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CARBON NANOTUBES (CNTS) ARE EMERGING AS COLON TARGETED DRUG DELIVERY SYSTEM

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Abstract

Carbon nanotubes (CNTs) are cylindrical nanostructures formed by sp2 hybridized carbon atoms and are a promising class of nanomaterials for biomedical applications, particularly in cancer therapy. Due to their unique structural, mechanical, and physicochemical properties such as nanoscale dimensions, very high surface area, and high thermal and electrical conductivity, CNTs are ideal for targeted drug delivery and diagnostic imaging. CNTs have been classified into single-walled, double-walled, and multi-walled based on their structural organization. These nanoscale materials have an amazing ability to penetrate the cell membrane, encapsulate or carry drugs, and deliver drugs specifically to cancerous sites, to decrease systemic toxicity and maximize therapeutic effects. In addition to drug delivery, CNTs also have prospects for contrast agents used in diagnostic medical imaging modalities such as photoacoustic imaging, fluorescence imaging, and Raman spectroscopy that can enable not only early tumor detection but also real-time tumor tracking and monitoring. The functionalization of CNTs and their ability to serve as drug delivery vehicles can improve drug loading capacity, and reduce off-target effects, and provide more effectiveness for tumor-targeted therapy according to the literature. The development of CNT-based nanomedicine offers a new direction for cancer diagnosis and treatment as the incidence of cancer rises across the world.

Keywords: Carbon Nanotubes (CNTs), Cancer Therapy, Biocompatibility/Toxicity, Tumor Targeted Delivery, Drug delivery systems

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INTRODUCTION

Carbon nanotubes (CNTs) are large cylindrical molecules that are consist of hexagonal arrangements of hybridized carbon atoms. Types of carbon nanotubes can be formed by rolling a single graphene sheet or multiple graphene sheets. CNTs are made of sp2 nanocarbon materials that have tubular shapes. Ultimately, these tubular shapes are the result of rolled up graphene sheets. The properties of carbon nanotubes are governed nearly solely by their crystalline or one-dimensional precursor shapes. These nanotubes possess extraordinary properties. Their incredible mechanical strength makes them perfect for reinforcement in composites (in fact they out-strength most of the natural and synthetic materials). They have excellent thermal conduction properties, making them suitable for heat dissipation applications [1].CNTs are produced with a hexagonal graphitic, unidimensional structure that has a horizontal alignment of stacked benzene rings. Due to their high aspect ratios, microscopic diameters, large surface areas, simple perforation of membranes, and ability to conjugate or encapsulate diverse medicinal compounds, carbon nanotubes (CNTs) have been broadly categorized as single-walled, double-walled, or multiwalled carbon nanotubes (MWCNTs) based on their diameters, construction, or arrangements [2-3].

Single-walled carbon nanotubes (SWCNTs)

This is consisting of tubular cylinder wrapped around a graphene unilayersheet which can in the form of chiral, armchair and zigzag. Due to the geometric arrangement of the nanotubes have a length of 1nm approximately and a diameter of about 1 nm.

Double - walled carbon nanotubes (DWCNTs)

It consist of two layers of graphite sheet stacked in a cylindrical pattern. The outside wall of DWCNTs is a coaxial nanostructure that incorporates a two-dimensional graphene sheet wrapped into a cylindrical form, the structure and characteristics of DWCNTs are similar to those of MWCNTs. DWCNTs do not include cylindrical tubes with a diameter of less than 1 nm.

The word "cancer" describes a variety of diseases that arise from uncontrolled cell division. Each disease has a different name, based on the tissue in which the cell first appears. The majority of patients die not from the primary tumor, but from the systemic problem of metastases and tumorous growths in areas far removed from the original tumor. Cancer is a disease that occurs when some of the body's cells grow uncontrollably and spread to other organs in the body. Cancer can develop in many different organs because the human body has trillions of cells. Cells multiply, through the process of division, so that new cells are available for the growth of tissue as determined by the body. Aging and injury to cells allows for the generation of new cells, as damaged cells die. Damaged or abnormal cells can bunch together forming lumps of tissue know as tumors. Tumors can be either benign or malignant. Malignant tumors can invade nearby tissues and spread or metastasize to distant sites and establish new tumors. Malignant tumors can also be referred to as cancerous tumors. Leukemia's and other blood malignancies often do not appear as solid tumors, but most other malignancies do [4].

