



## Review Article

### A Review: Recent Advancements in treatment of Cancer Research

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#### Abstract

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*The treatment of cancer has taken a remarkable new direction with the advent of innovative scientific and technological methods. Immunotherapy has revolutionized oncology by harnessing the body's immune system to identify and destroy cancerous cells, leading to long-term remissions in many cancer types. Precision medicine enhances treatment effectiveness by tailoring therapeutic interventions to individual patients based on genetic, environmental, and lifestyle factors, thereby reducing both efficacy and adverse effects. The development of liquid biopsy methods enables non-invasive, real-time cancer detection and monitoring through blood samples (circulating tumor DNA and other biomarkers), allowing for treatment adjustments based on early cancer diagnosis. Recent advancements in CRISPR-Cas9 gene editing have opened new avenues for correcting oncogenic mutations and developing gene-based treatments. The use of artificial intelligence (AI) in cancer diagnostics, prognostics, and drug discovery is becoming increasingly common, enhancing prediction accuracy and optimizing predictive treatment planning. Combination therapies have shown synergistic potential to boost therapeutic effects and overcome drug resistance mechanisms. Meanwhile, cancer metabolism studies aim to exploit the metabolic changes in cancerous cells for therapeutic benefit. Epigenetic therapeutics seek to reverse abnormal genomic developmental control by restoring normal cellular epigenetic patterns and functions. Additionally, research on microbiomes is uncovering the crucial role of gut and tissue microbiota in cancer initiation, progression, and therapy response, suggesting potential new prevention and treatment strategies. These interdisciplinary innovations represent a paradigm shift towards more effective, personalized, and sustainable cancer care, offering new hope for improved patient survival and quality of life.*

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**INTRODUCTION:**

Cancer is a complex group of diseases marked by the uncontrolled growth and spread of abnormal cells, stemming from genetic mutations and external factors(1). It affects millions worldwide and presents significant challenges to public health and medical research. Various types of cancer, including breast, lung, colorectal, prostate, and skin cancers, each have unique risk factors, symptoms, and treatment approaches. These treatments range from surgery and radiation therapy to chemotherapy and immunotherapy. Ongoing research is focused on developing targeted therapies, improving early detection methods, and understanding the molecular mechanisms underlying cancer progression(2). Prevention strategies emphasize lifestyle modifications such as quitting smoking, maintaining a healthy diet, regular exercise, and avoiding excessive sun exposure, alongside screening programs for early detection and intervention(3). The impact of cancer extends beyond physical health, encompassing psychological, social, and economic burdens on individuals, families, and healthcare systems. This necessitates a multidisciplinary approach to cancer care, involving oncologists, surgeons, radiologists, pathologists, nurses, and support staff, with palliative care playing a crucial role in managing symptoms and improving quality of life for those with advanced-stage cancer. Researchers continue to explore innovative treatment modalities such as gene therapy, personalized medicine, and cancer vaccines, aiming to improve survival rates and reduce treatment-related side effects(4). They also address disparities in cancer incidence and outcomes across different populations and socioeconomic groups, with global initiatives focusing on increasing access to cancer prevention, screening, and treatments in low- and middle-income countries. As the field of cancer research rapidly evolves, it incorporates advances in genomics, proteomics, and artificial intelligence to enhance our understanding of cancer biology and develop more effective diagnostic and therapeutic techniques. The ultimate goal is to reduce cancer incidence, improve patient outcomes, and eventually find a cure for this devastating disease that affects millions of lives worldwide(5).

The development of cancer is a multifaceted process that involves a blend of genetic mutations, epigenetic alterations, and cellular dysfunction. Cancerous cells typically acquire several hallmark capabilities, such as sustained proliferative signaling, evasion of growth suppressors, resistance to cell death, replicative immortality, induction of angiogenesis, and activation of invasion and metastasis. These mutations often impact proto-oncogenes, tumor suppressor genes, and DNA

repair genes. Oncogenes become activated, leading to uncontrolled cell growth and division, while tumor suppressors are inactivated, resulting in a lack of control over cell cycle checkpoints. Additionally, genomic instability may be observed in cancer cells, leading to further mutations and chromosomal aberrations. The tumor microenvironment, comprising surrounding stromal and immune cells, also plays a crucial role in cancer progression by providing growth factors, enhancing angiogenesis, and inhibiting immunity. Understanding these mechanisms is vital for designing targeted therapies and improving cancer management strategies(6).

