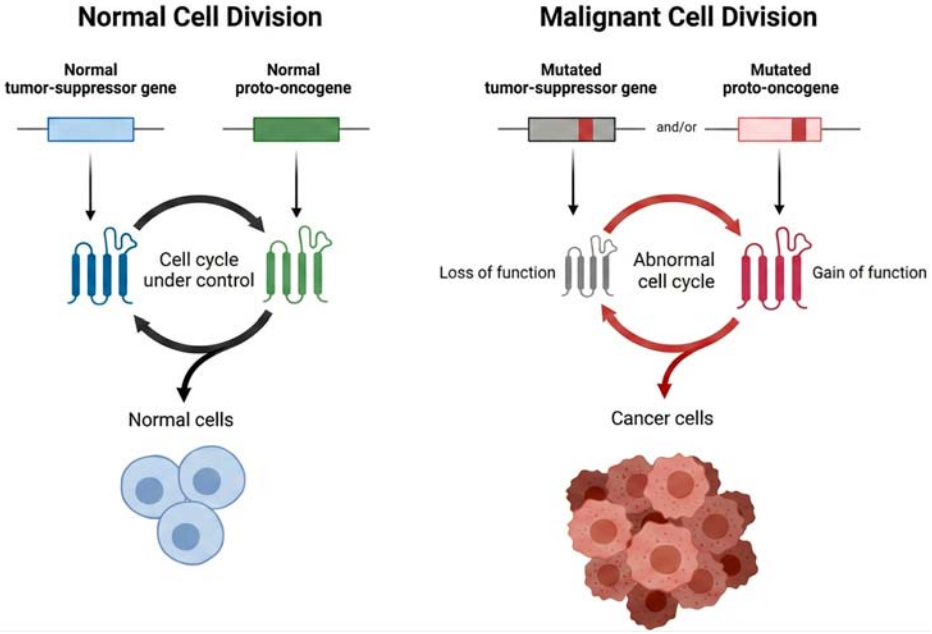

Fig. (1). Difference between normal cell division and malignant cell division.

GLOBAL BURDEN OF CANCER

Cancer is prevalent worldwide, and incidence and mortality vary by region. Various factors, including genetic predisposition, environmental influences, lifestyle choices, and access to healthcare, are responsible for such disparities. Lung, breast, colorectal, prostate, and stomach cancers are the most diagnosed cancers in the world, and the top five cancers causing death are lung, colorectal, liver, stomach, and breast cancers. Lung cancer is the number one cause of death due to cancer, accounting for nearly 1.8 million deaths annually. Breast cancer is the most common cancer in the world, with over 2.3 million cases diagnosed annually; however, increased early detection and hormone-targeted therapy have helped increase survival rates. Colorectal cancer is one of the top three cancers in the world, and its incidence is increasing due to dietary habits, obesity, and an aging population. Liver cancer has one of the worst prognoses. The most common form of this cancer is hepatocellular carcinoma, which is usually associated with hepatitis B/C infections and cirrhosis. The financial burden of cancer is staggering, with annual worldwide expenditures exceeding $1.16 trillion, and early detection, prevention, and proper treatment have become imperative public health issues [1, 3, 4].

The Hallmarks of Cancer: A Molecular Perspective

Cancer develops from the accumulation of genetic mutations and epigenetic alterations that derange normal cellular functions. Hanahan and Weinberg (2011) described “The Hallmarks of Cancer,” which are the following basic biological features that fuel tumorigenesis:

Prolonged proliferative signaling: Cancer cells receive continuous signals to proliferate without the usual check and balance. Oncogenes like KRAS, MYC, and EGFR are activated, leading to uncontrolled cell proliferation [5].

Inadequate growth inhibition: Tumor suppressor genes such as TP53, RB1, and PTEN become inactivated, thus permitting malignant cells to proliferate uncontrollably.

Resistance to cell death (apoptosis): Cancer cells avoid programmed cell death by overexpressing anti-apoptotic proteins, such as BCL-2, and also inactivating the pro-apoptotic pathways.

***Insensitiveness to cellular senescence*:** Cancer cells avoid normal cellular aging by upregulating telomerase, an enzyme that elongates chromosomal ends.