Chemotherapy drugs have limitations side effects. In the pharmaceutical field many pharmaceutical companies are exploring alternatives drugs that are able to deliver drugs with high therapeutic efficacy and minimal toxicity to patients. So, cell-targeting pharmacological formulations with broader therapeutic index remains as an unmet need. CNTs have shown significant capabilities as nanoscale drug delivery vehicles. The main advantage of CNTs is the ability to deliver drugs specifically to cancer cells. Cell targeting of drugs using CNTs is believed to be a more useful way to detect the expression of biomolecular attributes of early cancer due to the unique electrical, mechanical and thermal properties of carbon nanotubes. Photoacoustic imaging (PAI), fluorescence imaging (FI), and Raman imaging are the three medical imaging modalities related to carbon nanotubes. In photoacoustic imaging, carbon nanotubes have had benefits because they can be used as contrast agents with strong absorption in the near-infrared (NIR) region, leading to increased imaging signals. In fluorescence imaging, carbon nanotubes can be used for a multi-colored fluorescence imaging because each single-walled carbon nanotube has unique excitation and emission wavelengths. In the case of Raman imaging, multi-colored images can be achieved through isotopic-modification of single-walled carbon nanotubes. This is helpful since Raman imaging provides important information about the chemical composition of cells and tissues. All these findings demonstrate the high potential as well as the practical applications of carbon nanotubes in modern medical imaging and the early detection of cancers [5].

Epidemiology

About 293,000 new cases of cancer are occur in UK every year. More than one in three people will get cancer during their lifetime. The most commonly diagnosed cancer in the UK is colorectal cancer, while lung and breast cancer are the next most frequently diagnosed. Lung cancer and colorectal cancer are also the most commonly reported causes of cancer deaths [6].Cancer still presents as an important global public health issue, with 20 million new cases and 9.7 million deaths attributable to cancer (including nonmelanoma skin cancers (NMSCs)) in 2022, and it poses greater annual mortality than other conditions. One in five men and women will develop cancer in his or her lifetime, and one in nine men and one in twelve women will die from it. In women, breast cancer had the highest incidence and mortality of all cancers, and lung cancer had the highest frequency and mortality rate for all cancers in men. The predited figures show that by 2040, new cancer cases (29.9 million) and cancer deaths (15.3 million) will rise significantly, and there is no prediction for improvement [7].

Importance of CNTs in drug delivery

Chemotherapy drugs are subjected to limits inherently due to their toxic side effects. There exists a market segment for drug delivery systems that can have a high therapeutic efficacy but have lower toxicity for the pharmaceutical industry. Using CNTs as nanoscale drug delivery agents, has shown a lot of promise. Due to their unique properties, carbon nanotubes (CNTs) have attracted a great deal of interest as one of the most promising nanomaterials for a broad range of biomedical applications. The ability to deliver drugs directly to cancer cells, is one of the main benefits of CNTs. The use of CNTs to deliver drugs to their site of action is one of the primary areas of interest for a number of research organizations. This is primarily due to their unique chemical, physical, and biological properties; the monolithic hollow structure, nanoneedle shape, and ability to attain the required functional groups on their outer surface [8].

Literature review

Liu Z et al.2008 had researched Single-walled carbon nanotubes (SWNTs) are biocompatible, excretable and low toxicity. They have also shown potential for tumor-targeted accumulation in mice. SWNT can reduce tumors in mice in vivo medicine delivery.A water-soluble SWNT-paclitaxel conjugate (SWNTPTX) was prepared by conjugating the well-known cancer chemotherapy drug, paclitaxel (PTX), to branches of polyethylene-glycol (PEG) chains on the SWNTs by a cleavable ester link [9].

SR et al. 2010 had studied Carbon nanotubes (CNTs) have become a popular platform for the diagnosis and treatment of cancer because of their unique physicochemical properties. CNTs are thought to be among the most important nanomaterials because they can both recognize malignant cells as well as deliver drugs or other small therapeutic agents to them. In the last few years, CNTs have been studied in almost all cancer treatment modalities: gene therapy, drug delivery, thermal therapy, photodynamic therapy and lymphatic targeted chemotherapy [10].

Thakur CK et al, 2024 have studied for targeted drug delivery, multiwalled carbon nanotubes (MWCNTs) are at the forefront of nanotechnology enhancements for cancer treatment. The strength of the nanotubes is based on the graphene concentric layers. They are able to deliver large doses of therapeutic agents, which may reduce the frequency of treatment and improve compliance. Because of their size and surface alterations MWCNTs can load an immense number of drugs, circulate biological barriers, and be modified for drug delivery, all things that may help treat patients with cancer [11].

