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Perspective

Nanotechnology in Oncology: Targeting Tumour Microenvironments with Biotherapeutics

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DESCRIPTION

In the advanced field of cancer research, nanotechnology has opened new frontiers in the development of more targeted and effective therapies. One of the most promising applications is the use of nanotechnology to manipulate the Tumour Microenvironment (TME) to improve cancer treatment. Nanotechnology, through the use of nanoparticles, allows for precise targeting of the tumour site, allowing biotherapeutics to be delivered directly to cancer cells, thereby sparing healthy tissue and reducing side effects. The TME is a complex and dynamic ecosystem that includes cancer cells, stromal cells, blood vessels, immune cells, and the extracellular matrix. Unlike normal tissue, the TME is characterized by abnormal blood vessels, low oxygen levels, acidic pH, and immunosuppressive factors. These features contribute to the aggressive nature of tumours and their ability to evade conventional therapies. Furthermore, the TME plays an important role in cancer progression, metastasis, and resistance to treatments such as chemotherapy and radiotherapy.

Targeting the TME offers a new approach to treating cancer by modifying its components to improve the efficacy of existing treatments or directly disrupt tumour growth. This strategy may be more effective than targeting tumour cells alone because it addresses the causes of cancer spread and metastasis. Nanoparticles (NPs) exhibit unique physicochemical properties that make them ideal for modulating the TME. These properties include their small size, large surface area, and the ability to be functionalized with various biomolecules. Nanoparticles can be engineered to interact with specific components of the TME, such as abnormal blood vessels or Tumour Associated Macrophages (TAMs), and facilitate the delivery of therapeutic agents. One of the primary mechanisms by which nanotechnology benefits oncology is the concept of the Enhanced Permeability and Retention (EPR) effect. Tumour blood vessels are permeable and poorly organized, allowing nanoparticles to preferentially accumulate at the tumour site, where they can release their therapeutic payload. This targeted delivery can be further enhanced by coating nanoparticles with ligands or antibodies that specifically bind to receptors overexpressed on cancer cells or stromal cells in the TME.

The combination of nanotechnology and biotherapeutics, such as antibodies, nucleic acids, and small interfering RNA (siRNA), has shown great promise in targeting specific elements of the TME. For example, nanoparticles can be used to deliver monoclonal antibodies that inhibit signaling pathways responsible for tumour growth. These antibodies can target molecules such as Vascular Endothelial Growth Factor (VEGF), which is involved in angiogenesis, a process that tumours use to create a blood supply. In addition, RNA-based therapies, such as siRNA and microRNA (miRNA), can be delivered via nanoparticles to silence genes involved in tumour progression or drug resistance. For example, siRNAs can target genes involved in cancer cell resistance to chemotherapy, while miRNAs can regulate gene expression in the TME to shift it from a pro-tumourigenic to an anti-tumourigenic state. In addition, nanoparticles can be used to deliver immunomodulatory agents that activate the immune system to recognize and destroy tumour cells. Nanoparticles designed to enhance the activity of immune checkpoint inhibitors (e.g., PD-1/PD-L1 inhibitors) can induce antitumour immunity by reactivating T cells in the TME.

Despite the significant potential of nanotechnology in oncology, many challenges remain in translating these technologies into clinical practice. The complexity of the TME means that a single approach may not be sufficient to overcome the multifaceted nature of tumour resistance. Furthermore, the development of nanoparticles that are safe and effective for human use is ongoing. Future research should focus on optimizing the design of nanoparticles, improving their biocompatibility, and improving their ability to navigate the TME. Furthermore, combining nanotherapies with other treatment modalities, such as immunotherapy and precision medicine, has tremendous potential to produce synergistic effects in the fight against cancer. Nanotechnology offers a transformative approach to oncology by targeting the tumour microenvironment with biotherapeutics.

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