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Nanotechnology in Cancer Therapy and Diagnosis

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ABSTRACT:

Nanotechnology has shown great potential in both the diagnosis and treatment of cancer. In diagnosis, nanoparticles can be engineered to have unique properties that allow for highly sensitive and specific detection of cancer cells and biomarkers. This includes the use of nanoparticles as contrast agents for imaging, biosensors for detecting cancer biomarkers, liquid biopsy for detecting cancer cells in body fluids, and point-of-care tests for detecting cancer in remote or low-resource settings. In treatment, nanoparticles can be designed to deliver drugs or other therapeutic agents directly to cancer cells, while minimizing damage to healthy cells. This includes the use of nanoparticles to target specific cancer cells or tissues, to overcome drug resistance, and to enhance the efficacy of existing therapies. Additionally, nanoparticles can be used for photothermal therapy, photodynamic therapy, or gene therapy to destroy cancer cells or induce immune responses. Overall, the use of nanotechnology in the diagnosis and treatment of cancer has the potential to revolutionize cancer care, by providing more accurate and personalized diagnoses, and more effective and targeted therapies. Ongoing research and development in this field is crucial to further advance and optimize these technologies, and to ultimately improve the lives of cancer patients. In this review, we focus on the use of nanotechnology in treatment and diagnosis of cancer.

Keywords: Nanotechnology; Diagnosis; Treatment; Biosensors

Introduction:

Nanotechnology is an interdisciplinary field of science that deals with the design, production, and application of materials, devices, and systems at the nanometer scale. Nanoparticles, which are particles ranging from 1 to 100 nanometers in size, have unique physical and chemical properties that make them attractive for various biomedical applications, including cancer diagnosis and treatment. In recent years, nanotechnology has emerged as a promising tool in the fight against cancer.

Nanoparticles can be engineered to specifically target cancer cells and deliver drugs, genes, or imaging agents directly to the tumor site. This targeted approach allows for more effective treatment while minimizing the toxicity and side effects associated with traditional chemotherapy. Moreover, nanoparticles can also enhance the sensitivity and specificity of cancer detection and diagnosis.

There are several types of nanoparticles that have been explored for their potential in cancer treatment, including liposomes, polymeric nanoparticles, dendrimers, carbon nanotubes, and gold nanoparticles. These nanoparticles can be functionalized with specific ligands or antibodies that can recognize and bind to cancer cells, leading to targeted drug delivery. For example, liposomes are spherical nanoparticles composed of a lipid bilayer that can encapsulate hydrophobic drugs and protect them from degradation in the bloodstream. Polymeric nanoparticles, on the other hand, are made of synthetic or natural polymers and can be designed to release drugs in response to specific triggers, such as pH or temperature changes.

Gold nanoparticles are particularly attractive for cancer treatment because of their unique optical and thermal properties. They can absorb and scatter light, leading to selective heating of tumor cells when exposed to near-infrared radiation. This localized heating, known as photothermal therapy, can destroy cancer cells without damaging surrounding healthy tissues. Gold nanoparticles can also be functionalized with targeting ligands or antibodies for selective tumor targeting.

Another promising application of nanotechnology in cancer is the development of nanosensors for cancer diagnosis and monitoring. Nanosensors can detect biomarkers or changes in the tumor microenvironment that are indicative of cancer, allowing for early detection and personalized treatment. For example, carbon nanotubes can be used as biosensors that can detect cancer-specific molecules in blood or urine samples.

