Nanotechnology in Cancer Diagnosis: Current Trends and Future Prospects

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Abstract — Modern medicine has been waging a losing war against cancer for more than a century. Although cancer treatments have advanced significantly, they still need to be more specialized and less likely to cause systemic side effects. A technological revolution in diagnostic technologies is imminent, and improving prognosis outlook and patient quality of life requires early detection. Nanotechnology has demonstrated its ability to advance cancer treatment, radiotherapy, diagnostics, and imaging, all of which have witnessed consistent improvements. In order to develop radiation adjuvants with increased efficacy, precise early-detection instruments, and particularly focused cancer treatments, nanomaterials offer a wide variety of diversity, usefulness, and uses. The well-known cancer therapies, such as chemotherapy and radiotherapy, have a number of drawbacks, including slow illness identification and out-of-area medication distribution. These therapies have a very limited power to cure and track the effects of the medicine in the human body since the exact drug concentration is not only dispersed throughout the body but also reaches the tumor location. These restrictions have been partially addressed thanks to nanotechnology. This paper discusses the existing clinical and pre-clinical Nano technological approaches for cancer drug therapy.

Keywords: Nanomaterial, Cancer Therapies, Tumor, Chemotherapy

I. INTRODUCTION

Cancer still kills tens of millions of lives annually despite considerable advances in science and technology. Years of research have demonstrated the disease's dynamic nature, and even while there are now more effective treatment choices, severe chemotherapy still has considerable negative effects [1]. Particularly when malignant tumors lie dormant and then reappear, patients suffer when more aggressive therapy is needed. One of the major challenges to creating a cancer treatment that works is the persistent creation of resistance mechanisms. Resistance mechanisms are activated in parallel signaling pathways and reroute to support the growth of cancer after the main oncogenic pathways have been turned off [2]. The heterogeneity of tumor cells, patient tumor's, genetic abnormalities, and epigenetic patterns can limit the efficacy of therapeutic approaches.

The answer may lay in nanotechnology, which could enhance radiation therapy efficacy, decrease systemic toxicity, raise diagnostic sensitivity, enhance imaging, and enhance the targeting capabilities of current therapies [3]. Clinical translation of cancer Nano medicine has a long history, and the use of Nano-based drugs (Fig: 1.1) and components for imaging, diagnostics, and radiation therapy has steadily increased. The use of Nano-based imaging contrast agents, such as super paramagnetic iron oxide NPs (SPIONs) and gadolinium (Gd)-based contrast agents, improves the detection and imaging of tumor's in vivo when using conventional scanning technologies, such as magnetic resonance imaging (MRI), positron emission tomography (PET), and computed tomography (CT)

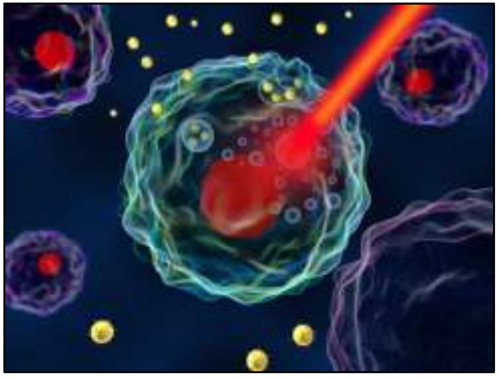

Fig. 1.1: Gold nanoparticles in cancer treatment

II. NANO FORMULATIONS

Nano formulations can circumvent resistance mechanisms by utilizing physical modalities to kill cancerous cells, enhancing specificity with triggered release, and focusing on several components with dual-drug loading. Nano scale carriers can flow through a tumor endothelium and passively accumulate in tumors as a result of leaky blood vessels and insufficient lymphatic drainage [4]. Furthermore, the unique physico-chemical properties of nanomaterial are utilized in very sensitive diagnostic processes, enabling the early identification of cancer and enhancing patient prognosis. Nanomaterial's can deliver highly tailored radiation doses to tumors while sparing healthy tissue because they act as radio sensitizers [5]. The versatility and utility of nanomaterial open up a wide range of possibilities for radiation, imaging, and cancer treatment (Fig:1.2). The systemic adverse effects of conventional therapies can be decreased, the prognosis can be improved, and the quality of life for the patient can be improved with early detection, lower radiation dose, and improved therapeutic specificity.

