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SYNTHESIS AND FUNCTIONALIZATION OF CARBON NANOPARTICAL FOR ADVANCED DRUG DELIVERY SYSTEM

Devendra Dhanorya *, Nidhi Uikey, Niharika Sarote, Lovely Paraste, Manisha Raidas, Muskan Sahu, Namita Wayam, Naman Dubey and Mohit Chourasiya

Department of Pharmacy, Mangalayatan University, Ricchaibarela, Jabalpur - 483001, Madhya Pradesh, India.

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Correspondence to Author:
Devendra Dhanorya

Department of Pharmacy, Mangalayatan University, Ricchaibarela, Jabalpur - 483001, Madhya Pradesh, India.

E-mail: ddhanorya@gmail.com

ABSTRACT: In the last few decades, carbon nanotubes (CNTs) have been the focus of significant research in the field of medicine owing to their unique characteristics and wide range of potential applications. Globally, there has been an urgent need to design and develop safe, effective, controllable, and targeted drug delivery systems, leading to the creation of a new class of therapeutic nanotubes. Research in nanotechnology and nanoscience is advancing to develop multifunctional CNTs with the desired features for future applications. Current perspectives on the applications of engineered carbon nanotubes in nanomedicine and bioengineering are focused on designing safe, effective, controllable, and targeted strategies. CNT-based drug delivery systems aim to deliver therapeutics to specific tissues, reduce adverse drug effects, enhance bioavailability, and repair damaged tissues. Additionally, they are utilized in detection, diagnostic, and monitoring devices. This review covers the recent developments in carbon nanotubes and their potential applicability with brief synthesis, functionalization, and the latest advancements in the medicinal chemistry of carbon nanotubes.

INTRODUCTION: Carbon nanotubes (CNTs) have recently been deemed as an evolving nanocarrier in the field of nanomedicine, a discipline that combines biology, nanotechnology, and medicine. These have a variety of applications, including controlled drug delivery, targeted delivery of drug molecules to a specific site, delivery of bio-nanotechnology products, as an additive to improve the solubility of poorly water-soluble drugs, vaccine delivery, hormone, and enzyme delivery, and as a nanofluidic device in drug delivery.

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CNTs have also been employed in a variety of biomedical applications, including diagnostic instruments such as nanosensors, nanorobots, nanoprobes, and actuators to detect diseases. According to the available literature on CNTs, this nanocarrier has a wide range of biomedical uses **Fig. 1**. [9].

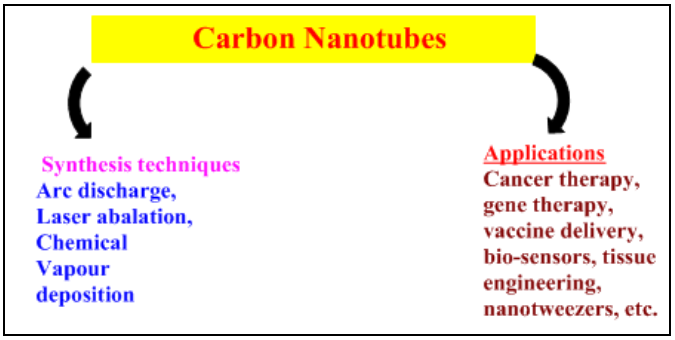

FIG. 1: VARIOUS SYNTHESIS METHODS OF CNT AND APPLICATIONS

Drug Delivery with Carbon Nanotubes: The quest for innovative and effective drug delivery systems remains a crucial and persistent challenge that demands continuous focus and research. A drug delivery system is often designed to enhance the pharmacological and therapeutic properties of a medicinal molecule. The capacity of f-CNT to penetrate cells suggests the possibility of using f-CNT as a vehicle for the delivery of small drugs. However, the utility of f-CNT for the delivery of anticancer, antibacterial, or antiviral medicines is still unknown. Developing delivery systems that can convey therapeutic drugs with recognition capabilities, optical signals for imaging, and customized targeting is crucial for treating cancer and infectious diseases. To this end, we devised a novel technique for the multiple functionalization of CNT with various types of molecules.