Despite the tremendous potential of nanotechnology in cancer, there are also some challenges that need to be addressed. One of the major concerns is the potential toxicity of nanoparticles, which can accumulate in the body and cause adverse effects. Moreover, the regulatory approval and commercialization of nanoparticle-based cancer therapies can be a lengthy and costly process. [1-2]

Different drug delivery systems that use Nanotechnology for cancer therapy:

Nanoparticles can be engineered to deliver drugs or other therapeutic agents directly to cancer cells, while minimizing damage to healthy cells. There are several different types of drug delivery systems that use nanoparticles for cancer treatment. Here are some of the most commonly used systems:

Liposomes: Liposomes are a type of nanoparticle that has been extensively studied and used in cancer treatment. They are spherical nanoparticles made of phospholipids that can encapsulate hydrophilic or hydrophobic drugs. Liposomes have a biocompatible and biodegradable nature, and can be functionalized with targeting moieties, such as antibodies or aptamers, to specifically deliver drugs to cancer cells. Liposomes have several advantages as drug delivery systems in cancer treatment. Firstly, they can protect drugs from degradation and elimination by the body, allowing for a longer circulation time and better drug efficacy. Secondly, they can selectively accumulate in tumor tissues due to their leaky vasculature and impaired lymphatic drainage, allowing for targeted drug delivery to cancer cells. Thirdly, they can reduce the toxic side effects of chemotherapy by minimizing damage to healthy cells. Liposomes have been used for a variety of cancer treatments, including chemotherapy and gene therapy. For example, Doxil (doxorubicin hydrochloride liposome injection) is a liposome-based formulation of the chemotherapy drug doxorubicin, which is used to treat ovarian and breast cancer. Doxil has been shown to have fewer side effects and improved efficacy compared to the traditional doxorubicin formulation. Another example is Onpattro (patisiran), a liposome-based RNA interference (RNAi) drug used to treat hereditary transthyretin-mediated amyloidosis. In addition to drug delivery, liposomes can also be used for diagnostic purposes in cancer imaging. For example, liposomes can be loaded with imaging agents such as fluorescent dyes or contrast agents, allowing for non-invasive imaging of tumours. [3]

Polymeric nanoparticles: Polymeric nanoparticles are a type of nanoparticle that has been extensively studied and used in cancer treatment. They are made of biocompatible polymers that can encapsulate drugs and release them in a controlled manner. Polymeric nanoparticles can also be functionalized with targeting moieties to specifically deliver drugs to cancer cells. Polymeric nanoparticles have several advantages as drug delivery systems in cancer treatment. Firstly, they can protect drugs from degradation and elimination by the body, allowing for a longer circulation time and better drug efficacy. Secondly, they can selectively accumulate in tumour tissues due to their leaky vasculature and impaired lymphatic drainage, allowing for targeted drug delivery to cancer cells. Thirdly, they can reduce the toxic side effects of chemotherapy by minimizing damage to healthy cells. Polymeric nanoparticles have been shown to be effective in delivering a wide range of therapeutic agents, including small molecules, peptides, and nucleic acids. For example, Abraxane (paclitaxel protein-bound particles for injectable suspension) is a polymeric nanoparticle-based formulation of the chemotherapy drug paclitaxel, which is used to treat breast cancer. Abraxane has been shown to have fewer side effects and improved efficacy compared to the traditional paclitaxel formulation. [4]

Dendrimers: Dendrimers are a type of synthetic nanoparticle with a highly branched structure that has been extensively studied for use in cancer therapy. They are composed of a core molecule with repeated branching that creates a large number of surface groups that can be functionalized with targeting moieties, such as antibodies or peptides, for specific targeting of cancer cells. Dendrimers have several advantages as drug delivery systems in cancer treatment. Firstly, they have a high surface-to-volume ratio, allowing for a large number of drug molecules to be loaded onto the surface of the nanoparticle. Secondly, they can be designed to have a uniform size and shape, allowing for precise control over drug release kinetics. Thirdly, they can be functionalized with targeting moieties for specific targeting of cancer cells. Dendrimers have been used for a variety of cancer treatments, including chemotherapy and gene therapy. For example, PEGylated dendrimers loaded with the chemotherapy drug doxorubicin have been shown to selectively target and kill breast cancer cells in vitro. Additionally, dendrimers can be used to deliver siRNA for gene therapy, which can selectively silence genes that promote tumour growth. [5]