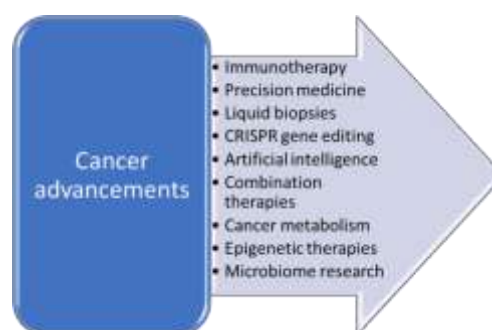


Figure 1 Emerging technologies in cancer Reserach

**Emerging technologies in cancer research**

In recent years, the field of oncology has increasingly embraced emerging technologies that have significantly transformed the diagnosis and treatment of cancer. Immunotherapy is revolutionizing cancer care by enhancing the body's natural immunity to target cancer cells. Precision medicine enables the customization of treatment regimens based on an individual's genetic and molecular profile, thereby improving treatment outcomes and minimizing side effects. Liquid biopsies provide a non-invasive approach for early cancer diagnosis, real-time imaging, and monitoring treatment responses through circulating biomarkers. CRISPR gene editing has opened new avenues for correcting genetic mutations and developing targeted cancer therapies(7). The role of artificial intelligence (AI) in cancer research and clinical decision-making is evolving with the use of advanced data analysis, predictive modeling, and drug discovery. Combination therapies leverage the synergistic effects of various treatment modalities to maximize efficacy and overcome resistance fig:1. The study of cancer metabolism focuses on exploiting the altered metabolism of cancer cells to disrupt their growth and survival. Epigenetic therapies aim to rectify abnormal gene expression by reversing aberrant epigenetic changes associated with cancer. Additionally, research into the microbiome explores the complex interactions between

human microbiota and cancer development, influencing treatment responses and overall patient well-being. These advancements are already driving a paradigm shift in oncology, leading to more effective, personalized, and sustainable cancer treatments that enhance patient outcomes and quality of life fig:1(8).

**1. Immunotherapy:** Immunotherapy has emerged as a groundbreaking approach to cancer treatment, leveraging the body's immune system to combat cancer cells. This innovative strategy encompasses various methods, notably checkpoint inhibitors and CAR-T cell therapy. Checkpoint inhibitors function by blocking specific proteins that can prevent immune cells from attacking cancer cells, effectively dismantling the immune system's barriers. These inhibitors target proteins such as PD-1, PD-L1, and CTLA-4, enabling T cells to more readily identify and destroy cancer cells. In contrast, CAR-T cell therapy involves genetically modifying a patient's T cells to express chimeric antigen receptors (CARs) aimed at cancer cells. These engineered T cells are then reintroduced into the patient's body, where they can detect and eliminate cancer cells with remarkable precision. Both methods have shown promising results in treating various cancers, including melanoma, lung cancer, and certain blood cancers. Immunotherapy can offer long-term remissions and, in some cases, even cures for patients who have exhausted other treatment options. However, it is important to note that not all immunotherapy is successful, and sometimes the side effects can be severe due to an excessive immune response. Current research is focused on enhancing the efficacy of these treatments, developing new targets, and devising combination therapies to improve outcomes for cancer patients(9).

**2. Precision medicine:** Precision medicine represents a paradigm shift in cancer treatment, moving away from the one-size-fits-all approach to a personalized strategy that considers the genetic makeup of a patient's specific tumor. This innovative treatment method leverages cutting-edge genomic sequencing technologies to examine the unique genetic mutations and alterations present in cancer cells. Oncologists can then develop a tailored treatment plan targeting these specific molecular anomalies. By identifying a tumor's distinct genetic signature, medical professionals can select treatments with a higher likelihood of effectiveness against that particular cancer, potentially benefiting the patient and minimizing unnecessary adverse effects. This strategy has led to the development of targeted therapies, such as tyrosine kinase inhibitors and monoclonal antibodies, designed to disrupt the molecular pathways that drive tumor growth and progression. In breast cancer, the discovery of HER2 overexpression has led to the development of trastuzumab, a targeted therapy that has significantly improved survival rates for patients with

