Chapter 7

Transformative Approaches in Breast Cancer Treatment:

The Role of Polymers, Biomaterials, Nanomaterials, and Metal Ions

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ABSTRACT

The transformative role of polymers, biomaterials, nanomaterials, and metal ions in breast cancer treatment have highlighted their potential to enhance diagnosis and therapeutic outcomes. Traditional cancer therapies have often fallen short due to their "one-size-fits-all" approach, leading to increased patient non-responsiveness. The integration of interdisciplinary research—from biomedical science to nanotechnology—promises more precise and effective treatments. Polymers enable targeted drug delivery with reduced side effects, while biomaterials enhance regeneration and drug delivery systems. Nanomaterials improve drug accumulation in tumors and combat resistance, and metal ions disrupt cancer cell metabolism and DNA. By exploring case studies and applications of these advanced materials,

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this paper underscores their significant contributions to personalized cancer therapies and improved patient quality of life. Looking forward, innovations in multifunctional nanomaterials and biosensors are anticipated to further revolutionize breast cancer treatment strategies.

1. INTRODUCTION

In the recent years, polymers, biomaterials, nanomaterials and metal ions have emerged as crucial elements in the domain of science and technology. The unique properties of each material makes them valuable in treatment of breast cancer. In spite of the remarkable achievement in diagnosis and treatment of breast cancer, it remains a major concern. WHO and Globocan have projected that by mid-century 2050, there will be 3.2 million new breast cancer cases and 1.1 million related deaths each year (Bray et al., 2024; Sung et al., 2021a, 2021b; UN, 2024). This amounts to a huge rise in both the diagnostic and therapeutic burden. The traditional therapeutic approaches concentrating on the "one size solution" have, since, become outdated, indicated by the increased in-patient number failing to respond to treatment.

Chemotherapy, radiation, and targeted therapies are examples of conventional breast cancer treatments that are ridden with challenges which restrict their effectiveness and patient outcomes. For instance, chemotherapeutic drugs like doxorubicin and taxanes non-selectively damage both malignant and healthy cells (Mozafari, 2024). They create systemic toxicity, which is still a significant problem. This can result in dose-limiting side effects such as cardiotoxicity, bone marrow suppression, and gastrointestinal upset, some of which may be life threatening (Gupta, 2022; Yu et al., 2022).

Additionally, both acquired and innate drug resistance impair the effectiveness of treatment. Through processes such as accelerated DNA repair, epigenetic changes, and upregulation of drug efflux pumps (e.g., ABC transporters), up to 50% of cases of triple-negative breast cancer (TNBC) develop resistance to anthracyclines and taxanes. Tumor heterogeneity makes resistance worse by allowing certain sub-populations of cancer stem cells to elude treatment, which can result in metastasis and relapse (Kinnel et al., 2023; Prihantono & Faruk, 2021).

In immunosuppressive microenvironments (TME) or thick tumor stroma, where myeloid-derived suppressor cells (MDSCs) and cancer-associated fibroblasts (CAFs) impede medication delivery and immune cell function, conventional therapies frequently fall short. For example, the acidic and hypoxic conditions of the TME reduce the effectiveness of drugs and encourage pro-tumorigenic signalling (J. J. Li et al., 2021; Zhang et al., 2023). Furthermore, real-time monitoring of therapy response is limited by the older techniques' limited theragnostic capabilities (Caballero et al., 2022).

The growing demand of ecofriendly, biodegradable and safe technology has encouraged the development of materials that advances medical treatment and minimize the impact on environment and reduces toxicity. For instance, polymers have emerged as an important component in the future of cancer therapy due to their efficient drug delivery system and targeting of cancer cells, while minimizing side effects. Biomaterials, particularly, are being utilized for regeneration purposes and as nanocarriers for drug delivery, which enhances precision of the breast cancer treatment. Moreover, nanomaterials, offer unique properties that helps in overcoming drug resistance and effectively targeting breast cancer cells. Further, metal ions are exploited for their ability in disturbing metabolism and DNA of cancer cells, with high efficacy and limited drug resistance.

Polymers have emerged as a vital component in the future of cancer treatment due to their versatility and efficiency in drug delivery systems. Polymeric carriers have the ability to increase concentration