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Review Article

Nanotechnology: A Review on Personalized Cancer Therapy and Diagnosis

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Abstract

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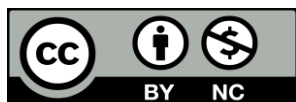
Diagnosis, Novel drug delivery

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In the field of cancer Theranostics, nanotechnology has become a game-changer by combining therapeutic and diagnostic properties into a single platform. The role of several nanomaterials, such as carbon dots, albumin-based nanoparticles, gold Nano shells, quantum dots, and PEGylated multi-functional nanoparticles, in improving cancer diagnosis and treatment is highlighted in this abstract. Semiconductor nanoparticles known as quantum dots (QDs) have remarkable fluorescent characteristics that enable multiplexed cancer cell detection and high-resolution imaging. Because of its adaptable optical qualities, low toxicity, and biocompatibility, carbon dots (CDs) have attracted interest. A single platform is created using PEGylated Multi-Functional Nanoparticles, which integrate multiple technologies. Polyethylene glycol (PEG) surface modification results in these nanoparticles having longer circulation times, decreased immunogenicity, and increased durability. A major development in cancer Theranostics is represented by the integration of quantum dots, carbon dots, albumin-based nanoparticles, gold Nano shells, and PEGylated multi-functional nanoparticles, as this review article briefly explains. These advancements promise to increase clinical outcomes and patient management in oncology by providing tailored therapeutic delivery, individualized treatment approaches, and improved diagnostic precision.

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1. Introduction

Cancer is a major global health concern, with cardiovascular diseases ranking as the leading cause of death worldwide. The disease's complexity and the emergence of drug-resistant tumors mean that despite advances in medical research, healthcare systems still face difficulties in treating it. A concerning trend has been shown by recent statistics: 10. Million fatalities and 19.3 million new cases of cancer are expected worldwide in 2020, according to the Global Cancer Statistics. This amounts to about one out of every six deaths globally. More than 70% of these deaths take place in low- and middle-income nations, and they are made worse by lifestyle choices like smoking, obesity, eating too few fruits and vegetables, not moving around much, and drinking a lot of alcohol. [1]

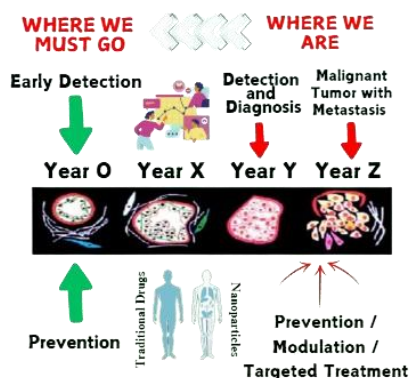


Figure 1. Nanotechnology: Shifting the Cancer Care Paradigm

1.1 Traditional Cancer Treatments and Their Limitations

Current standard treatments include chemotherapy, radiotherapy, and surgical interventions. While these methods have been the mainstay of cancer treatment for decades, they come with significant limitations. These include:

A. **Low Tumour Selectivity:** Treatments often affect healthy cells, leading to systemic toxicity.

B. **Off-Target Effects:** Unintended damage to non-cancerous tissues can cause severe side effects.

C. **Multidrug Resistance:** Tumors frequently develop resistance to medications, rendering treatments less effective over time.

D. **Recurrence:** There is a high probability of cancer returning, often because the tumour becomes resistant to previously successful therapies.

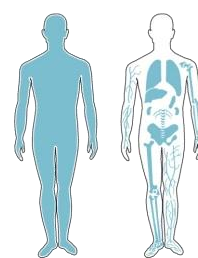


Figure 2. Traditional Medicine vs Nano medicine for Cancer Therapy

More individualized and efficient treatment plans are desperately needed in light of these difficulties. Promising advancements include the development of monoclonal antibody therapeutics that target tumor-specific and tumor-associated antigens, as well as antibody-drug conjugates (ADCs) that target cancer cells more accurately while sparing healthy cells. These methods do, however, have certain drawbacks, and further research into novel strategies is always being conducted. [2]

1.2 Nanotechnology in Cancer Therapy

Thanks to the discovery of nano Theranostics, nanotechnology has become a game-changing technique in the treatment of cancer. This cutting-edge science uses the special qualities of nanoparticles (NPs) to combine therapeutic and diagnostic roles, thereby improving cancer care.