HER2-positive tumors. Similarly, identifying EGFR mutations and ALK rearrangements in non-small cell lung cancer has resulted in targeted therapies like erlotinib and crizotinib, which have shown remarkable efficacy in patients with these genetic defects. Pharmacogenomics, a component of precision medicine, explores the relationship between an individual's genetic makeup and their response to medication. This knowledge allows healthcare providers to predict how patients might respond to a particular treatment and identify those at higher risk of adverse effects, enabling more informed decision-making and reducing treatment-related complications. Furthermore, precision medicine can revolutionize clinical trial design by allowing for more precise patient selection using genetic biomarkers, potentially accelerating drug development and approval(9). Precision medicine is expanding to include other molecular characteristics beyond genomics, such as epigenetics, proteomics, and metabolomics, offering a more comprehensive view of tumor biology and therapeutic targets. Despite its potential, precision medicine faces challenges, including the need for advanced bioinformatics systems to analyze complex genomic data, the establishment of standardized guidelines for tumor profiling, and addressing cost and access issues to ensure all patients can benefit from these innovative approaches. Additionally, as tumors may evolve and develop resistance to specific targeted therapies, ongoing research aims to overcome these resistance mechanisms and identify new therapeutic targets. As the field of precision medicine continues to advance, it is poised to significantly impact cancer treatment outcomes, reduce healthcare costs by preventing ineffective treatments, and ultimately enhance the quality of life for cancer patients by providing more effective and less toxic treatment options tailored to their unique tumor profiles(10).

**3. Liquid biopsies:** Liquid biopsies represent an innovative approach to cancer diagnostics and monitoring, utilizing blood samples to identify and screen for cancer-related biomarkers. This non-invasive technique primarily targets circulating tumor DNA (ctDNA), which consists of DNA fragments released into the bloodstream by tumor cells. By examining these fragments, cancer-specific genetic mutations can be identified, enabling early detection and monitoring of treatment response. In addition to ctDNA, liquid biopsies also analyze other biomarkers such as circulating tumor cells (CTCs), exosomes, cell-free RNA, and proteins, offering a comprehensive view of the cancer's molecular landscape. The applications of liquid biopsies are diverse, encompassing early cancer diagnosis, drug selection and monitoring, tumor dynamics, discovery of drug resistance mechanisms, and minimal residual disease. One of the most significant advantages of liquid biopsies is their

non-invasive nature compared to traditional tissue biopsies, allowing for repeated sampling and real-time monitoring of disease progression or treatment response. This method also assesses tumor heterogeneity across multiple sites, providing a more detailed account of the disease than single-site tissue biopsies. However, liquid biopsies face challenges, including the need to improve sensitivity and specificity, standardize methodologies and interpretations, and integrate them into clinical practice. Current research is focused on overcoming these challenges to enhance the applicability of liquid biopsies in cancer treatment. Future trends in liquid biopsy development include multi-analyte methods that integrate multiple biomarkers to improve diagnostic accuracy and the use of artificial intelligence for data analysis and interpretation. As new technologies emerge and the clinical knowledge base expands, liquid biopsies are poised to become integral to personalized cancer care, potentially leading to earlier diagnoses, optimal treatment choices, and improved patient outcomes(11). The non-invasive nature of liquid biopsies offers a favorable solution for patients and healthcare professionals, reducing patient discomfort and complications associated with traditional tissue biopsies. Furthermore, the ability to perform liquid biopsies repeatedly allows for continuous monitoring of cancer progression and treatment efficacy, enabling timely adjustments to treatment strategies. Real-time monitoring is particularly valuable for tracking drug resistance development and determining when alternative treatment options should be considered. As research progresses, liquid biopsies could play a significant role in cancer screening programs, potentially enabling the detection of cancer at its earliest, most treatable stages. Combining liquid biopsy data with other clinical information, such as imaging data and patient history, may lead to a more comprehensive and accurate approach to cancer management. Although challenges remain in standardizing techniques and interpreting results across various cancer types and stages, the potential of liquid biopsies to revolutionize cancer management is promising. As technology advances and clinical validation continues, liquid biopsies are set to become an indispensable tool in the fight against cancer, offering patients worldwide the opportunity for better lives and outcomes(12).