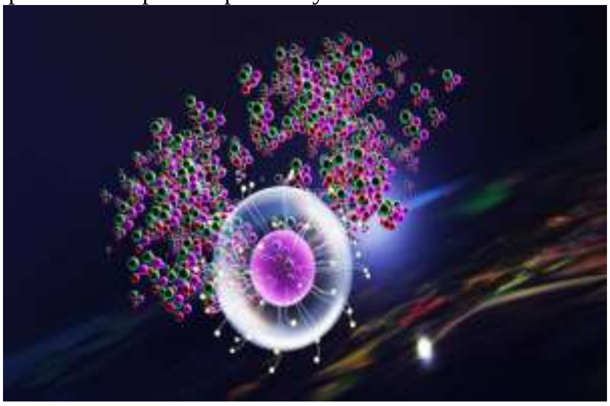

Fig. 1.2: Therapeutic agents carried by Nano robots

III. CLINICAL IMPORTANCE OF NANOMATERIAL

Nanoparticles are objects with overall dimensions in the Nano scale, or less than 100 nm. With therapeutic applications ranging from contrast agents in imaging to carriers for the delivery of medications and genes into cancers, these materials have recently emerged as key players in modern medicine. The application of nanotechnology in the medical field is revolutionizing how healthcare is provided on a worldwide scale [6]. This revolution has been driven by the vastness of the tools developed to understand, diagnose, and treat the disease. With increased effectiveness and accuracy. One of the many advantages of using nanoparticles in medical applications is their ability to carry active substances. Their vast surface area enables the anchoring of medicinal molecules to their surface as well as the modification of bio distribution, protection from degradation processes, and improvement of solubility of poorly soluble compounds, in addition to acting as containers to enclose diverse chemicals [7]. When using combination therapies, which allow the simultaneous administration of many medications in both time and location, this can be extremely useful. By using Nano formulations, the compounds may also be more efficiently guided toward the area that needs to be treated, resulting in lower dosages of the active ingredient and less adverse effects.

IV. CONVENTIONAL CANCER THERAPIES

Chemotherapy, radiation therapy, and surgery are the three most common types of cancer treatment, either independently or in combination. The type of treatment is dependent on the type of cancer, the severity of the condition, the rate of progression, the patient's condition, and the response to therapy [8]. Surgery is still the most common and efficient type of cancer therapy, despite the fact that the development of alternative treatment modalities has reduced the degree of surgical intervention in treating particular cancers. Chemotherapy is still the primary treatment for the majority of tumors, and drug research is constantly evolving and shifting toward cancer-specific targets. Common chemotherapeutic drugs that harm DNA and prevent cellular reproduction include antimetabolites, mitotic inhibitors, topoisomerase inhibitors, alkylating agents, and antibiotics (Fig: 1.3). Despite the fact that traditional chemotherapies are very effective, due to their non-specificity, patients nevertheless face adverse effects [9]. Traditional chemotherapy is exceedingly harmful to healthy cells while having little effect on cancerous cells, causing severe side effects for patients.

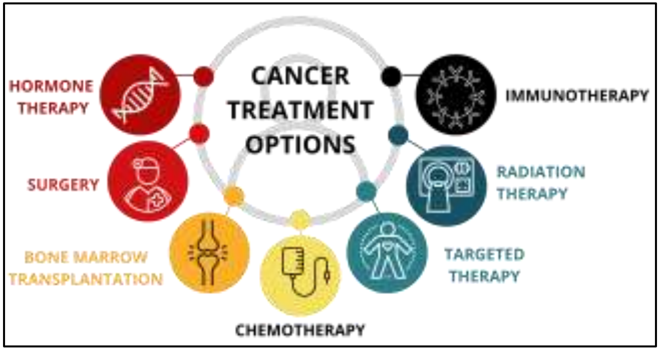

Fig. 1.3: Cancer treatment options

V. CURRENT NANOTECHNOLOGY IN CANCER TREATMENT

Research on cancer therapy using nanotechnology extends beyond the development of existing drugs to create new ones that are only made possible by the special properties of nanomaterial. Despite being much smaller than cells, nanoparticles are big enough to hold a variety of microscopic substances [10]. At the same time, the relatively large surface area of nanoparticles can be functionalized by adding ligands like small molecules, DNA or RNA strands, peptides, aptamers, or antibodies. These ligands can be used therapeutically or to regulate how nanoparticles behave in living things. The distribution of numerous medications, multi-modal therapy, and combination therapeutic and diagnostic, or "theranostic," activity are all made possible by these traits. The physical properties of nanoparticles, such as energy absorption and re-radiation, can also be used to destroy diseased tissue, similar to laser ablation and hyperthermia applications.

