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Short Communication

Circulating Tumour DNA as a Dynamic Biomarker in Precision Oncology

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DESCRIPTION

Precision oncology is an emerging approach to cancer management that seeks to tailor treatment strategies based on the molecular characteristics of individual tumours [1]. The development of predictive and prognostic biomarkers is central to this strategy, as they allow clinicians to monitor tumour progression, assess response to therapy, and adjust treatments in real time. Circulating tumour Deoxyribonucleic Acid (DNA) is a fragment of genetic material released into the bloodstream from tumour cells undergoing apoptosis, necrosis, or active secretion. These fragments carry genetic alterations reflective of the tumour genome, offering a minimally invasive method to interrogate tumour dynamics and heterogeneity. Over the last decade, circulating tumour DNA has emerged as a powerful and dynamic biomarker, capable of guiding personalized treatment decisions and improving outcomes for cancer patients.

Circulating tumour DNA can be detected and quantified in plasma or serum using highly sensitive molecular techniques such as digital polymerase chain reaction and next generation sequencing. These methods allow for the identification of mutations, insertions, deletions, and copy number variations specific to tumour cells. Because circulating tumour DNA originates from multiple regions of the tumour and metastatic sites, it provides a comprehensive view of tumour heterogeneity that is difficult to obtain from single tissue biopsies [2,3]. Longitudinal monitoring of circulating tumour DNA enables clinicians to track tumour evolution, detect the emergence of resistance mutations, and make timely therapeutic adjustments. This dynamic aspect distinguishes circulating tumour DNA from conventional static biomarkers and provides a more accurate representation of tumour biology over time.

One of the most important clinical applications of circulating tumour DNA is in the detection of minimal residual disease following primary therapy [4-6]. Patients who achieve clinical remission may still harbor microscopic tumour deposits that are undetectable by imaging. Circulating tumour DNA can identify these residual tumour cells by detecting trace levels of tumour specific mutations in the bloodstream. Early detection of residual disease allows for prompt intervention, including adjuvant therapy or clinical trial enrollment, thereby reducing the risk of relapse.

Another key application is the monitoring of treatment response. Circulating tumour DNA levels fluctuate in accordance with tumour burden, and changes in the concentration of these fragments can provide an early indication of therapeutic efficacy. For example, a rapid decline in circulating tumour DNA following the initiation of chemotherapy or targeted therapy often correlates with radiographic tumour shrinkage, whereas stable or rising levels may indicate resistance or disease progression.

Circulating tumour DNA also enables the identification of mechanisms of acquired resistance. Tumours often develop secondary genetic alterations that confer resistance to targeted therapies, rendering treatment ineffective over time [7,8]. Traditional tissue biopsies may miss these alterations due to spatial heterogeneity or practical challenges in repeated sampling. In contrast, circulating tumour DNA provides a non invasive window into the evolving tumour genome. By sequencing circulating tumour DNA at multiple time points, clinicians can detect the emergence of resistance mutations and adjust therapy accordingly, either by switching to alternative targeted agents or incorporating combination strategies. This approach exemplifies the concept of adaptive cancer therapy guided by real time molecular monitoring.

In addition to informing treatment decisions, circulating tumour DNA has potential as a prognostic tool. Quantitative analysis of circulating tumour DNA levels can stratify patients based on disease aggressiveness, likelihood of response to therapy, and overall survival outcomes. Higher baseline levels of circulating tumour DNA are often associated with more advanced disease and poorer prognosis, whereas declining levels following therapy predict favorable outcomes [9]. By integrating circulating tumour DNA analysis into routine clinical practice, clinicians can identify high risk patients who may benefit from more intensive surveillance or treatment escalation.

Despite its promise, several challenges remain in the clinical implementation of circulating tumour DNA. Sensitivity and specificity depend on the abundance of circulating tumour DNA

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in the bloodstream, which may be low in early stage disease or in certain tumour types. Pre analytic variables, including sample collection, processing, and storage, can influence results and require standardization. In addition, interpretation of complex mutational profiles demands robust bioinformatics pipelines and clinical validation. circulating tumour DNA into precision oncology workflows.

Future directions for circulating tumour DNA include its use in combination with other liquid biopsy markers, such as circulating tumour cells and extracellular vesicles, to enhance diagnostic accuracy and predictive power. Multi analyte approaches may provide complementary information about tumour biology, immune interactions, and metastatic potential. Additionally, circulating tumour DNA can facilitate the development of personalized therapeutic vaccines and targeted therapies by identifying patient specific neoantigens and actionable mutations [10]. The integration of circulating tumour DNA with advanced computational modeling and artificial intelligence may further improve treatment prediction, optimize therapy sequencing, and guide individualized cancer management strategies.

CONCLUSION

Circulating tumour DNA represents a dynamic and versatile biomarker in precision oncology. It offers non invasive access to tumour genetic information, enabling longitudinal monitoring of tumour evolution, detection of minimal residual disease, assessment of treatment response, and identification of resistance mechanisms. By providing real time insights into tumour biology, circulating tumour DNA enhances the ability to personalize therapy, optimize treatment efficacy, and improve patient outcomes. Continued technological advancements, clinical validation, and integration with complementary biomarkers will solidify the role of circulating tumour DNA as a central tool in precision oncology, transforming cancer care from reactive management to proactive and adaptive strategies.

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