1.3 Key Advantages of Nanotechnology:

- **Enhanced Drug Delivery:** NPs can be engineered to preferentially accumulate

in Tumour tissues due to their size and the leaky nature of Tumour blood vessels. This targeted approach enhances therapeutic efficacy and minimizes damage to healthy tissues.

- **Improved Imaging and Diagnosis:** NPs can be used as imaging agents due to their unique physicochemical properties. For example, iron oxide NPs are utilized in magnetic resonance imaging (MRI) to enable concurrent diagnosis and treatment.
- **High Drug Loading Capacity:** Nanoparticles have a high surface area, allowing for significant drug loading and efficient delivery to Tumour sites.

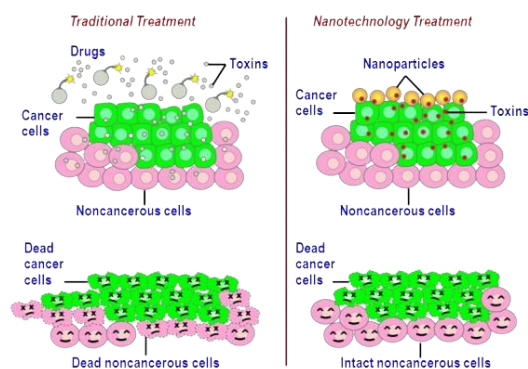


Figure 3. Advantages of Nanotechnology Treatment

1.4 Theranostics Systems: Integration of Diagnosis and Therapy

A new science called "theranostics" integrates medicinal and diagnostic properties into one system. This integrated approach allows for:

- **Simultaneous Monitoring:** Theranostics systems can track drug delivery and therapeutic response in real-time, facilitating more precise and effective treatment.
- **Personalized Medicine:** By combining diagnostic information with therapeutic delivery, these systems enable tailored treatments based on individual patient profiles. [3]

2. Nanotechnology in Cancer Diagnosis

2.1 Quantum dots --Medical imaging:

The structure of a nanoparticle has a big impact on its optical characteristics. In particular, a quantum dot's (a semi-conductor nanoparticle's) wavelength (color) is determined by its diameter. After injecting the quantum dots (QD) into a patient, it is possible to detect them by stimulating them to release light.

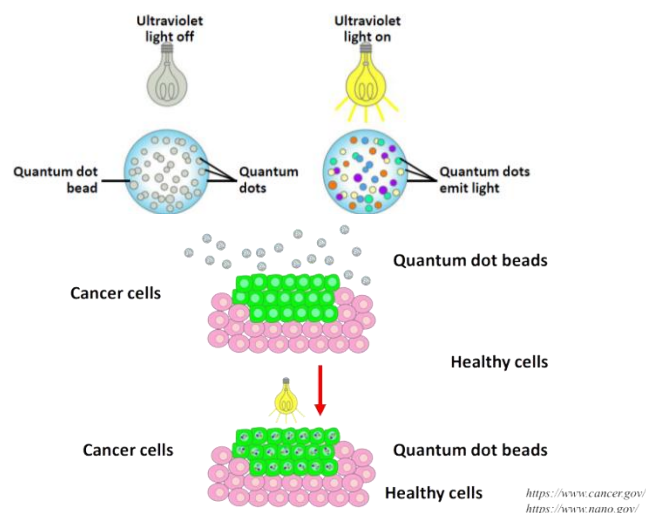


Figure 4. Quantum Dots Diagnosis mechanism with UV Light

It needs to be multiplexed, meaning that several biomarkers need to be found at once. A particular mix of biomarkers is present on the membrane of cancer cells that exhibit a particular phenotype. Varying phenotypes exhibit varying degrees of aggression in their metastatic behavior. [4]

2.1.1 QDs to identify live breast cancer cells

A research team from Quantum Dot Corporation and Genentech proved the potential of QDs to identify live breast cancer cells that are likely to respond to an anti-cancer drug. QD technology helps cancer researchers to observe fundamental molecular events occurring in the tumor cells by tracking the QDs of different sizes and thus different colors, tagged to multiple different biomolecules, in-vivo by fluorescent microscopy. Applications for QD technology in medical diagnostics and nanobiotechnology, where QDs could be employed as labels, are quite promising.