Ramesh GB et al. 2024 have investigated carbon nanotubes (CNTs) in the field of cancer therapies has shown great promise. This investigation explores the many anticancer properties of bio-functionalized carbon nanotubes. Due to their unique physicochemical and structural characteristics, carbon nanotubes provide a flexible platform for novel methods of cancer diagnosis, treatment, and understanding of the underlying molecular mechanisms. In order to improve CNTs' compatibility and specificity with living things and enable more accurate targeting of cancer cells, the bio-functionalization procedure is essential [12].

Guan F et al. 2024 have studied that the Warburg effect was first proposed over 100 years ago &showed that cancer cells mainly rely on glycolysis in the carcinogenesis process with plenty of oxygen available, thus changing the primary energy metabolism pathway from the tricarboxylic acid cycle to aerobic glycolysis,between tumor cells and immune cells, stromal cells and other cells [13].

Ramezani Farani M et al 2024have researched Colorectal cancer (CRC) is responsible for 9.4% of cancer-related deaths and 10% of newly diagnosed cancer cases, making it a substantial public health issue globally. While the prevalence of colorectal cancer is increasing, current standard therapies such as radiation, chemotherapy, or surgery have limited efficacy and need innovative treatment options. Nanoparticles exist at nanoscale, and their unique properties at the nanoscale exploit the metabolic differences between healthy and malignant cells. This property allows nanoparticles to cause significant cytotoxicity to cancer cells while minimizing damage to healthy tissues [14].

Brito CL et al 2024 have developed and enhance the pharmacological profiles of numerous molecules employed for therapeutics and tissue bioengineering, carbon nanotubes (CNTs), which represent nanometric materials, are being used in pathogen detection, environmental preservation, food preservation, and health diagnostics and therapies as effective drug delivery systems. carbon nanotubes (CNTs) possess a variety of physical, mechanical and chemical properties, they also have great potential for amalgamation with other materials in order to facilitate applications across multiple medical disciplines [15].

Nabitabar M et al .2024 have researched that Carbon nanotubes (CNTs) can act as drug delivery vehicles and gene therapies, which is useful for cancer treatment. Co-delivery of curcumin (CUR) and methotrexate (MTX) has received interest for cancer treatment because it uses less medication with fewer side effects.the efficacy of CUR, this experiment used MTX-conjugated albumin (BSA)-based nanoparticles (BSA-MTX) [16].

Gao S et al.2024 have studied thatCarbon nanotubes (CNTs) are an exciting drug candidate in nanomedicine because of their unique and remarkable mechanical, electrical, and physiochemical properties, which recently stimulated the interest of a broad range of scientists in this recent form of nanomaterial. Carbon nanotubes have many potential applications in cancer treatment, including imaging applications, drug delivery, and combination therapy. Carbon nanotubes can deliver anticancer drugs known, as well as release them in a targeted manner, potentially increasing therapeutic efficacy and reducing toxicity to healthy tissues. Carbon nanotubes can also be used in contrast to other modalities as mentioned above (i.e. photodynamic and photothermal therapy), for the effective destruction of cancer cells [17] .

Tajabadi M, 2025 have researched the advantages of current developments in carbon nanotubes, specifically SWNT, to improve breast cancer treatment. Future tumor therapy, utilizing low drug dosing, will benefit immensely from the nanotube drug delivery method by using an effective treatment with no side effects [18].

Zheng H et al. 2025 have characterized tumor immune escape, by immune cell dysfunction and immune inhibitory molecule overexpression, presents a major therapeutic hurdle for cancer. Tumor immunotherapy, in order to effectively control and eradicate tumors, differs from conventional anti-tumor strategies by the goal of restoring normal anti-tumor immune responses. Active ingredients of Traditional Chinese Medicine (TCM) exhibit a range of anti-tumor activities and mechanisms, including immune cell function modification and tumor-associated suppressive factor inhibition that could improve anti-tumor immune responses [19].