**4. CRISPR gene editing:** CRISPR-Cas9 gene editing has emerged as a powerful tool in cancer research and management, thanks to its unparalleled precision in manipulating genes associated with cancer expression. One of the most prevalent applications of CRISPR in cancer treatment is targeting oncogenes, which are cancer-causing genes that become mutated or overexpressed when altered. By using CRISPR to disable or modify these oncogenes, scientists aim to halt or slow cancer progression. A notable example is the promising

results in targeting the KRAS gene, which is frequently mutated in various cancers, including pancreatic, lung, and colorectal cancers. Another significant area of interest is the enhancement of tumor suppressor genes. These genes naturally protect cells against cancer but can be deactivated in cancer cells. CRISPR technology offers the potential to restore the function of these genes, such as p53, known as the "guardian of the genome," which plays a crucial role in preventing tumor formation. Additionally, CRISPR may be instrumental in altering genes involved in DNA repair mechanisms(13). Malfunctions in these repair pathways can lead to certain cancers and genomic instability. By correcting these defects or enhancing repair capabilities, CRISPR could add a new level of effectiveness to existing cancer treatments, including chemotherapy and radiation therapy. Immunotherapy, a novel approach to cancer treatment, could also greatly benefit from CRISPR gene editing. Researchers are exploring ways to modify immune cells, particularly T cells, to enhance their ability to recognize and destroy cancer cells. Efforts are underway to enhance the expression of chimeric antigen receptors (CARs) on T cells, aiming to develop improved CAR-T cell therapies for various cancer types. CRISPR technology offers the potential to combat drug resistance in cancer cells. Researchers are focused on identifying and modifying the genes responsible for resistance mechanisms, thereby making cancerous cells more susceptible to existing treatments. This approach could restore the efficacy of drugs that have been compromised by resistance. Additionally, a significant challenge lies in the delivery of CRISPR components into cancer cells in vivo. Future research aims to develop efficient and safe delivery systems, such as viral vectors and nanoparticles, to ensure the CRISPR machinery reaches the target cells. Ethical considerations surrounding gene editing, particularly in humans, remain a concern. As CRISPR technology advances, it is crucial to establish robust regulatory measures and ethical guidelines to govern its application in cancer treatment(14).

**5. Artificial intelligence:** Artificial intelligence (AI) and machine learning (ML) algorithms have revolutionized oncology, offering unprecedented opportunities to enhance cancer diagnosis, treatment planning, and drug discovery. These advanced computational techniques leverage vast amounts of medical data to identify patterns, predict outcomes, and generate insights that were once unattainable. AI-driven image analysis tools can swiftly and accurately detect subtle anomalies in medical imaging tests, such as MRIs, CT scans, and mammograms, which are crucial for cancer diagnosis. These systems enable early detection and more precise diagnoses by identifying potential tumors, classifying their characteristics, and even predicting their likelihood of becoming malignant. AI algorithms can also integrate

data from various sources, including genetic information, medical history, and clinical parameters, to create comprehensive risk profiles and personalized screening recommendations. During treatment planning, AI aids oncologists in developing customized therapeutic strategies by analyzing patient data and comparing it with extensive databases of treatment outcomes. Machine learning models can predict treatment responses, anticipate potential side effects, and optimize dosage schedules, leading to more effective and less harmful interventions. AI-driven decision support systems can also assist physicians in navigating complex treatment options by considering factors such as patient preferences, available clinical trials, and tumor genetics. In drug discovery, AI's ability to analyze large chemical libraries, predict molecular interactions, and simulate drug effects accelerates the development of new cancer treatments. Machine learning algorithms can significantly reduce the time and cost associated with traditional drug discovery methods by screening millions of compounds to identify potential drug candidates. Additionally, AI-powered systems can analyze genomic data to discover novel therapeutic targets and predict drug resistance mechanisms, paving the way for more targeted and effective treatments. Furthermore, by uncovering unexpected molecular similarities among various diseases, AI facilitates the repurposing of existing medications for cancer treatment. The integration of AI in cancer research has given rise to precision oncology, where treatments are tailored to the specific genetic and molecular characteristics of each patient's tumor. Machine learning algorithms can analyze complex genomic data to identify driver mutations, predict treatment outcomes, and guide the selection of immunotherapies or targeted therapies. This personalized approach has the potential to significantly improve the quality of life and treatment outcomes for cancer patients. Additionally, AI is transforming patient recruitment and clinical trial design by predicting trial outcomes and identifying suitable candidates based on genetic profiles. This not only increases the likelihood of successful trials but also accelerates the drug development process. As these technologies advance, the impact of AI and machine learning on cancer treatment is expected to grow rapidly. However, challenges remain, such as the need for large, diverse, and high-quality datasets for AI model training, ensuring the interpretability and transparency of AI-generated recommendations, and addressing ethical concerns related to algorithmic bias and data privacy. To overcome these challenges and establish robust frameworks for the ethical development and application of AI in oncology, collaboration among clinicians, researchers, data scientists, and policymakers is essential. In conclusion, incorporating artificial intelligence and machine learning algorithms into cancer research and

clinical practice holds immense potential for improving patient outcomes across the entire cancer care spectrum, from early detection to personalized treatment and drug discovery(15).