A fluorescent sensor for monitoring cellular absorption of the material and an antibiotic moiety as the active molecule were covalently bonded to CNT. MWNTs were functionalized with amphotericin B and fluorescein. In comparison to the antibiotic incubated alone, the antibiotic bound to the nanotubes was easily internalised into mammalian cells with no harmful consequences **Fig. 2**. Amphotericin B coupled with carbon nanotubes (CNTs) has retained its potent antifungal activity against a wide spectrum of pathogens, including *Candida albicans*, *Cryptococcus neoformans*, and *Candida parapsilosis*. Another group has reported the functionalization of single-walled carbon nanotubes (SWNTs) with substituted carborane cages, creating a novel delivery system for efficient boron neutron capture therapy. These water-soluble CNTs were designed to treat cancer cells. Experiments demonstrated that carborane was present in specific tissues following intravenous injection of the CNT conjugate, with significant localization at the tumor site. Another family of carbon nanomaterials, similar to CNTs, has been employed for drug delivery [65]. Various findings suggest that functionalized CNTs (f-CNTs) could represent a novel class of delivery vehicles, capable of transporting and translocating drug molecules into various types of mammalian cells. Although these CNT conjugates have shown minimal cytotoxicity in vitro, further research is needed to analyze their metabolism, biodistribution, and elimination from the body [10].

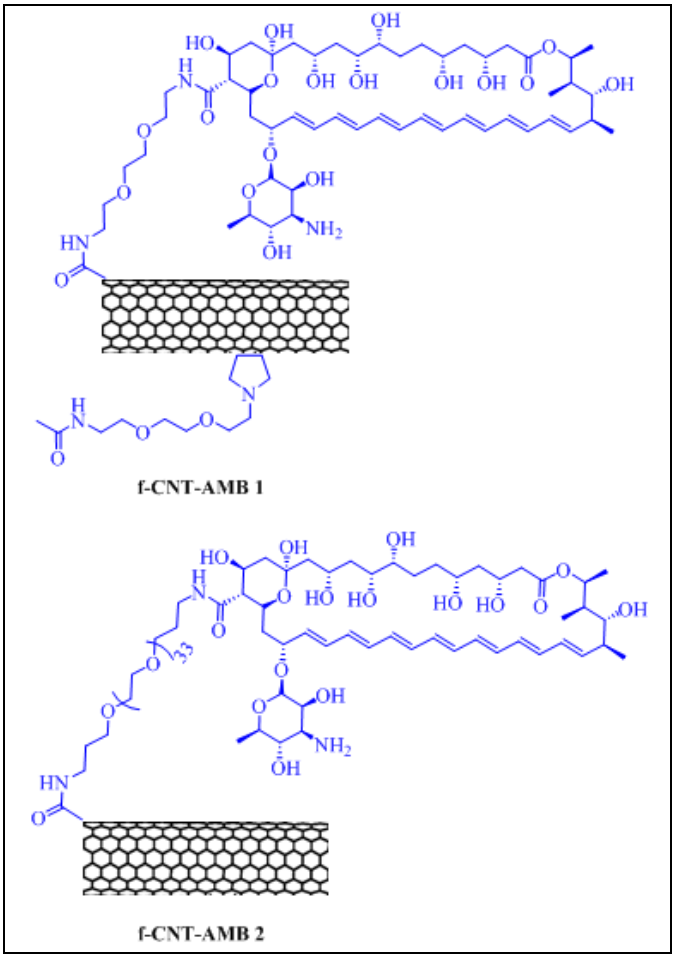

FIG. 2: STRUCTURE OF THE F-CNT-AMB CONJUGATES USED IN THIS STUDY

Carbon nanotubes have been synthesized using three primary methods: arc discharge, chemical vapor deposition (CVD), and laser ablation. In the first two methods, solid-state carbon precursors produce the carbon needed for nanotubes, converting it into gas at extremely high temperatures. Despite producing many by products, these techniques are known for creating high-quality, nearly perfect nanotube structures. CVD uses metal catalyst particles as "seeds" and hydrocarbon gases as sources of carbon atoms to build nanotubes at comparatively low temperatures (500-1000°C) [20, 66, 84, 91]. CVD methods have enabled the production of SWNTs with high crystallinity and perfection, comparable to arc and laser ablation methods [95]. Moreover, various studies have shown that solid-state nanotubes (SWNTs) can be efficiently deposited *via* CVD on discrete pre-manufactured nanoparticles. Metallic SWNTs serve as model systems for studying rich quantum phenomena, such as Luttinger liquid behavior, weak localization, ballistic transport, and

quantum interference. However, cutting-edge building blocks for nanoelectronics, including transistors, logic circuits, memory devices, and sensory devices, have been developed using semiconducting nanotubes [21, 24, 45, 51, 58].

