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Advancements in Liquid Biopsy A Non-Invasive Approach for Cancer Diagnosis and Monitoring

Cheng Wei*

Department of Molecular Diagnostics, Peking University, 72 Medical St, Beijing, 100084, China

Introduction

Cancer remains one of the leading causes of death worldwide, with early detection and continuous monitoring being pivotal in improving survival rates. Traditionally, cancer diagnosis and monitoring have relied on invasive methods such as tissue biopsies and imaging techniques, which can be uncomfortable, costly, and often impractical for routine use. In recent years, liquid biopsy has emerged as a revolutionary non-invasive alternative for cancer diagnosis, treatment monitoring, and detection of Minimal Residual Disease (MRD). Liquid biopsy involves the analysis of biological fluids, such as blood, urine, or saliva, to detect tumor-derived material, including Circulating Tumor DNA (ctDNA), Circulating Tumor Cells (CTCs), exosomes, and circulating microRNAs. This approach allows for real-time monitoring of tumor dynamics and enables the identification of genetic alterations, mutations, and other biomarkers that are crucial for personalizing cancer treatment. Liquid biopsy offers numerous advantages, including convenience, minimal patient discomfort, and the ability to monitor cancer progression and treatment response over time without the need for invasive procedures [1].

The potential applications of liquid biopsy in oncology are vast, ranging from early cancer detection to monitoring treatment efficacy and detecting relapse. One of the most significant advantages of liquid biopsy is its ability to provide a comprehensive overview of tumor heterogeneity, as it captures DNA or cells from multiple tumor sites, providing a more accurate reflection of the overall tumor landscape than traditional biopsies, which typically sample only a single tissue site. Additionally, liquid biopsy can be performed at multiple time points, allowing for dynamic monitoring of tumor evolution and the development of treatment resistance. This is particularly important in cancers like lung cancer, colorectal cancer, and breast cancer, where tumors may evolve rapidly, acquiring new mutations that make them resistant to initially effective treatments. By detecting these mutations early, clinicians can adapt treatment plans to target emerging resistance mechanisms. Liquid biopsy also holds promise for detecting Minimal Residual Disease (MRD) after treatment, which can serve as an early warning system for relapse, even before clinical symptoms appear. As the field advances, liquid biopsy is expected to become a cornerstone of personalized cancer care, enabling more accurate diagnosis, timely intervention, and better long-term outcomes for patients [2].

Description

A key component of liquid biopsy is the detection of Circulating Tumor DNA (ctDNA), which is released into the bloodstream as cells in the tumor undergo apoptosis or necrosis. ctDNA is often fragmented and carries tumor-specific genetic mutations, such as point mutations, Copy Number Variations (CNVs), and gene rearrangements, which are critical for cancer diagnosis and treatment monitoring. Since ctDNA reflects the genetic makeup of the primary tumor as well as metastases, it provides a dynamic picture of the tumor's genetic evolution. This makes ctDNA a highly valuable tool for detecting mutations associated with targeted therapies or immunotherapies. For instance, in Non-Small Cell Lung Cancer (NSCLC), EGFR mutations and ALK rearrangements can be detected in ctDNA, guiding the use of specific tyrosine kinase inhibitors (TKIs). Additionally, liquid biopsy can be used to monitor treatment response by tracking changes in ctDNA levels, with decreasing ctDNA levels often indicating a favorable treatment response, while stable or rising ctDNA levels may signal resistance or disease progression. This allows clinicians to adjust treatment plans earlier than with traditional imaging methods, which may not detect small changes in tumor size until later stages [3].

Circulating Tumor Cells (CTCs) are another critical analyte detected through liquid biopsy. CTCs are cancer cells that have detached from the primary tumor and entered the bloodstream, where they can travel to distant organs and initiate metastasis. The detection and characterization of CTCs can provide insights into tumor metastasis, clonal evolution, and drug resistance. Techniques like the CellSearch System and microfluidic devices have been developed to capture and isolate CTCs from blood samples. These technologies enable the enumeration and molecular profiling of CTCs, providing valuable prognostic information and helping to assess the likelihood of metastasis. CTC analysis can also help predict patient outcomes, monitor treatment efficacy, and assess the development of therapeutic resistance. For example, in breast cancer, a higher number of CTCs detected in the blood has been associated with poor prognosis and increased risk of metastasis. Furthermore, by analyzing the molecular characteristics of CTCs, clinicians can obtain information on the specific mutations driving cancer progression, enabling more personalized treatment regimens [4].

Exosomes and circulating microRNAs are emerging biomarkers that offer additional insights into cancer biology through liquid biopsy. Exosomes are small vesicles secreted by tumor cells into the bloodstream, and they carry a variety of molecules, including proteins, lipids, RNA, and DNA, reflecting the molecular profile of the tumor. The analysis of exosomal content can provide insights into tumor signaling, immune evasion, and metastatic potential. For instance, certain miRNAs found in exosomes have been shown to be involved in cancer progression, metastasis, and resistance to chemotherapy, making them valuable targets for diagnosis and monitoring. Additionally, circulating microRNAs, small non-coding RNA molecules that regulate gene expression, have been implicated in cancer initiation, progression, and response to treatment. miRNA profiles in blood or urine samples may provide diagnostic and prognostic information, helping clinicians to identify specific subtypes of cancer or predict responses to therapies. Both exosomes and miRNAs hold promise as non-invasive biomarkers for early cancer detection, disease monitoring, and assessing therapeutic efficacy, paving the way for the development of liquid biopsy-based diagnostics that can be easily integrated into routine clinical practice [5].

Conclusion

In conclusion, liquid biopsy represents a transformative approach to cancer diagnosis and monitoring, offering a non-invasive, dynamic, and highly informative method for detecting and tracking cancer in real time. By analyzing components such as Circulating Tumor DNA (ctDNA), Circulating Tumor Cells (CTCs), exosomes, and microRNAs, liquid biopsy provides valuable insights

***Address for Correspondence:** Cheng Wei, Department of Molecular Diagnostics, Peking University, 72 Medical St, Beijing, 100084, China; E-mail: wei.cheng@fudan.edu*

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into tumor heterogeneity, genetic mutations, and the evolution of treatment resistance. This approach offers several advantages over traditional biopsy methods, including its ability to capture the full spectrum of tumor-derived material, provide real-time monitoring of treatment response, and detect minimal residual disease, even in the absence of clinical symptoms. As liquid biopsy technologies continue to evolve, their integration into clinical practice has the potential to revolutionize cancer care by enabling earlier diagnosis, more personalized treatment, and improved patient outcomes. Furthermore, the ability to monitor tumor dynamics non-invasively could lead to more precise adjustments in treatment strategies, improving survival rates while minimizing unnecessary side effects. As research advances and the sensitivity and specificity of liquid biopsy improve, this approach is expected to become a cornerstone of precision oncology, guiding treatment decisions and offering a more personalized approach to cancer management.

Acknowledgement

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Conflict of Interest

None.

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