**6. Nanotechnology:** Nanotechnology, a rapidly advancing field at the intersection of science, engineering, and medicine, has transformed the development of nanoparticles for targeted drug delivery and enhanced imaging techniques. This revolution offers unprecedented opportunities to improve diagnostic and therapeutic approaches in healthcare by leveraging the unique characteristics of materials at the nanoscale, such as increased surface area-to-volume ratio, enhanced reactivity, and the ability to penetrate biological barriers. These properties enable the creation of highly efficient and precise drug delivery systems that can selectively target specific cells or tissues, minimizing side effects and maximizing therapeutic efficacy(12). Simultaneously, advancements in imaging technologies provide more detailed and accurate visualizations of biological frameworks and processes at the molecular level. Applications range from cancer treatment and neurological disorders to cardiovascular and infectious diseases, where nanoparticles can be engineered to carry a wide variety of payloads, including small molecule drugs, proteins, nucleic acids, and imaging agents. They can also be functionalized with targeting moieties such as antibodies, peptides, or aptamers to enhance their specificity and affinity for particular cellular receptors or biomarkers, thereby improving the pharmacokinetics and biodistribution of therapeutic agents and minimizing off-target effects. In imaging, nanoparticles can serve as contrast agents for various modalities, including magnetic resonance imaging (MRI), computed tomography (CT), positron emission tomography (PET), and optical imaging, offering enhanced sensitivity, improved resolution, and multimodal capabilities that enable more comprehensive and accurate diagnoses(16). Recent advancements focus on developing "theranostic" nanoparticles that combine both therapeutic and diagnostic functions in a single platform, allowing for real-time monitoring of drug delivery and treatment efficacy, as well as personalized medicine approaches that tailor treatments to individual patients based on their unique molecular profiles. Ongoing research continues to address challenges such as optimizing nanoparticle size, shape, and surface properties to enhance their stability, biocompatibility, and targeting efficiency, as well as developing novel fabrication techniques and scalable manufacturing processes to ensure consistent production and quality control of nanoparticle-based formulations. Efforts are also directed towards understanding and mitigating potential toxicity and long-term effects of nanoparticles in biological systems, as well as addressing regulatory and ethical considerations surrounding their

use in clinical applications(17). As the field of nanotechnology continues to evolve, promising new developments include stimuli-responsive nanoparticles that can release their payload in response to specific environmental cues such as pH, temperature, or enzymatic activity, as well as nanorobots capable of performing complex tasks within the body, such as targeted drug release or minimally invasive surgery. The integration of nanotechnology with other cutting-edge fields like artificial intelligence, gene editing, and 3D bioprinting is expected to further expand the possibilities for precision medicine and personalized healthcare, ultimately leading to more effective treatments, earlier disease detection, and improved patient health(18).

**7. Combination therapies:** In medicine, combination therapies have shown considerable promise, especially in treating infectious and cancerous conditions. Healthcare practitioners aim to enhance therapeutic efficacy, reduce side effects, and overcome drug resistance by integrating various treatment modalities. This approach leverages the synergistic effects of different drugs or therapeutic methods to improve patient outcomes. One of the primary advantages of combination therapies is their ability to target multiple pathways or mechanisms simultaneously. In cancer treatment, combining targeted therapies with chemotherapy can attack cancer cells through various mechanisms, potentially increasing the likelihood of tumor regression(19). This multifaceted strategy is particularly effective when dealing with heterogeneous tumors, where different cancer cell populations may respond variably to single-agent treatments. Another crucial benefit of combination therapies is their capacity to overcome drug resistance. Over time, diseases may develop resistance to single-drug therapies, diminishing their effectiveness. By employing multiple medications with distinct modes of action, the risk of resistance development is reduced. This approach has proven especially effective in HIV treatment, where combination antiretroviral therapy (cART) has significantly improved patient outcomes and life expectancy(20). Additionally, combination therapies allow for the reduction of individual component dosages, potentially minimizing side effects while maintaining or enhancing efficacy. For instance, combining lower doses of two different antihypertensive drugs can often achieve better blood pressure control with fewer side effects than using a higher dose of a single drug. The concept extends beyond pharmacological treatments. Combining medications with other treatment forms, such as immunotherapy, radiation therapy, or surgery, can yield better outcomes. Neoadjuvant chemotherapy followed by surgery has become a standard treatment for many solid tumors to improve surgical results and overall survival rates(21). Developing effective combination treatments presents challenges. Drug-drug interactions must be carefully

