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Perspective

Bioengineering Strategies for Improving Nanomedicine in Bladder Cancer Therapy

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DESCRIPTION

Bladder Cancer (BC) is the most prevalent urological malignancy globally, with several histological subtypes that present distinct characteristics. The most common subtype is Transitional Cell Carcinoma (TCC) or Urothelial Carcinoma (UC), which accounts for over 90% of Bladder Cancer cases. Urothelial Carcinoma arises from the urothelium, the tissue lining the bladder and can be classified as either invasive or non-invasive based on its penetration into the bladder wall. The second most common subtype, Squamous Cell Carcinoma (SCC), represents 1%-5% of BC cases and originates from squamous epithelial cells. However, SCC is often diagnosed at a later stage, making treatment more challenging and less effective than UC.

The development of BC is influenced by multiple factors. Smoking remains the leading risk factor, responsible for over 30% of BC cases. Additional contributing factors include chronic exposure to environmental pollutants, previous radiotherapy for other cancers, parasitic infections such as schistosomiasis and genetic predisposition, with a family history increasing the likelihood of developing the disease. Persistent urinary tract infections and certain metabolic disorders also elevate the risk of BC. Current diagnostic methods for BC face significant limitations, such as the low sensitivity of urine cytology, particularly for detecting early-stage cancers. While biopsy remains the gold standard, it is invasive and may not provide a comprehensive view of the tumor. Cystoscopy, while effective in detecting visible tumors, may miss microscopic lesions, leading to delayed diagnoses and lesser prognoses.

Nanotechnology holds promise in addressing the challenges of BC treatment and diagnosis. Nanoparticles, due to their small size, can cross the urothelial barrier and deliver drugs directly to cancer cells, enhancing the efficacy of treatment while minimizing systemic side effects. These nanoparticles can also be designed for diagnostic purposes, loaded with imaging agents to visualize tumors during treatment.

Ligand-based targeting strategies utilize molecules such as antibodies, peptides or small molecules that bind specifically to receptors or antigens overexpressed on cancer cells. This targeted approach improves drug delivery to cancer cells while reducing exposure to healthy tissues. Environmental-based targeting takes advantage of the unique microenvironment of tumors, such as altered pH, temperature, or redox potential, to release therapeutic agents only when they reach the tumor site. Another likely strategy involves using immune cells like neutrophils or leukocytes, which naturally migrate to sites of infection or inflammation, to deliver drugs directly to tumors. Stem cells or bladder-resident cells may also be utilized for targeted drug delivery, enhancing specificity and minimizing side effects.

The use of various nanocarriers, including polymeric nanoparticles, liposomes, micelles and dendrimers, is being actively explored for BC treatment. Polymeric nanoparticles can be engineered to carry multiple therapeutic agents and exhibit properties that facilitate targeted delivery. Liposomes, which mimic cell membranes, can fuse with cancer cells to release their payloads, while micelles, self-assembling structures, are capable of encapsulating hydrophobic drugs and exploiting the Enhanced Permeability and Retention (EPR) effect to accumulate in tumors. Dendrimers, with their highly branched structure, offer a large surface area for attaching therapeutic agents or targeting ligands.

The review's novelty lies in its focus on ligand-based, environmental-based and cell-based targeting strategies using nanoparticles. While current knowledge on BC subtypes, risk factors, diagnosis and treatment will be discussed, the main contribution of this study will be the in-depth exploration of these innovative targeting approaches to improve treatment specificity, reduce side effects and ultimately enhance patient outcomes.

CONCLUSION

In conclusion, this study highlights the potential of cell-targeting nanomedicine as a transformative approach for bladder cancer treatment. By exploring the use of silver nanoparticles and Carbon NanoTubes (CNTs), the research highlights how these nanomaterials can improve treatment accuracy, induce apoptosis

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and stop the cancer cell cycle in Non-Muscle Invasive Bladder Cancer (NMIBC). The application of photo-thermal ablation using CNTs further supports the growing promise of targeted therapies. This work paves the way for more modified and effective treatment strategies, offering valuable insights for future research and clinical practices in bladder cancer therapy.