Use of QDs in humans requires extensive research to determine the long-term effects of administering QDs. [5]

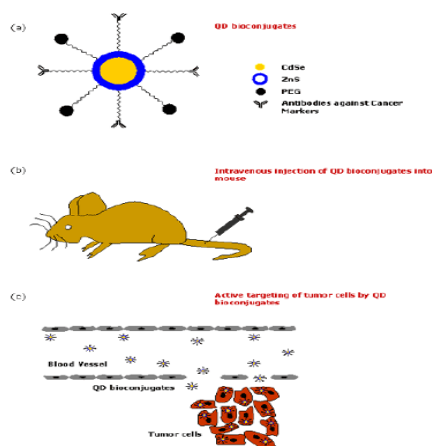


Figure 5. QDs in Identifying Live Breast Cancer cells

2.2 Carbon Dots (C-Dots)

Carbon dots (C-dots) are the fluorescent nanomaterials that have emerged recently providing an alternative to conventional toxic metal based quantum dots in terms of their biocompatibility and ecofriendly behavior. C-dots are fluorescent nanomaterials that are tiny (2–15 nm) and primarily made of carbon. C-dots exhibit unique optical properties such as efficient fluorescence performance, high photo stability, and broad excitation spectra and size-dependent emission wave length.

2.2.1 Synthesis of Carbon Dots

Synthesis of CDs by micro-wave pyrolysis method:

1. Add 0.2g of chitosan was added to solution containing 25mL of water and 4mL of concentrated H_2SO_4 .
2. Then add 0.2g of PEG-4000 to the above solution and stir at 500rpm for 15minutes.
3. Subject the solution to micro-wave irradiation using a domestic micro-wave oven (IFB) operating at 100% power level (700W) for different cyclic times (20son, 10soff).

4. Allow the solution to cool naturally to room temperature.

5. Centrifuge the obtained dark brown solution at 14000rpm for 15minutes to separate the less fluorogenic, insoluble black deposit from fluorogenic, yellowish brown supernatant.

6. The supernatant's yellowish-brown color indicates that CDs are forming. [6]

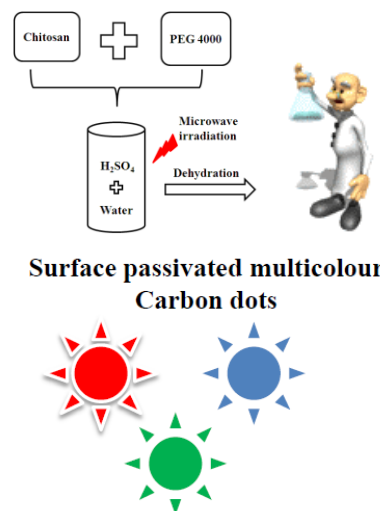


Figure 6. Synthesis of Carbon Dots

2.3 Comparison of in-vivo imaging

A comparison of in vivo imaging results (sub cutaneous injection on the back of mice) between the carbon dots (top) and commercial CdSe–ZnS QDs (Invitrogen, aqueous Qdot® 525 ITK™ amino (PEG) QDs, bottom), with the same number of dots under the same imaging conditions (434nm band-pass for excitation and 474nm cut-off filter for emission) [7]

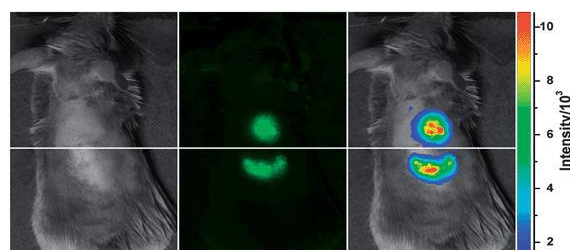


Figure 7. Comparison of in-vivo imaging of QDs & CDs

3. Nanotechnology in Cancer Therapeutics

Nanotechnology has become a game-changing technique in the treatment of cancer. NPs can be engineered to preferentially accumulate in tumour tissues due to their size and the leaky nature of tumour blood vessels. Nanoparticles have a high surface area, allowing for significant drug loading and efficient delivery to tumour sites. [8]

