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Short Communication

Cancer Molecular Mechanisms: Precision Medicine and Targeted Therapies

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DESCRIPTION

Cancer is a complex and multifaceted disease marked by the uncontrolled growth and spread of abnormal cells. Gaining insight into the molecular mechanisms that drive cancer has been major in the advancement of precision medicine and targeted therapies. These approaches provide more effective and less toxic treatments compared to traditional methods. Precision medicine customizes medical treatment based on the unique characteristics of each patient, while targeted therapies focus on attacking cancer cells according to their specific molecular traits [1,2].

Molecular mechanisms of cancer

Cancer results from genetic and epigenetic changes that disrupt normal cellular processes, causing uncontrolled cell growth, resistance to cell death, angiogenesis, and metastasis. Key molecular mechanisms involved in cancer development include:

Oncogenes and tumor suppressors: Mutations in oncogenes (e.g., *MYC*, *RAS*) and tumor suppressor genes (e.g., *TP53*, *RB1*) play a major role in cancer initiation and progression. Oncogenes promote cell growth and division, while tumor suppressor genes inhibit these processes. Mutations or dysregulation of these genes can lead to unchecked cell proliferation.

Signal transduction pathways: Abnormal activation of signaling pathways, such as the PI3K/AKT/mTOR, MAPK/ERK, and Wnt/β-catenin pathways, is common in cancer. These pathways regulate cell growth, survival, and metabolism, and their dysregulation can lead to tumorigenesis.

DNA repair mechanisms: Defects in DNA repair pathways, such as Mismatch Repair (MMR) and Homologous Recombination (HR), can lead to genomic instability and accumulation of mutations. For example, *BRCA1* and *BRCA2* mutations impair Homologous Recombination (HR), increasing the risk of breast and ovarian cancers.

Epigenetic modifications: Changes in DNA methylation, histone modifications, and non-coding RNA expression can alter gene expression without changing the DNA sequence. These epigenetic changes can contribute to cancer development by silencing tumor suppressor genes or activating oncogenes.

Microenvironmental factors: The tumor microenvironment, including immune cells, fibroblasts, and extracellular matrix components, plays a significant role in cancer progression and response to therapy. Interactions between cancer cells and their microenvironment can promote tumor growth, angiogenesis, and immune evasion [3-5].

Precision medicine in cancer

Precision medicine aims to personalized cancer treatment based on the genetic, epigenetic, and molecular profile of an individual's tumor. This approach involves several key components:

Genomic profiling: Advanced genomic technologies, such as Next-Generation Sequencing (NGS), allow for comprehensive analysis of tumor DNA and RNA to identify genetic mutations, copy number alterations, and gene fusions. This information can guide the selection of targeted therapies and identify potential biomarkers for response [6,7].

Biomarker identification: Biomarkers are measurable indicators of a biological state or condition. In cancer, biomarkers can predict response to therapy, prognosis, and disease progression. For example, *HER2* overexpression in breast cancer and *EGFR* mutations in Non-Small Cell Lung Cancer (NSCLC) are used to guide targeted therapy decisions.

Targeted therapies: Targeted therapies are designed to precisely inhibit specific molecular targets involved in cancer growth and survival. By focusing on these targets, these therapies can offer more effective and less toxic treatment compared to traditional chemotherapy, as they are intended to attack cancer cells while minimizing damage to normal cells. Examples include:

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Tyrosine Kinase Inhibitors (TKIs): Drugs like imatinib (Gleevec) target BCR-ABL in Chronic Myeloid Leukemia (CML), while erlotinib and gefitinib target *EGFR* mutations in NSCLC.

Monoclonal antibodies: Trastuzumab (Herceptin) targets *HER2* in breast cancer, and rituximab targets CD20 in B-cell lymphomas [8].

PARP inhibitors: Olaparib and rucaparib target PARP enzymes in *BRCA*-mutated cancers, exploiting the concept of synthetic lethality.

Immunotherapy: Precision medicine also includes immunotherapies that harness the immune system to fight cancer. Immune checkpoint inhibitors, such as pembrolizumab (Keytruda) and nivolumab (Opdivo), target PD-1/PD-L1 pathways to enhance the immune response against tumors. CAR-T cell therapy, which involves engineering T cells to target specific cancer antigens, represents another innovative approach to treatment.

Combination therapies: Combining targeted therapies, immunotherapies, and traditional treatments (surgery, radiation, chemotherapy) can improve outcomes and overcome resistance. Precision medicine enables the rational design of combination therapies according to the molecular characteristics of the tumor [9,10].

CONCLUSION

Understanding cancer's molecular mechanisms has initiated in a new era of precision medicine and targeted therapies, providing more effective and less toxic treatments. By customizing treatment to the unique characteristics of each patient's tumor, precision medicine aims to improve outcomes and reduce side effects. Despite ongoing challenges, continuous research and technological advancements are driving progress in this field.

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