Section 1: Synthesis of Carbon Nanotubes: Carbon nanotubes are among the most exceptional examples of novel nanostructures generated through bottom-up chemical synthesis techniques. They possess the greatest diversity and richness of forms and structure-property connections of any nanomaterial, combined with the simplest molecular composition and atomic bonding pattern [26].

Arc Discharge: The arc discharge method for synthesizing carbon nanotubes (CNTs) is one of the earliest and most well-established techniques. It involves generating CNTs through the use of high-current electric arcs between two graphite electrodes.

SWNTs Synthesis: CNT deposition can be carried out using various catalyst precursors or without them. Using a transition metal catalyst, however, results in the production of SWNTs **Fig. 3**. A composite anode is typically used in an argon or hydrogen atmosphere to develop SWNTs *via* arc discharge. Graphite is combined with a metal such as Fe, Co, Ni, Pd, Ag, Pt, *etc*., to form the anode. Graphite may also be combined with metals like Co, Fe, and Ni to form alloys such as Co-Cu, Co-Ni, Ni-Cu, Ni-Ti, Fe-Ni, etc. The metal catalyst significantly impacts the process yield. To achieve high efficiency, it is essential to maintain a constant gap distance between the electrodes, ensuring consistent current density and anode consumption rate [16, 17, 83]. This approach frequently produces unwanted by products such as MWNTs and fullerenes. The arc discharge procedure is still utilized to synthesize SWNTs, albeit with variations. Chen *et al.* described the FH (ferrum-hydrogen) arc discharge method, which generates SWNTs by evaporating a carbon anode with a 1% Fe catalyst in an H2-Ar mixed gas using a hydrogen DC arc discharge [16]. The resulting SWNTs exhibit high crystallinity. To remove the coexisting Fe catalyst nanoparticles, an oxidation purification process using H_2O_2 has been developed for newly manufactured SWNTs, resulting in more than 90% pure SWNTs. Fan and colleagues explored an inexpensive method for developing SWNTs. Their experimental results clearly showed that charcoal has the potential to lower the cost of SWNT production, thanks to this accessible and reasonably priced material [14]. In a separate publication, Wang *et al.* investigated the effect of Mo on SWNT growth using the arc discharge method. They included Mo in two common arc system configurations: Ni/Y-He and Fe-Ar/H2. Mo significantly increased the soot generation in both systems. According to the researchers, the inclusion of Mo had no significant effect on the purity of SWNTs in the Ni-Y/Mo-He system; however, the purity of the Fe/Mo-Ar/H2 system increased dramatically [18].

DWNTs Synthesis: Although the development of DWNTs **Fig. 4** is a more difficult procedure than the fabrication of SWNTs and MWNTs, there have been numerous documented successful arc discharge preparation methods for these materials. The initial description of DWNTs, an arc discharge technology, was made by Hutchison *et al*. in an argon and hydrogen mixture atmosphere [40]. A graphite rod with a diameter of 8.2 mm that was loaded with catalyst served as the anode. Ni, Co, Fe, and S were mixed as a catalyst. Bundles of the collected DWNTs were frequently constructed. Sometimes, SWNTs were thought to be a by-product. Sugai *et al*. described a novel method for producing high-quality DWNTs using Y/Ni alloy catalysts in high-temperature pulsed arc discharge [92].