Gold nanoparticles: Gold nanoparticles have gained significant interest as a potential tool for cancer therapy due to their unique physical and chemical properties. These nanoparticles can be easily synthesized in a variety of sizes and shapes, allowing for precise control over their properties and interactions with biological systems. Gold nanoparticles have several advantages as drug delivery systems in cancer treatment. Firstly, they can be functionalized with targeting moieties such as antibodies, peptides or aptamers, which can selectively target cancer cells and improve the specificity of the therapy. Secondly, they can be loaded with therapeutic agents such as chemotherapy drugs, siRNA, or photodynamic therapy agents, allowing for a controlled release at the target site. Thirdly, gold nanoparticles can be used for photothermal therapy, where they absorb near-infrared light and convert it into heat, killing cancer cells in the process. One of the key advantages of gold nanoparticles is their ability to selectively accumulate in tumor tissues due to the enhanced permeability and retention (EPR) effect. This allows for targeted drug delivery to cancer cells, reducing the toxicity of the treatment to healthy tissues. Additionally, gold nanoparticles have shown promising results in photothermal therapy, which involves using near-infrared light to heat up the nanoparticles and kill cancer cells. Gold nanoparticles have been tested in several preclinical and clinical studies for a variety of cancer types, including breast, prostate, ovarian, and lung cancers. For example, a clinical trial using gold nanoparticles for the treatment of head and neck cancer showed a complete response in more than half of the patients. [6]

Carbon nanotubes: Carbon nanotubes are a type of synthetic nanomaterial with unique physical and chemical properties that make them attractive for biomedical applications, including cancer therapy. Carbon nanotubes have a high surface area, high aspect ratio, and can be easily functionalized with a variety of biomolecules, including drugs, peptides, and antibodies. Carbon nanotubes have been studied for a variety of cancer treatments, including photothermal therapy, gene therapy, and drug delivery. In photothermal therapy, carbon nanotubes are functionalized with targeting moieties, such as antibodies or peptides, and then selectively delivered to cancer cells. Once the nanotubes are taken up by the cells, they are exposed to near-infrared light, which causes the nanotubes to heat up and destroy the cancer cells. Carbon nanotubes can also be used for gene therapy, where they are functionalized with siRNA or other nucleic acid sequences that can selectively silence genes that promote tumour growth. Additionally, carbon nanotubes can be used for drug delivery, where they are functionalized with chemotherapy drugs and selectively delivered to cancer cells. One of the key advantages of carbon nanotubes is their ability to penetrate cell membranes, allowing for efficient delivery of therapeutic agents to the target cells. Additionally, carbon nanotubes have a high loading capacity for therapeutic agents, which allows for efficient drug delivery and reduces the amount of toxic side effects on healthy cells. Although carbon nanotubes have shown great potential for cancer therapy, there are still challenges that need to be addressed before they can be used in clinical settings. For example, the toxicity and biocompatibility of carbon nanotubes need to be thoroughly investigated to ensure their safety. Additionally, the pharmacokinetics and biodistribution of carbon nanotubes need to be optimized to ensure effective drug delivery to the target site. [7]

Different types of cancers which can be treated by Nanotechnology:

The development of nanotechnology is based on the usage of small molecular structures and particles as tools for delivering drugs. Nano-carriers such as liposomes, micelles, dendritic macromolecules, quantum dots, and carbon nanotubes have been widely used in cancer treatment. Nanotechnology has shown great potential in the treatment of various types of cancer, including:

- Breast cancer: Breast cancer is one of the most common types of cancer in women, and nanoparticle-based therapies have been developed for targeted drug delivery to breast cancer cells. Liposomes, polymeric nanoparticles, and gold nanoparticles have been studied for their ability to deliver chemotherapeutic drugs directly to the tumor site and improve treatment efficacy.
- Lung cancer: Lung cancer is one of the deadliest forms of cancer, and nanoparticle-based therapies have been developed for targeted drug delivery to lung cancer cells. Carbon nanotubes, gold nanoparticles, and dendrimers have been studied for their ability to deliver chemotherapeutic drugs or gene therapies to lung cancer cells.
- Prostate cancer: Prostate cancer is a common cancer in men, and nanoparticle-based therapies have been developed for targeted drug delivery to prostate cancer cells. Polymeric nanoparticles and dendrimers have been studied for their ability to deliver chemotherapeutic drugs or gene therapies to prostate cancer cells.
- Brain cancer: Brain cancer is a highly aggressive and difficult-to-treat cancer, and nanoparticle-based therapies have been developed for targeted drug delivery to brain cancer cells. Liposomes, polymeric nanoparticles, and dendrimers have been studied for their ability to cross the blood-brain barrier and deliver drugs directly to the tumor site.
- Colorectal cancer: Colorectal cancer is a common cancer in both men and women, and nanoparticle-based therapies have been developed for targeted drug delivery to colorectal cancer cells. Liposomes, polymeric nanoparticles, and gold nanoparticles have been studied for their ability to deliver chemotherapeutic drugs directly to the tumor site and improve treatment efficacy.
- Pancreatic cancer: Pancreatic cancer is a highly aggressive and difficult-to-treat cancer, and nanoparticle-based therapies have been developed for targeted drug delivery to pancreatic cancer cells. Liposomes, polymeric nanoparticles, and gold nanoparticles have been studied for their ability to deliver chemotherapeutic drugs or gene therapies to pancreatic cancer cells.

These are just some examples of the types of cancers that can be treated using nanotechnology. Ongoing research and development in this field will undoubtedly lead to further advances and breakthroughs in the fight against cancer. [8]

Nanotechnology in the Diagnosis of Cancer:

Nanotechnology has also shown great potential in the diagnosis of cancer. Nanoparticles can be engineered to have unique physical, chemical, and biological properties that can be used for imaging and detection of cancer cells and biomarkers. Here are some of the ways nanotechnology is being used in the diagnosis of cancer: [9]

- Imaging: Nanoparticles can be used as contrast agents for various imaging modalities, such as magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET). By targeting nanoparticles to specific cancer cells or biomarkers, it is possible to improve the sensitivity and specificity of these imaging techniques.
- Biosensors: Nanoparticles can be functionalized with biomolecules, such as antibodies or aptamers, that can recognize specific cancer biomarkers. By detecting the binding of these biomolecules to the cancer biomarkers, it is possible to develop highly sensitive and specific biosensors for cancer diagnosis.
- Liquid biopsy: Liquid biopsy is a minimally invasive technique for detecting cancer biomarkers in blood, urine, or other body fluids. Nanoparticles can be used to isolate and enrich cancer cells or biomarkers from these fluids, allowing for highly sensitive detection and monitoring of cancer progression.
- Point-of-care testing: Nanoparticles can be used to develop portable and inexpensive diagnostic tests for cancer that can be used in remote or low-resource settings. By combining nanoparticles with microfluidic devices or paper-based assays, it is possible to develop point-of-care tests that can detect cancer biomarkers in a matter of minutes.
- Multiplexed detection: Nanoparticles can be engineered to have different sizes, shapes, or surface properties that can be used to distinguish multiple cancer biomarkers in a single sample. By combining multiple nanoparticles with different properties, it is possible to develop multiplexed detection platforms for cancer diagnosis.

Side-effects of use of Nanotechnology in Cancer therapy:

While nanotechnology has shown great promise in cancer diagnosis and treatment, there are potential side effects and risks associated with the use of nanoparticles. These side effects can vary depending on the type, size, and surface properties of the nanoparticles, as well as the route of administration and dose. [10]