CHAPTER 9

Biomarkers: Prospects for Personalized and Targeted Treatments

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Abstract: Biomarkers are used for diagnostic, prognostic, and predictive purposes. They play key roles in the diagnosis, progression, and management of diseases. The roles of biomarkers are as follows: diagnostic biomarkers help recognize precise diseases, such as troponin levels representing heart attacks, prognostic biomarkers offer insights into disease development or outcomes, like gene profiles predicting cancer survival, and predictive biomarkers forecast treatment responses, such as HER2 status guiding breast cancer therapy. Biomarkers are transforming modern medicine by facilitating personalized and targeted treatment approaches, enabling more precise, effective, and individualized therapeutic strategies. Biomarkers are measurable biological indicators, such as molecules, genes, or other markers of disease, that play a pivotal role in advancing healthcare by providing a deeper understanding of disease biology at the individual level. They are critical not only for diagnosing and predicting the progression of various conditions but also for guiding the selection of optimal treatments tailored to specific patient populations. The emergence of personalized medicine, which leverages individual biomarkers to create customized treatment plans, represents a groundbreaking shift in contemporary healthcare. This chapter delves into the significant roles of biomarkers in driving advancements in personalized and targeted therapies, with a particular focus on their utilization in oncology, cardiovascular diseases, and neurological disorders. Additionally, it highlights emerging trends and technologies in biomarker discovery, addresses challenges in clinical implementation, and explores future directions for this rapidly evolving field.

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Keywords: Advancing healthcare, Biomarkers, Clinical research, Personalized medicine, Precision oncology, Targeted treatment, Therapeutic intervention.

INTRODUCTION

Biomarkers are essential to the methodical creation of medications and medical equipment. Nevertheless, despite their enormous significance, there is a great deal of misunderstanding regarding their fundamental definitions and the ideas underlying their use in clinical and research contexts. Furthermore, it has been acknowledged that the complexity of biomarkers stands in the way of improving our knowledge of nutrition and chronic illnesses. Biomarkers have emerged as essential instruments for disease diagnosis and therapy response assessment in recent decades [1]. By defining biomarkers as biological molecules in blood, other bodily fluids, or tissues that show the presence of illness or normal or aberrant processes and evaluate the body's reaction to therapies, the National Cancer Institute further refines this description.

A biomarker, as used in medicine generally, is a measurable trait that indicates the existence or severity of a disease state. A biomarker is, more broadly, anything that can be utilized as a sign of a certain disease condition or another physiological state of an organism [2]. An objectively measured and assessed trait that serves as an indicator of normal biological processes, pathogenic processes, or pharmacological reactions to a therapeutic intervention is what a working group of the National Institutes of Health characterized as a biomarker in 2001. Genes, proteins, genetic variants, and variations in metabolic expression have been identified as biomarkers from various sources, including bodily fluids and tissues [3].

A biomarker is a chemical that is added to an organism to evaluate other health factors or organ function. It may also be a material that signals the presence of a particular illness or an antibody that indicates an infection. More specifically, biomarkers are changes in the expression or status of proteins linked to the occurrence, progression, or response to treatment of an illness. Body parts like blood or tissue include these measurable biological characteristics, which indicate either normal or aberrant activities. Biomarkers encompass various entities, including cells, chemicals, genes, gene products, enzymes, hormones, and even complex organ functions and structural changes. Although the term is relatively new, biomarkers have long been used in preclinical research and clinical diagnosis [4].

TYPES OF BIOMARKERS

Based on their intended uses, biomarkers can be divided into a number of subgroups (Fig. **1**). Notably, a single biomarker may serve multiple purposes in multiple settings, but distinct evidence needs to be provided for each use case. These subtypes may have similar definitions, but they may have distinctive traits that specify their particular applications. Depending on their use, biomarkers can provide insightful additional information about a condition or the treatment under consideration [5].

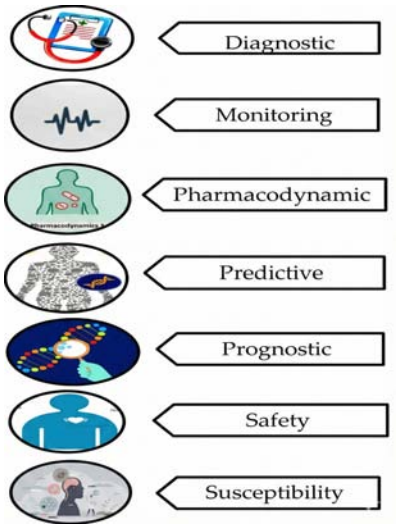

Fig. (1). Types of biomarkers.

Pathogenesis, the onset of the first clinical symptoms, diagnosis, the results of treatment, or recovery are some of the stages at which they can be recognized. The FDA-NIH Biomarker Working Group divides biomarkers into a number of groups according to their primary clinical, susceptibility/risk, monitoring, pharmacodynamic/response, predictive, prognostic, and safety applications. Notably, a single biomarker may serve several purposes or have unique qualities that qualify it for a given use [6].

Diagnostic Biomarkers

Diagnostic biomarkers are used to detect or validate the existence of a disease or condition or differentiate between disease subtypes. Significant progress is being made in diagnostic biomarkers with the emergence of precision medicine. These biomarkers play a crucial role in both redefining illness categories and disease detection. For example, cancer diagnosis is moving from organ-based

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