considered to avoid side effects or reduced efficacy. Determining the optimal timing and dosage for multiple treatments can be complex, often necessitating extensive clinical trials. Personalized medicine has further enhanced the potential of combination therapies. By analyzing characteristics such as genetic profiles and biomarkers, healthcare professionals can tailor combination treatments to individual patients' needs, potentially improving outcomes and reducing unnecessary treatments(22). In the realm of drug discovery, artificial intelligence and machine learning have opened new avenues for identifying potential combination treatments. These technologies can analyze vast amounts of data to predict effective drug combinations and enhance treatment strategies. As research advances, combination treatments are likely to become more intricate and personalized. It is expected that integrating genomics, proteomics, and other -omics technologies with traditional clinical data will further refine combination therapy approaches, leading to more individualized and effective treatment plans. In essence, compared to single-agent methods, combination therapies offer enhanced efficacy, reduced resistance, and potentially fewer side effects, representing a significant leap forward in medical treatment(23). The development and application of combination therapies are anticipated to play an increasingly vital role in improving patient outcomes across various medical fields as understanding of disease mechanisms and drug interactions deepens. In medicine, combination therapies have demonstrated significant promise, particularly in treating infectious and cancerous conditions. Healthcare professionals aim to boost therapeutic efficacy, minimize side effects, and overcome drug resistance by integrating different treatment modalities. This approach leverages the synergistic effects of various drugs or therapeutic methods to enhance patient outcomes. One of the primary benefits of combination therapies is their ability to target multiple pathways or mechanisms simultaneously. In cancer treatment, combining targeted therapies and chemotherapy can attack cancer cells through diverse mechanisms, potentially increasing the likelihood of tumor regression(24). This multifaceted approach can be especially effective when treating heterogeneous tumors, where different cancer cell populations may respond variably to single-agent treatments. Another key advantage of combination therapies is their capacity to overcome drug resistance. Over time, diseases may develop resistance to single-drug therapies, diminishing their effectiveness. By employing multiple medications with different modes of action, the risk of resistance development is reduced. This strategy has proven particularly effective in treating HIV, where combination antiretroviral therapy (cART) has significantly improved patient outcomes and life expectancy. Additionally,

combination therapies allow for the reduction of individual component dosages, which may decrease side effects while maintaining or enhancing efficacy(25). For instance, combining lower doses of two distinct antihypertensive drugs can often achieve better blood pressure control and fewer side effects in treating hypertension than using a higher dose of a single drug. The concept extends beyond pharmacological treatments. Combining medications with other treatment forms, such as immunotherapy, radiation therapy, or surgery, can yield better outcomes. To enhance surgical outcomes and overall survival rates, neoadjuvant chemotherapy followed by surgery has become a standard treatment for many solid tumors. However, developing effective combination treatments presents challenges(26). Drug-drug interactions must be carefully managed to avoid side effects or reduced efficacy. Determining the optimal timing and dosage for multiple treatments can be complex, often necessitating extensive clinical trials. The potential of combination therapies has been further amplified by personalized medicine. By analyzing characteristics such as genetic profiles and biomarkers, healthcare professionals can tailor combination treatments to individual patient needs, potentially improving outcomes and reducing unnecessary treatments. In drug discovery, artificial intelligence and machine learning have opened new avenues for identifying potential combination treatments. These technologies can analyze vast amounts of data to predict synergistic drug combinations and optimize treatment strategies(27). As research advances, combination treatments are likely to become more sophisticated and personalized. The integration of genomics, proteomics, and other -omics technologies with traditional clinical data is expected to further refine combination therapy approaches, leading to more individualized and effective treatment plans(28).