VI. NANO BASED IMMUNOTHERAPY

Two examples of the many different types of therapies that make up the complex discipline of immunotherapy include checkpoint inhibition and cellular therapies. Even while some patients have had remarkable outcomes, only a small percentage of patients receiving treatment for just a limited subset of tumors have durable responses to these drugs [11]. To maximize the effects of immunotherapy, a fuller understanding of the interplay between the immune systems of the tumor and host is required. New methods for molecular and functional study of single cells are being used to investigate immune and tumor cells, revealing molecular markers and functional immunological responses to therapy (Fig: 1.4). Targeted delivery is one of the key benefits of nanomaterial-based cancer therapy over conventional treatments. Nanoparticle-based targeted delivery has recently advanced. The idea of targeted delivery aims to precisely target individual cancer cells using either passive or active targeting [12]. Active targeting involves conjugation with antibodies, peptides, and small molecules, whereas passive targeting makes use of the increased permeability and retention (EPR) effect.

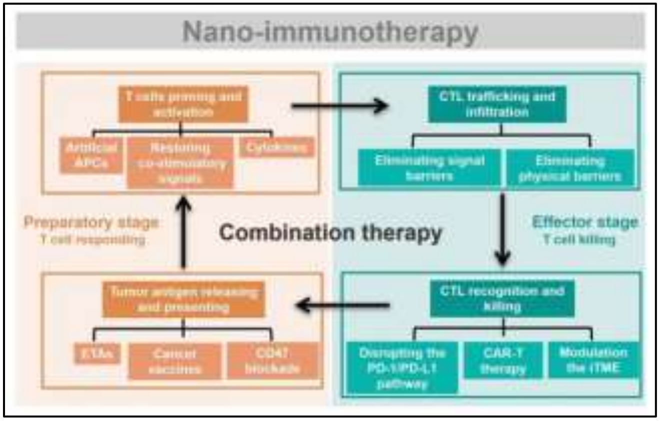

Fig. 1.4: Pathways in Nano-immunotherapy

VII. NOVEL DRUG DELIVERY SYSTEMS (NDDS) FOR THE TREATMENT OF COLON CANCER

Novel drug delivery systems is a term used to describe a special technique that uses NPs to treat cancer. Anticancer therapy involving diagnostics, imaging, and drug administration have been altered by nanotechnology (Aneja et al., 2015; Rahman et al., 2012; Somwanshi et al., 2013). The medicine is shielded from chemical and enzymatic breakdown via encapsulation. Benefits of using NPs in cancer treatment include a decrease in side effects, extension of circulation half-lives, enhancement of drug solubility and stability, and better pharmacokinetics [13].

VIII. NANO CARRIERS AND GENE THERAPY

With the delivery of nucleic acids to express pro-apoptotic proteins, replace defective genes, down-regulate or silence oncogenic pathways, create anti-cancer cytokines, and/or engage the immune system against cancer, gene therapy is a significant role in the fight against cancer [14]. The efficient delivery of nucleic acids to the target site while preventing degradation is one of the main difficulties in gene delivery. The clinical translation of gene therapy continues to be hampered by the lack of effective and secure delivery mechanisms. Recombinant viral vectors are better at delivering genes than nonviral vectors, but they also have drawbacks such immune responses, large-scale manufacture, size restrictions on genes, restricted cell tropisms, and a lack of surface modifiability without jeopardizing vector integrity.