3.1 Passive Targeting

Passive targeting is based on the "enhanced permeability and retention (EPR) effect". Cancerous tissues often exhibit a unique characteristic: their blood vessels are more permeable (leaky) than normal tissues, and their lymphatic drainage is often impaired. This allows macromolecules, including nanoparticles, to extravasate (leak out) from the blood vessels into the tumor tissue and accumulate there. [9]

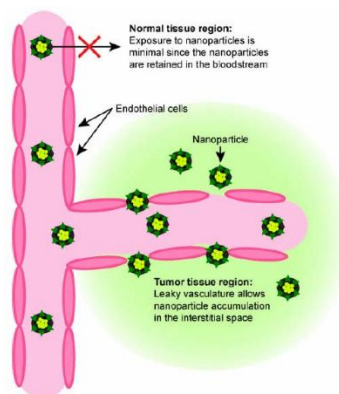


Figure 8. Passive Targeting

3.2 Active Targeting

Unlike passive targeting, which relies on tumor characteristics, active targeting uses engineered nanoparticles to specifically recognize and bind to cancer cells. Active targeting utilizes nanoparticle functionalization with ligands that specifically bind to receptors overexpressed on cancer cells, enhancing drug delivery and accumulation while minimizing damage to healthy tissues. [10, 11]

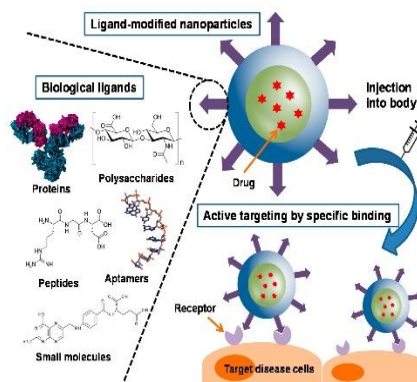


Figure 9. Active Targeting

4. Nanotechnology based drug delivery

In most cases, resistance develops when cancer cells begin expressing a protein, known as p-glycoprotein that is capable of pumping anti-cancer drugs out of a cell as quickly as they cross through the cell's outer membrane.

New research shows that nanoparticles may be able to get anti-cancer drugs into cells without triggering the p-glycoprotein pump. [12, 13]

4.1 Multifunctional nanoparticle:

The following are illustrated: the ability to carry one or more therapeutic agents; bio molecular targeting through one or more conjugated antibodies or other recognition agents; imaging signal amplification, by way of co-encapsulated contrast agents; and bio-barrier avoidance, exemplified by an endothelial tight-junction opening permeation enhancer, and by poly ethylene glycol (PEG) for the avoidance of macrophage uptake by macrophages. [15]

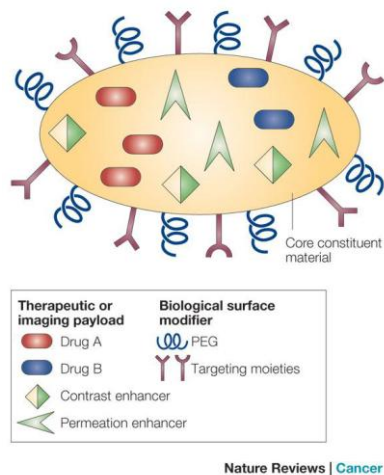


Figure 10. Multifunctional Nanoparticle

Conclusion

Nanotechnology, combined with AI-driven nanorobots, offers transformative potential in cancer therapy by enabling precise drug delivery, real-time monitoring, and targeted treatment, improving efficacy, minimizing side effects, and advancing personalized medicine promotes better patient outcomes by giving the right treatment to the right patient at the right time. The role of several nanomaterials and multi-functional nanoparticles, in improving cancer diagnosis and treatment is significant as they enable precise targeting of therapeutics, controlled release mechanisms, improved efficacy while minimizing side effects and showcasing the ongoing progress and future prospects in this cutting-edge field.

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Ethical Approval

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Informed Consent

Not Applicable.

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Conflict of Interest

There are no apparent conflicts of interest between the authors' personal relationships or financial interests that may have affected the results of this study, the authors state. There is no conflict of interest, according to the writers. All ideas and opinions expressed in this article are those of the authors.

Financial Interests

The authors declare they have no financial interests.

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