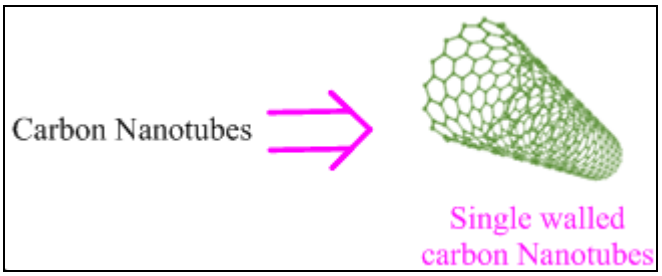

FIG. 3: STRUCTURE OF SINGLE-WALLED CARBON NANOTUBE

Demonstrated the efficient and large-scale synthesis method for DWNTs with relatively high structural integrity employing an arc discharge method and a trace halide as a promoter in an iron sulphide catalyst [72]. Both synthetic and pure DWNTs were resistant to oxidation at high

temperatures. The selective synthesis of DWNTs with exceptional oxidation resistance up to 800 °C using a hydrogen arc discharge approach was disclosed by Liu *et al*. in a distinct work [97].

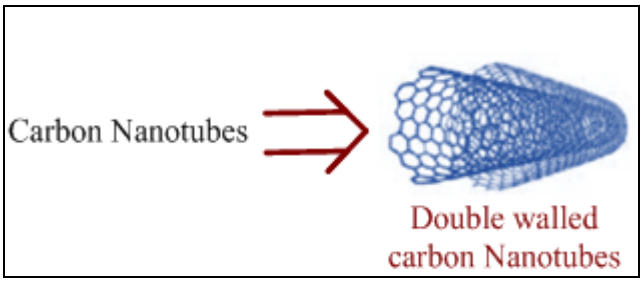

FIG. 4: STRUCTURE OF DOUBLE-WALLED CARBON NANOTUBE

The method of producing DWNTs from MWNTs using a hydrogen arc discharge was described by Li *et al*. The carbon source for the large-scale production of DWNTs was either MWNTs or graphite powders. The purity of their DWNT product was found to be higher than that of graphite powders. HRTEM observations revealed that more than DWNTs made up more than 80% of the CNTs, while SWNTs made up the remaining 20%. The isolated DWNTs were found to have uncapped ends, and it was established that the catalyst's main ingredient, cobalt, was essential to the development of the DWNTs made in this manner [50]. The main issue with manufactured carbon nanotubes is the existence of impurities, which frequently affect the final characteristics of carbon nanotubes as a material that might be employed in a certain application [56, 68, 81].

MWNTs Synthesis: The synthesis of MWNTs **Fig. 5** during an arc discharge is fairly simple if all growth parameters are satisfied. The most widely used methods employ an arc discharge between two graphite electrodes, commonly water-cooled, with diameters between 6 and 12 mm in a helium-filled chamber at sub-atmospheric pressure. Zhao *et al*. discovered that evaporation in the case of CH_4 gas was more pronounced than that in the case of He gas in terms of the alteration of carbon nanotube shape [64]. In a different study, Zhao *et al*. generated fine and long MWNTs in a hydrogen gas atmosphere. There is a significant difference between He and methane gases, according to comparisons. In particular, the evaporation of He and CH_4 gases produced far more carbon smoke than that of H_2 gas [110].

Most of the time, non-standard CNTs are deposited using arc discharge. There have been various works employing arc discharge in liquid solutions that are described, in contrast to normal MWNT deposition using a gas environment. By using an arc discharge in liquid nitrogen, Jung *et al*. reported the method would work well for producing high-purity MWNTs on a wide scale [41]. Sornsuwit and Maaithong utilized a similar technique to deposit MWNTs, and According to Montoro *et al*., employing pure graphite electrodes and an arc discharge in H3VO4 aqueous solution, high-quality SWNTs and MWNTs were produced. A DC arc discharge was formed between two high-purity graphite electrodes [22, 62]. The extremely crystalline, orderly, and defect-free nature of MWNTs was evident from the high-resolution TEM pictures. They produce MWNTs with a graphene interlayer distance of roughly 0.35 nm and an outside diameter of 10-20 nm. By creating an arc discharge in water between electrodes made of only pure graphite, Guo *et al*. were also able to produce MWNTs in high yield [31].