**8. Cancer metabolism:** Metabolic reprogramming refers to the process by which cancer cells exhibit distinct metabolic characteristics that differentiate them from healthy cells. This altered metabolism supports their rapid growth, survival, and metastasis. Understanding these unique metabolic pathways enables the development of targeted cancer treatments. One of the most recognized metabolic alterations in cancer is the Warburg effect, where cancer cells preferentially utilize glycolysis for energy production, even in the presence of oxygen. This aerobic glycolysis results in increased lactate production and glucose uptake. To facilitate this process, cancer cells upregulate the expression of glycolytic enzymes and glucose transporters, such as GLUT1. Beyond rapid ATP production, the Warburg effect supplies intermediates for biosynthetic pathways crucial for cell division(29). Another significant pathway altered in many cancers is

glutamine metabolism. Cancer cells often exhibit "glutamine addiction" due to their heavy reliance on this amino acid for energy production and biosynthesis. Glutamine replenishes TCA cycle intermediates (anaplerosis) and provides nitrogen for nucleotide synthesis. Glutaminase, an enzyme that converts glutamine into glutamate, is frequently overexpressed in cancer cells and may serve as a therapeutic target. Dysregulation of lipid metabolism is also prevalent in cancer(13). Many cancer cells demonstrate increased de novo lipid synthesis, essential for membrane biogenesis and signaling molecules. Key enzymes in this pathway, such as fatty acid synthase (FASN) and ATP citrate lyase (ACLY), are often overexpressed in various cancers and are being explored as potential therapeutic targets(30,31). The pentose phosphate pathway (PPP) is another critical metabolic pathway altered in cancer. This pathway generates ribose-5-phosphate for nucleotide synthesis and NADPH, necessary for redox balance and biosynthesis. Cancer cells often upregulate the PPP to meet their heightened biosynthetic demands and manage oxidative stress. Contrary to common belief, mitochondrial metabolism also plays a significant role in many cancers. While some cancer cells depend on mitochondrial oxidative phosphorylation, others primarily rely on glycolysis. This metabolic flexibility allows cancer cells to adapt to different microenvironments and energy needs. Preclinical research has shown promise in targeting mitochondrial metabolism, particularly by inhibiting complex I of the electron transport chain(32). Numerous treatment strategies have emerged from the understanding of these metabolic changes. Clinical trials have explored glycolysis inhibitors such as lonidamine and 2-deoxyglucose. Cancers with a high dependence on glutamine are being examined in relation to glutaminase inhibitors like CB-839. TVB-2640 is among the FASN inhibitors being clinically developed to target lipid metabolism. Additionally, clinical trials are underway to evaluate mitochondrial inhibitors, including IACS-010759 and metformin. However, targeting cancer metabolism poses several challenges. Cancer cells often exhibit metabolic plasticity, utilizing different pathways to adapt to metabolic inhibition. Moreover, the type, stage, and microenvironment of a tumor can influence the metabolic requirements of cancer cells. For effective treatment, combination therapies that target multiple metabolic pathways or integrate metabolic inhibitors with other cancer therapies may be necessary(14,33).

**9. Epigenetic therapies:** Various epigenetic alterations in cancer cells contribute to their malignant characteristics. These changes encompass chromatin remodeling, histone modifications, and DNA methylation variations. The aim of epigenetic therapies is to reverse these aberrant changes and restore normal gene