- Toxicity: One of the main concerns with nanoparticles is their potential toxicity. Nanoparticles can accumulate in the body, leading to cellular damage and inflammation. Moreover, some nanoparticles may have specific toxic effects, such as inducing oxidative stress, disrupting cell membranes, or interfering with cellular signaling pathways.
- Immunological reactions: Nanoparticles can also trigger immune reactions, such as the activation of complement proteins, the recruitment of immune cells, or the production of inflammatory cytokines. These immune reactions can lead to tissue damage and inflammation, and may affect the efficacy and safety of nanoparticle-based therapies.
- Clearance: Nanoparticles can have a long half-life in the body, which can lead to accumulation in organs such as the liver, spleen, and lungs. This can cause toxicity and impair organ function.
- Non-specific targeting: Nanoparticles can also target non-cancerous cells, leading to off-target effects and toxicity. This can occur when nanoparticles are not specifically designed to target cancer cells or when the targeting ligands are not selective enough.
- Biodistribution: The biodistribution of nanoparticles can vary depending on their size, shape, and surface properties. This can affect the efficacy and safety of nanoparticle-based therapies, as well as the interpretation of imaging and diagnostic results.
- Regulatory challenges: The regulatory approval and commercialization of nanoparticle-based therapies can be a lengthy and costly process, as these therapies require rigorous safety and efficacy assessments.

Conclusion:

In conclusion, while nanotechnology has the potential to revolutionize cancer diagnosis and treatment, there are also potential side effects and risks that need to be carefully considered and addressed. Ongoing research and development in this field will be crucial to optimize the efficacy and safety of nanoparticle-based cancer therapies.

References:

1. Aslan, B., Ozpolat, B., Sood, A. K., & Lopez-Berestein, G. (2013). Nanotechnology in cancer therapy. Journal of drug targeting, 21(10), 904–913.
2. Jin, C., Wang, K., Oppong-Gyebi, A., & Hu, J. (2020). Application of Nanotechnology in Cancer Diagnosis and Therapy - A Mini-Review. International journal of medical sciences, 17(18), 2964–2973.
3. Huwyler, J., Drewe, J., & Krähenbuhl, S. (2008). Tumor targeting using liposomal antineoplastic drugs. International journal of nanomedicine, 3(1), 21–29.
4. Tewari, A. K., Upadhyay, S. C., Kumar, M., Pathak, K., Kaushik, D., Verma, R., Bhatt, S., Massoud, E. E. S., Rahman, M. H., & Cavalu, S. (2022). Insights on Development Aspects of Polymeric Nanocarriers: The Translation from Bench to Clinic. Polymers, 14(17), 3545.
5. Lee, C. C., MacKay, J. A., Fréchet, J. M., & Szoka, F. C. (2005). Designing dendrimers for biological applications. Nature biotechnology, 23(12), 1517–1526.
6. Yang, Y., Zheng, X., Chen, L., Gong, X., Yang, H., Duan, X., & Zhu, Y. (2022). Multifunctional Gold Nanoparticles in Cancer Diagnosis and Treatment. International journal of nanomedicine, 17, 2041–2067.
7. Thiruvengadam, M., Rajakumar, G., Swetha, V., Ansari, M. A., Alghamdi, S., Almehmadi, M., Halawi, M., Kungumadevi, L., Raja, V., Sabura Sarbudeen, S., Madhavan, S., Rebezov, M., Ali Shariati, M., Sviderskiy, A., & Bogonosov, K. (2021). Recent Insights and Multifactorial Applications of Carbon Nanotubes. Micromachines, 12(12), 1502.
8. Akhter, S., Ahmad, I., Ahmad, M. Z., Ramazani, F., Singh, A., Rahman, Z., Ahmad, F. J., Storm, G., & Kok, R. J. (2013). Nanomedicines as cancer therapeutics: current status. Current cancer drug targets, 13(4), 362–378.
9. Chaturvedi, V. K., Singh, A., Singh, V. K., & Singh, M. P. (2019). Cancer Nanotechnology: A New Revolution for Cancer Diagnosis and Therapy. Current drug metabolism, 20(6), 416–429.
10. Mahmood Rasool, Arif Malik, Sulayman Waquar, Mahwish Arooj, Sara Zahid, Muhammad Asif, Sumaira Shaheen, Abrar Hussain, Hamid Ullah & Siew Hua Gan (2022) New challenges in the use of nanomedicine in cancer therapy, Bioengineered, 13:1, 759-773