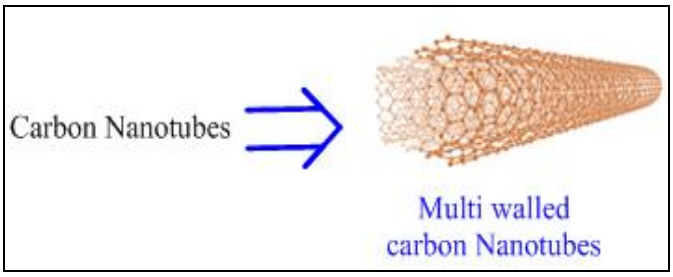

FIG. 5: STRUCTURE OF MULTI-WALLED CARBON NANOTUBES

Section 2: Laser Ablation: Many things can change the properties of the CNT made by pulsed laser deposition (PLD). These include the structure and chemical makeup of the target material, the pressure and chemical make-up of the chamber, the flow and pressure of buffer gas, the substrate and the temperature outside, the distance between the target and the spill target, and more. When it comes to making high-quality and pure SWNTs, laser ablation and the critical phase of PLD are two of the best methods. Laser ablation, which is an important part of PLD, is one of the best ways to make high-quality and pure SWNTs. Zhang *et al*. used continuous wave CO_2 laser ablation to make SWNTs without heating the object anymore. They saw that the average width of SWNTs made by CO_2 lasers got bigger when the laser power went

up [11]. Since a UV laser is better at photochemical ablation than an infrared laser, which is better at photothermal ablation, it is possible to think that it makes new types of nanoparticles and a new way of making CNTs. By ablation with a UV-laser (KrF excimer) on a graphite target that had been suitably doped with a Co/Ni metal catalyst, Lebel *et al*. produced SWNTs [47]. SWNTs as prepared were tested in their study as a polyurethane reinforcing agent [48] Stramel *et al*. successfully deposited composite thin films onto silicon substrates using PLD with a pulse using PSNTs and commercial MWNTS-polystyrene targets (MWNTs-PSNTs) [90]. They found that compared to utilizing PSNT targets, employing pure MWNTs targets produces a thin film with a substantially higher quality of MWNTs. utilizing pellets of commercial polystyrene-nanotubes, Bonaccorso *et al*. produced MWNTs thin films that were then deposited utilizing PLD techniques [12].

Chemical Vapor Deposition (CVD): Other substrates, like tungsten foil and graphite, were also put to the test. Cu/Ti/Si, Ni, SiO_2, Si, Cu, stainless steel, or glass are frequently used substrates, although $CaCO_3$ is only infrequently used [2]. A novel substrate called mesoporous silica was also put to the test since it serves as a template for the growth of different nanotubes. For example, Ramesh *et al*., the high-yield selective CVD synthesis of DWNTs over Fe/Co-loaded high-temperature stable mesoporous silica was also successful [74]. Zeolites were looked into by Hiraoka *et al*. as an additional substrate. They employed CCVD of acetylene over evenly dispersed metal particles embedded in heat-resistant zeolites at temperatures above 900°C for the selective production of DWNTs [36].

One of the key factors influencing the growth of CNTs is catalyst selection. As a result, its preparation is likewise an essential stage in the development of carbon nanotubes. The effect of the catalyst nanoparticles' composition and morphology on the production of CNTs by CVD is covered in a paper [94]. Xiang *et al*. has produced CNTs by CCVD of acetylene on various catalysts made of Co/Fe/Al layered double hydroxides (LDHs). They discovered that the precursors' Co content had a noticeable impact on the development of CNTs. Because there were more active Co species with better dispersion, the carbon yield increased with increasing Co content. The production of CNTs with smaller diameters and less structural disarray was influenced by higher Co concentration [105].

For the one-step CCVD reaction procedure in an argon flow, Feng *et al*. synthesized high-quality DWNTs thin films using acetone as a carbon source, ferrocene as a source of Fe catalyst, and thiophene as a promoter [29, 54]. Dimethyl sulfide (C_2H_6S), a carbon source that is infrequently utilized, was pyrolyzed at 1000 degrees Celsius to developed CNTs by Du *et al* [27].