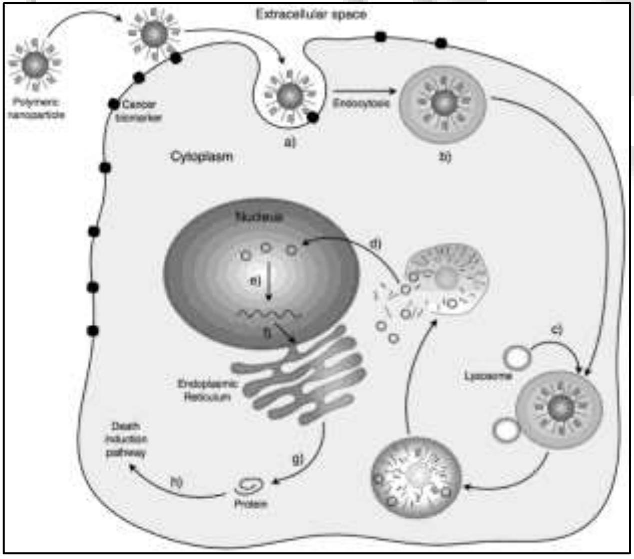

Fig. 1.5: Mechanism of gene therapy

IX. ADVANCED CANCER THERAPY

Numerous preclinical investigations are being conducted to develop triggered drug release and multi-modal therapies that will be extremely selective toward malignant cells as developing nanotechnologies work to increase PK/PD, efficacy, and specificity. Targeted drug release has the potential to reduce overall toxicity and the minimal effective dose even further, enhancing patient quality of life and efficacy [15]. Therapeutics can be created to obtain the best efficacy and the least amount of toxicity when technology develops to use specialized delivery. Currently, cancer immunotherapy depends on two main strategies: using monoclonal antibodies (mAbs) to regulate effector immune cells and using chimeric antigen receptor- T cells or bispecific T cell-engaging antibodies to enable co-engagement of T cells and tumor cells [16].

X. CANCER DIAGNOSTICS AND IMAGING

Because they accumulate at tumor sites and are effectively excreted through urine, ultra small gold Nano clusters (AuNCs) have been proven to be good probes for in vivo imaging. A colorimetric signal generated by multifunctional protease Nano sensors in the cancer cell microenvironment might be detected in urine [17]. Researchers discovered that tumor-affected mice showed a 13-fold increase in signal compared to healthy mice in urine samples taken from colon cancer mouse models. Additionally, new imaging agents with increased sensitivity and specificity can aid in the visualization of the tumor margin during surgical resection and enhance early identification during routine screening.

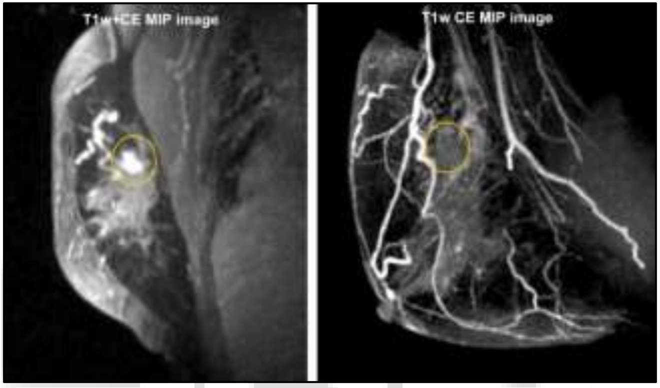

Fig. 1.6: Cancer diagnostics and imaging of cells

XI. RECENT TREND IN RADIOTHERAPY

Because it is so successful at causing DNA damage and subsequently cellular death, particularly in cancer cells that divide quickly, radiation therapy (RT) is widely used to treat cancer. Radiotherapy is quite successful, however it is still not localized enough to prevent negative effects on other body areas [18]. Combination chemo radiotherapy is the mainstay of care for many cancer types, but it also increases the risk of systemic toxicity. However, recent technological developments have resulted in notable improvements [19].

XII. CURRENT CHALLENGES AND FUTURE PERSPECTIVE

Nanomaterial’s have various benefits, are extremely adaptable, and can enhance cancer treatments and diagnostics [20]. However, the potential advantages must be evaluated against concerns like production costs, scalability, safety, and the complexity of Nano formulations. Costs, manufacturing requirements, and testing parameters all rise in tandem with an increase in design and material complexity [21]. Even if some Nano medicines may clearly outperform conventional formulations in terms of clinical outcomes, if cost and production barriers prevent clinical translation, it may never happen.

XIII. CONCLUSION

With highly advanced technology advancing treatments and diagnostics and machine learning applications enhancing to significantly reduce time and resources needed, the future of Nano medicine is undoubtedly bright. Numerous clinical and preclinical studies have shown the advantages of nanotechnology in cancer treatment, imaging, and diagnostics; nonetheless, it is crucial that these developments be applicable in the real world. The use of early detection techniques is undoubtedly an important factor in enhancing cancer patient outcomes. As was previously said, early-stage malignancies are typically considerably easier to treat, and early discovery greatly increases the likelihood of a patient surviving five years while also lowering the cost of care.

XIV. REFERENCES

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