Liquid Biopsy in Oncology: Circulating Biomarkers and Non-Invasive Cancer Detection

Dr. Hakim K. Saboowala
M.B.B.S (Bom), M.R.S.H. (London), F.F.M. (UK)
Independent Medical Scholar
Affiliated with Indian Medical Association (IMA), New Delhi

DOI: https://doi.org/10.5281/zenodo.18708554
ORCID iD: https://orcid.org/0009-0005-3523-774X

This is a structured academic manuscript formatted for scholarly indexing, citation, and research visibility.

Abstract

Liquid biopsy has emerged as a transformative approach in oncology, enabling non-invasive detection and monitoring of cancer through circulating biomarkers in body fluids. Key components include circulating tumor DNA (ctDNA), circulating tumor cells (CTCs), and extracellular vesicles such as exosomes. This narrative review explores the biological basis, technological advances, and clinical applications of liquid biopsy, emphasizing its role in early cancer detection, treatment monitoring, and precision oncology. The integration of molecular diagnostics with minimally invasive sampling represents a significant advancement over traditional tissue biopsy methods.

This article is a narrative review based on existing literature and does not present original experimental data.

Keywords

liquid biopsy, circulating tumor DNA, ctDNA, circulating tumor cells, exosomes, cancer biomarkers, non-invasive diagnostics, oncology

Introduction

Early detection of cancer significantly improves prognosis and survival outcomes. Traditional tissue biopsy, although considered the gold standard, is invasive and limited by tumor heterogeneity. Liquid biopsy offers a minimally invasive alternative by analyzing tumor-derived components present in blood, urine, and other body fluids. This approach enables dynamic monitoring of tumor evolution and provides insights into molecular alterations in real time [1].

1. Biological Basis of Liquid Biopsy

Tumors release various components into circulation, including:

- **Circulating tumor DNA (ctDNA)** – fragmented DNA from tumor cells
- **Circulating tumor cells (CTCs)** – intact tumor cells in bloodstream
- **Extracellular vesicles (exosomes)** – carriers of proteins, RNA, and DNA

These biomarkers reflect tumor burden and genetic alterations [2].

2. Detection Technologies

Advanced analytical techniques include:

- Polymerase chain reaction (PCR)-based assays
- Next-generation sequencing (NGS)
- Digital droplet PCR (ddPCR)

These methods allow high sensitivity and specificity in detecting low-abundance tumor biomarkers [3].

3. Clinical Applications

Liquid biopsy has multiple applications:

- **Early cancer detection**
- **Monitoring treatment response**
- **Detection of minimal residual disease**
- **Identification of resistance mutations**

It is particularly useful in cancers where tissue biopsy is difficult [4].

4. Advantages Over Traditional Biopsy

- Minimally invasive
- Allows repeated sampling
- Captures tumor heterogeneity
- Real-time monitoring

These advantages make liquid biopsy a promising tool in precision medicine [5].

5. Limitations and Challenges

Despite its potential:

- Low biomarker concentration in early disease
- Technical variability
- Need for standardization

Further research is required for widespread clinical implementation [6].

Discussion

Liquid biopsy represents a paradigm shift in cancer diagnostics. Its ability to provide molecular insights through non-invasive sampling aligns with the principles of personalized medicine. Integration with advanced technologies

such as artificial intelligence may further enhance diagnostic accuracy and predictive capability.

Conclusion

Liquid biopsy is a rapidly evolving field with significant implications for early cancer detection and management. Continued advancements in detection technologies and biomarker validation are essential to fully realize its clinical potential.

Table 1. Key Components of Liquid Biopsy

Component	Description	Clinical Utility
ctDNA	Tumor-derived DNA fragments	Mutation detection
CTCs	Circulating tumor cells	Metastasis monitoring
Exosomes	Vesicles carrying biomolecules	Biomarker discovery

Figure 1. Liquid Biopsy Workflow in Cancer Detection

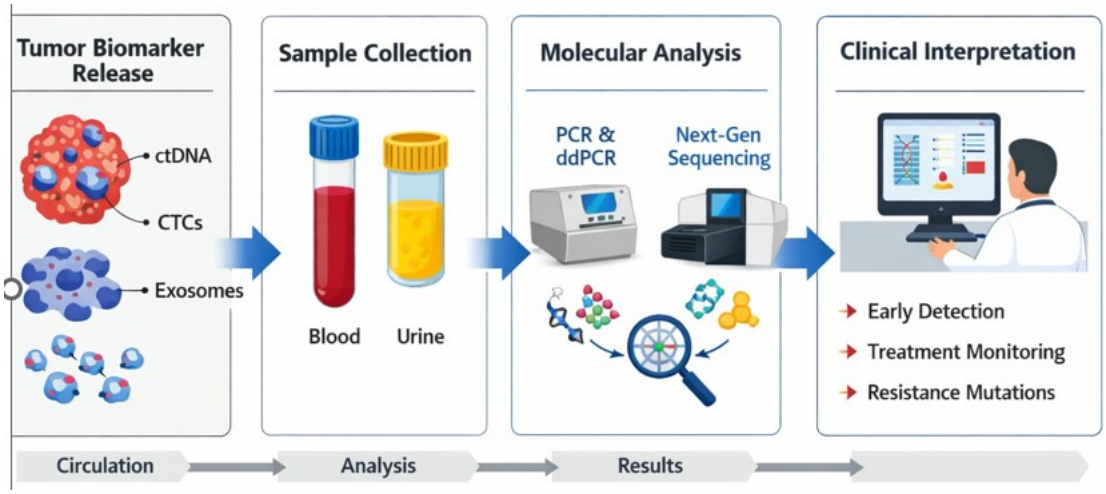

Fig. 1. *Diagram illustrating tumor-derived biomarker release into circulation, sample collection (blood/urine), molecular analysis, and clinical interpretation for cancer detection and monitoring.*

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