Functionalization of Carbon Nanotubes: Due to their weak dispersibility and insolubility in many solvents, CNT uses are limited in some fields. High surface energy and many p-p-interactions between the electrons inside the tubes cause the CNTs to clump together. CNT applications have been amplified through functionalization. You can prevent the aggregation of CNTs by employing either a mechanical or chemical technique. To separate the nanotubes, mechanical techniques use ultrasonication, strong shear, and high impact. Mechanical procedures have a limited application since they take too long and are inefficient. On the other hand, chemical treatments increase a substance's adsorption stability and wetting or adhesion characteristics. The CNT can be modified with biological or active molecules, or it can be functionalized covalently or noncovalently [6, 60].

Covalent Functionalization: For the covalent strategy to build various chemical bonds over the surface of CNTs, either at the sidewalls or the end, several chemical methods have been developed. Covalent bonds are produced between the carbon skeleton found in the carbon nanotubes and the functional components. Increasing the CNTs' dispersion will improve their wetting or adhesion properties and reduce their tendency to aggregate. The covalent technique has two subcategories: direct covalent sidewall functionalization and indirect chemical modification. Amidation, thiolation, halogenation, oxidation, hydrogenation, the addition of nitrene, carbenes, radicals, etc. are all examples of chemical functionalization. Covalent functionalization causes sp^3 hybridization on the carbon sites and inhibits p-electrons from

migrating, without altering the CNTs' granularity [4, 7, 37, 44, 46, 77, 79, 88, 89]. However, because the commonly used medications often contain free amine or carboxylic groups, the covalently attached drug with carrier gives advantages of high drug loading. However, it also brings up several problems, including slow drug release and the potential for conjugation-related drug inefficiency.

Chemical functional groups come in three main varieties, including nitro-phenyl ($C_6H_4NO_2$), benzoic acid (C_6H_4COOH), and amino-phenyl ($C_6H_4NH_2$), which were added to the sidewalls of MWCNTs in a study by Sahoo *et al*. The study's goal was to determine whether liquid crystalline polymer (LCP) is compatible. The impact of electron-withdrawing and electron-donating groups was studied. It was discovered that LCP and multiple wall CNTs (MWCNTs) interacted most strongly with amino phenyl ($C_6H_4NH_2$). The rheological and mechanical characteristics of CNTs were enhanced by these interactions [50, 76, 82].

Non-covalent Bonding: Polymers, amphiphilic surfactants, and other functional groups may be amenable to enfolding or supra-molecular adsorption using the non-covalent approach. These functional groups can be bound by a variety of adsorption forces, including van der Waals forces, electrostatic forces, hydrogen bonds, and p-stacking interactions. The main disadvantage of this function is a potential decrease in efficiency due to weakening interactions between wrapping molecules and nanotubes [76]. These methods can be used to improve the solubility and dispersibility of CNTs. However, van der Waal's forces are insufficient, making it difficult to carry drugs. Zhang and colleagues researched the impact of amino compounds from the tetrazine compound on MWCNTs. This alteration formed a p-stacking with graphite sidewalls that let the epoxy matrix disseminate evenly [93].

A variety of spectroscopic methodologies, heating, diffraction techniques, and separation procedures are used to assess the physical and chemical composition of CNTs [42, 86]. Based on surface functionalization and conjugation, CNTs can enter cells through various mechanisms, including pinocytosis, membrane adsorption, phagocytosis, and endocytosis.

Internalization is influenced by surface chemistry or functionalization, metal impurities, aggregation, cellular processes, biodistribution, and degradation kinetics. The size, dimensions, and colloidal behaviour of material surfaces, as well as CNT individualization, significantly impact their interaction with membranes [4, 42, 63, 86]. Various properties of CNTs and their Characterization Tools are listed in **Table 1.**