Table 1: Literature review

Sr.no	Author Name/Year	Method/Approach	Finding	Journal name
1.	**Liu Z et al.2008**	In vivo study using PEG-SWCNT conjugated with paclitaxel in mice	SWNT-PTX conjugates increase tumor uptake via EPR effect and reduce systemic toxicity compared to Taxol®	Cancer research.
2.	**SR et al. 2010**	Comprehensive review on CNTs in diagnostics & multiple therapeutic applications	CNTs can aid in drug, gene, and photothermal therapy; issues around toxicity and in vivo validation remain	Biophysica Acta (BBA)-Reviews on Cancer.
3.	**Thakur CK et al, 2024**	ligand-conjugated MWCNTs for targeted drug delivery	MWCNTs functionalized with ligands enable selective drug delivery, reducing side effects; high payload efficiency observed	Frontiers in Pharmacology
4.	**Ramesh GB et al. 2024**	Bio-functionalized CNTs for anticancer therapy	CNTs can be tuned for multiple anticancer mechanisms including apoptosis induction and 5.targeted delivery; challenges in standardization noted	Journal of Inorganic and Organometallic Polymers and Materials.
5.	**Guan F et al. 2024**	Tunneling nanotubes and mitochondrial transfer in cancer therapy	Highlights mitochondrial hijacking by tumor cells via tunneling nanotubes; proposes targeting this process in immunotherapy and drug resistance control	Journal of Experimental & Clinical Cancer Research
6	**Ramezani Farani M et al 2024**	CRC prevalence and nanoparticle applications	CRC accounts for 9.4% of cancer deaths and 10% of new cancer cases. Nanoparticles selectively target cancer cells while sparing healthy tissues.	Carbon Letters
7.	**Brito CL et al 2024**	Carbon nanotubes (CNTs) in biomedical applications	CNTs enhance drug pharmacology, aid in diagnostics, pathogen detection, and drug delivery; their properties support cross-disciplinary medical applications.	ACS omega
8.	**Nabitabar M et al .2024**	Nanoparticle-based co-delivery system using BSA-MTX for CUR and MTX	CNTs are effective in co-delivery systems for cancer therapy; BSA-MTX nanoparticles improve curcumin efficacy with reduced drug dosage and side effects.	Scientific Reports.
9.	**Gao S et al.2024**	Systematic review on CNTs in diagnostics, therapy, and biotoxicity	CNTs can be used in combination therapies (e.g., photothermal+drug delivery); focus on safe functionalization	Frontiers in Bioengineering and Biotechnology
10.	**Tajabadi M, 2025**	Focused review on SWCNTs in breast cancer therapy	SWCNTs offer high NIR absorbance and potential	Drug research

			for low-dose, high-efficiency drug delivery in breast cancer	
11.	**Zheng H et al. 2025**	Imunotherapy with TCM active ingredients	Tumor immune escape hampers therapy; TCM compounds help restore immune functions and suppress tumor-promoting factors, enhancing anti-tumor immunity.	Journal of Nanobiotechnology

Research Gap

Safety and Toxicity

Despite their biocompatibility and targeting capabilities, the long-term toxicity, biodegradability, and clearance mechanisms of carbon nanotubes (CNTs) remain undefined. Study have brought cytotoxic potential and accumulation in the liver, kidney, and spleen into question, but none addressed these concerns in any detail.

Lack of Standardized Functionalization Methods

There is no standard method for functionalizing CNTs, which varies quite a bit depending on the goals of increasing solubility, targeting, and decreasing toxicity and no comparison of single-walled (SWCNTs) and multi-walled (MWCNTs) carbon nanotubes for biosafety and drug delivery potential.

Limited in Vivo Validation and Clinical Translation

Most of the work is still at the in vitro or animal model stage. Clinical trials are rare.*In vivo* usefulness has been inadequately tested, particularly in terms of pharmacokinetics and immune response.

Lack of Integration with Personalized Medicine

Using imaging-guided therapeutics and patient-specific molecular markers to include CNTs into personalized nanomedicine is still largely speculative.

Ethical and Regulatory Barriers

There is a considerable regulatory gap related to the clinical access, approval, and safety assessment of CNT-based therapeutic systems.

Conclusion

In nanomedicine, the role of carbon nanotubes represents aadvance particularly for cancer detection and treatment. They are unique in their structure and ability to be functionalized with therapeutics and targeted ligands, enabling carbon nanotubes to act as highly effective methods for drug delivery. Although cancer remains one of the most chronic and fatal diseases worldwide, the need for new treatments that are less toxic and can deliver therapy specifically is even greater than before. There are advantages that CNTs have over conventional cancer therapies, such as relation to bioavailability, fewer doses needed, and focused drug delivery. Their uses in medical imaging can also broaden opportunities for early detection and surveillance for cancer. Although a lot of possible lies with CNTs, more research is needed to characterize the efficacy and long-term safety, and biodegradability in targeted drug delivery therapies. it appears that CNTs will prove to be an essential tool for cancer therapies and personalized medicine in the future, given the expanding scope of functionalization methods used with CNTs, and their improved biocompatibility.

Disclosure Statement

There are no conflicts of interest.

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