expression patterns. DNA methylation inhibitors, such as decitabine and azacitidine, target DNA methyltransferases (DNMTs) to reduce global DNA methylation. These drugs have shown efficacy in treating acute myeloid leukemia and myelodysplastic syndromes(34). Histone deacetylase (HDAC) inhibitors, like vorinostat and romidepsin, enhance histone acetylation and gene activation, showing promise in treating multiple myeloma and certain lymphomas. To enhance effectiveness and overcome resistance, combination therapies targeting multiple epigenetic mechanisms are being explored. For example, preclinical studies have demonstrated synergistic effects when combining DNA methylation inhibitors with HDAC inhibitors. Emerging epigenetic targets include histone methyltransferases, histone demethylases, and bromodomain proteins. Inhibitors of these enzymes, such as JQ1 (a BET inhibitor) and tazemetostat (an EZH2 inhibitor), are in clinical development. Challenges with epigenetic therapies include potential toxicity to healthy cells and off-target effects(35). Ongoing research aims to develop more targeted inhibitors and optimize dosage schedules. Identifying predictive biomarkers to select patients most likely to benefit from epigenetic therapies is another challenge. Tumor epigenetic profiling may assist in monitoring response and guiding treatment decisions. Resistance to epigenetic therapies can arise through mechanisms like the activation of alternative epigenetic pathways or genetic mutations. To overcome resistance, combination strategies with immunotherapies or other targeted therapies are under investigation. Beyond their direct anti-tumor effects, epigenetic therapies hold additional potential. By modifying the tumor microenvironment or enhancing tumor immunogenicity, these drugs may improve the efficacy of other cancer treatments. Reprogramming cancer stem cells through epigenetic therapies has shown promise in addressing tumor metastasis and recurrence. Research is underway to identify the epigenetic readers, writers, and erasers that maintain cancer stem cell characteristics(36). New delivery systems, such as nanoparticle formulations, are being developed to improve the pharmacokinetics and target specificity of epigenetic drugs. This approach may reduce systemic toxicity while enhancing efficacy. Epigenetic editing technologies, like CRISPR-Cas9-based systems, offer the potential to precisely modify epigenetic markers at specific genomic sites. Although these methods are still in the preclinical stage, they may eventually enable highly targeted epigenetic therapies. Understanding the complex interactions between genetic and epigenetic changes in cancer is crucial for developing successful combination strategies. The integration of genomic and epigenomic profiling may guide personalized epigenetic therapy approaches. Further research is needed to assess the long-term effects of

epigenetic therapies, including any potential transgenerational impacts, to ensure safety and efficacy. Continued exploration of the fundamental mechanisms of epigenetic regulation in cancer is likely to uncover novel therapeutic targets and strategies for epigenetic modification(11,37).

**10. Microbiome research:** Research on the microbiome has become crucial for understanding the onset of cancer and its response to treatment. The human gut microbiome, composed of trillions of microorganisms, plays a vital role in maintaining overall health and influencing various physiological functions. Recent studies suggest that alterations in the gut microbiota's composition can impact cancer development, progression, and treatment outcomes. Scientists are investigating how specific bacterial species and their metabolites influence tumor growth and interact with the host immune system. Certain gut bacteria have been found to produce metabolites that promote inflammation and DNA damage, potentially leading to cancer development. Conversely, other bacterial species may offer protection by producing anti-inflammatory compounds or enhancing the immune system's defenses against cancer cells. Another significant research area is the microbiome's effect on cancer treatment efficacy. Some gut bacteria have been shown to modify the body's response to immunotherapy and chemotherapy, affecting treatment success(38,39). For example, certain bacterial species might enhance the immune system's ability to recognize and attack cancer cells, while others could metabolize chemotherapy drugs, reducing their effectiveness. Understanding these interactions could lead to personalized treatment plans that consider a patient's microbiome profile. Scientists are exploring ways to modify the gut microbiota to improve cancer prevention and treatment effectiveness. This includes investigating fecal microbiota transplantation as a potential therapeutic approach and developing probiotics or prebiotics to promote beneficial bacteria growth. Additionally, research into the microbiome's role in cancer could lead to new biomarkers for prognosis and early detection(40,41).

**Conclusion:**

Immunotherapy, which harnesses the body's immune system to fight cancer cells, has revolutionized cancer treatment, yielding long-lasting effects across various cancer types. Precision medicine enhances efficacy and reduces side effects by tailoring treatments to each patient, considering lifestyle, environmental, and genetic factors. Liquid biopsies, by analyzing circulating tumor DNA and other biomarkers in blood samples, enable the non-invasive detection and monitoring of cancer. CRISPR gene editing technology offers unprecedented potential for repairing genetic mutations and developing innovative cancer treatments. Artificial intelligence is

transforming cancer research and care through improved drug discovery, treatment planning, and diagnostics. Combination therapies enhance efficacy and overcome resistance mechanisms by leveraging the synergistic effects of multiple drugs or therapeutic approaches. Cancer metabolism research focuses on understanding and addressing metabolic changes in cancer cells to develop novel treatment strategies. Epigenetic therapies aim to reverse abnormal epigenetic modifications in cancer cells to restore normal gene expression patterns and cellular functions. Microbiome research, by exploring the complex interactions between the human microbiome and cancer's onset, progression, and treatment response, opens new avenues for cancer prevention and treatment.

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