TABLE 1: PROPERTIES OF CNTS AND THEIR CHARACTERIZATION TOOLS

S. no.	CNT properties	Characterization technique	Reference
1	Inters hell gap, number of layers, diameter, and internal structure	AFM and TEM	(Sharma et al.
2	Length, diameter, and aggregation	SEM	(Ünlü et al.
3	Crystal structure, impurities, and interlayer spacing	XRD	(Sharma et al.
4	Relative intensity of bands, position, width, purity, and electronic structure	Raman spectroscopy	(Rathod et al.
5	Electronic and optical properties	Photoluminescence spectroscopy	(Umemura et al.
6	Functionalization, chemical structure	XPS	(Wang et al.
7	Elemental composition of CNTs	EDS	(Kaur et al.
8	Atomic-level structure and tunneling density study	STM	(Odom et al.
9	Possible distortion of network and bond length	Neutron diffraction	(A Barzinjy
10	Evaluatepurity and thermal stability of CNT systems	TGA and DTG	(A Barzinjy
11	Dispersion capacity, relative purity, length, and diameter distribution	UV-Visible spectroscopy	(A Barzinjy
12	Impurities during synthesis and functional group presence	IR and FTIR	(Mehra & Jain
13	Size, chirality, and Dispersion capacity	Fluorescence spectroscopy	(Prajapati
14	Separation and purification of size	Size exclusion chromatography	(Herrero-Latorre et al.

Section 3: Applications of Carbon Nanotubes: CNTs have been used to develop a range of drug delivery systems by conjugating different bioactive compounds or ligands [3]. At what are known as "therapeutic effect-related sites," CNTs are known to enhance bioavailability, solubility, residence time, and therapeutic efficacy. Additionally, CNT-based delivery systems can be monitored in real-time. Some applications are outlined below.

CNTs in Cancer Therapy: Unregulated cell division drives the development of tumors in cancer. CNTs are preferred over other nanocarriers due to their superior drug-loading capabilities and nanometric size. Their high surface functionality allows for the conjugation of bioactive compounds and improved site-specific delivery. The main challenges with anticancer medications are the side effects they cause in non-target organs and the difficulty of delivering the right dose to the right location. To target HT-29 colon cancer cell lines, Prajapati *et al.* coupled Polyethylene Glycol (PEG) and Hyaluronic Acid (HA) to MWCNTs. Gemcitabine (GEM), known to prevent DNA replication, showed enhanced effectiveness when delivered via DOX/MWCNTs, significantly reducing tumor growth compared to untreated controls. This was attributed to the prolonged circulation duration and focused accessibility of FA-coupled MWCNTs [69].

CNTs in Gene Therapy: Gene therapy, an innovative approach to treating hereditary and acquired illnesses, involves the transfer of active molecules such as small-interfering ribonucleic acid (siRNA), short hairpin ribonucleic acid (shRNA), and micro-ribonucleic acid (miRNA). CNTs can form complexes to transport various nucleic acids, making them promising vectors for gene delivery. Their modified surfaces facilitate the effective transport of nucleic acids. Due to their size and lipophilicity, CNTs bypass the cell's endocytic processes and enter directly through the plasma membrane. In an *in-vitro* cytotoxicity study by Cifuentes-Rius et al., cell viability decreased as the concentration of CNTs increased in 3T3 cells (ATCC) [8, 19, 73 109].

CNTs in Vaccine Delivery: Carbon nanotubes (CNTs) have been utilized in cancer and infectious disease vaccines due to their exceptional *in-vivo* stability, lack of inherent immunogenicity, low toxicity, and ability to link with multiple antigen copies. Their unique hollow shape allows CNTs to aggregate multiple antigens simultaneously. Unlike typical vaccines that trigger an innate immune response, CNTs attached to antigen peptides can modulate this response, avoiding issues such as hypersensitivity, anaphylactic reactions, and improper absorption. Using MWCNTs boosted the synergism between CpG and aCD40, significantly reducing the growth of OVAB16F10 in tumor models. In metastatic tumor models, OVA-expressing B16F10 melanoma cells showed significant growth inhibition, indicating MWCNTs as a promising vector for effective tumor eradication [30, 34, 85].

CNTs in Photothermal Therapy (PTT): Photothermal therapy (PTT) is a promising, noninvasive method that uses a near-infrared (NIR) laser to generate heat and kill tumor cells [114]. PTT reduces the negative effects on healthy cells. The length of nanotubes affects the efficiency of heat conduction and the destruction of cancer cells [18, 97]. Combining chemotherapy and gene therapy with CNT-based PTT can enhance cancer treatment efficacy. CNTs and magnetic nanoparticles can be combined for both therapeutic and diagnostic purposes in PTT applications [80]. In a different study, Suo et al. developed an antibody-conjugated MWCNT formulation for PTT, which increased cellular absorption of MWCNTs after anti-Pgp therapy. In tumor spheroids containing multidrug-resistant (MDR) cancer cells, targeted MWCNTs caused phototoxicity due to the formulation's enhanced intra-tumor diffusion and cellular absorption [93].

CNTs in Tissue Engineering: Various polymers, including gelatin, polyester, and polyanhydride, have been reported by Prajapati *et al.* for use in tissue engineering [69]. Tissue engineering is advancing, necessitating the constant examination of new techniques and cutting-edge biomaterials to accelerate tissue growth. CNTs are preferred for constructing artificial scaffolds due to their physical and chemical similarities to biological extracellular matrix. Magnetic resonance imaging and radiotracer contrast agents can be used to monitor tissue formation using CNTs. CNTs enhance the capabilities of scaffold and tissue

production. Scaffolds for bone and cartilage engineering require improved mechanical properties [32, 47]. The primary requirement is selecting a biocompatible material for the scaffold to support tissue and cell growth, resulting in a 3D porous network. Cellular activities such as migration, spanning, and alignment control tissue formation, and characteristics like geometry, pore size, and material orientation influence these activities. The mechanical and electrical properties of the CNT-composite scaffold, including enhanced pore volume, surface area, *in-vitro* activity, porous microstructure, and strength, are crucial. Col/f-MWCNT/CS scaffolds showed excellent biocompatibility and increased biomineralization capacity [32, 90].

CNTs in Biosensors: Various biosensing assays have been developed to detect biological analytes such as medicines, nucleic acids, infections, and toxins using specific affinity layers (antibodies, enzymes, nucleic acids, or receptors) [113]. Due to their photoluminescence in the NIR and substantial Raman scattering resonance, CNTs are an excellent choice for biological detection. Many classes of CNT biosensors have been developed to analyze various cancer biomarkers, and they have been coupled with DNA or aptamers, antibodies, peptides, proteins, or enzymes. Recently, biomarker oligonucleotides (microRNA) present in bodily fluids like serum and urine have been detected using CNTs [33]. In a study, Zanganeh *et al.* developed an electrical biosensor using vertically aligned CNTs with amine functionalization coupled with folic acid (FA-VACNTs) for cancer cell detection. The MRC-5 and QUDM cell lines, representing normal and malignant cells respectively, were taken from the human lung. FA-VACNT arrays had a higher percentage of cancer cells trapped compared to VACNTs. It was found that sensors with FA-VACNT electrodes had improved electrical response [107].

CNTs in Nanotweezers: Nanotweezers are probes propelled by electrostatic interaction between the probe tips of two nanotubes. They operate on the balance between electrostatic and elastic restoring forces. Nanotweezers have been used to modify and manipulate the form, size, physiology, and morphology of cells, as well as DNA, in various biomedical sectors. The use of CNT-based nanotweezers in analytical research and the treatment of various diseases has the potential to expedite simultaneous variation relations [9, 75, 86].

CONCLUSION: Due to their functional and chemical versatility, carbon nanotubes (CNTs) have acquired numerous beneficial medical properties and exhibit tremendous promise for upcoming novel drug delivery systems. It is crucial to meticulously evaluate all parameters associated with CNTs, such as material homogeneity, residual metals, individual nanotube separation, and sensitivity to emitted gases. Nonetheless, urgent attention must be given to reducing nanoparticle toxicity. Proactive measures are essential to ensure the safe application of nanotechnology. This article briefly discusses current findings on CNTs and their potential applications. The findings underscore the need for further research to develop straightforward and effective methods for functionalization and characterization to enhance CNT biodegradation. It is also crucial to develop procedures that facilitate the water solubility, biocompatibility, non-cytotoxicity, and optimal biodegradability of CNTs. Simplified methods for conjugating hydrophilic polymers or other bioactive substances are necessary to maximize the benefits of CNTs. The safety concerns and efforts to enhance CNTs' biocompatibility will largely shape the future applications of these materials.

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