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A Review on Carbon Nanotubes as Targeted Drug Delivery System.

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ABSTRACT:Carbon nanotubes (CNTs) are a leading and unique invention in the field of nanotechnology. Since its discovery in 1991, numerous industries and businesses have been drawn to it due to its enormous production capacity. Crystal structures are almost identical to the nuclear atomic configuration of diamond and graphite. While diamond is owned by sp3-hybridized carbon, graphite is a member of sp2-bonded carbon. There are three techniques which can be used for the synthesis of carbon nanotubes (CNTs): chemical vapor deposition, arc deposition, and laser deposition. CNTs possess unique mechanical, electrical, physical, thermal and chemical properties. Their superiority in delivering drugs directly into cells without requiring the body to metabolize them has been established. The types, synthesis, functionalization, properties, applications, and biosafety are all covered in this review. The carbon nanotubes can be purified using a variety of techniques. Subsequently, CNTs have been widely used in a variety of other applications, including tissue regeneration, biosensor diagnosis, enantiomer separation of chiral drugs, gene therapies, and the extraction of drugs. Furthermore, it was recently discovered that CNTs are a promising antioxidant. The limitations and patents surrounding carbon nanotubes are also examined, as well as the pharmacokinetics, metabolism, and toxicity of various forms of CNTs.

KEYWORDS: Carbonnanotubes, Synthesis, Functionalization, Pharmacokinetics.

I. INTRODUCTION

The previous several years have been the discovery, progress and in certain cases, large-scale production of novel materials with a nano meter-scale structure. Most of the time, these novel nanomaterials which can be either organic or inorganic have never been investigated in relation to drugs. Carbon nanotubes are essentially long, thin cylinders of graphite that were ascertained in 1991 by Japanese scientist Sumio Iijima. A lot of people believe that nanotechnology will be a major technological advancement in the twenty-first century, affecting numerous important industrial sectors. Nanotechnology has the potential to completely transform both our general way of life and the state of health in particular. It is a new field that includes the increasingly complex manipulation of matter at the nanoscale (0.1 nm to 1000 nm), leading to the creation of novel materials, goods, and apparatuses with novel and peculiar properties. In contemporary science, it is one of the most significant fields for research and development. these cylindrical carbon molecules have the potential to be employed in many different fields of science, engineering, and medicine, including mechanical, structural, thermal, electrical and electronics, optical, and biomedical. Allotropes of carbon are called carbon nanotubes, or CNTs. Carbon is an extremely important element. Its atomic number is six, meaning that it contains six electrons that can occupy the atomic orbitals of 1s2, 2s2, and 2p2. Four of theseelectrons are valence electrons, meaning they have the ability to hybridize into sp, sp^2, or sp^2forms. In bulk and at the nanoscale, carbon can take on a wide range of fascinatingconfigurations. Research has been directed on the distinct inherent chemical and physical properties of carbon nanotubes. From special electrical properties and a thermal conductivity greater than diamond to mechanical properties where the stiffness, strength, and resilience surpass any existing material, carbon nanotubes offer enormous potential for the development of fundamentally new material systems. After functionalization, CNTs show reduced toxicity and do not educe an immune response, opening up a wide range of tremendous applications in the fields of biomedicine and nanobiotechnology. CNTs have a broad range of therapeuticmolecules that they can effectively absorb. Because they enter cells directly and deliver

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drugswithout undergoing metabolism while in the delivery vehicles, carbon nanotubes must be functionalized or altered because they are poorly soluble in aqueous solutions.

II. STRUCTURE OF CARBON NANOTUBES

A sequence of benzene rings rolled up into a tubular structure makes up a carbon nanotube. It is comparable to the configuration in graphite. These innovative synthetic nanostructures are made of three atoms bonded to carbon atoms via sp^2 (planar) and sp^3 (cubic) forms. The sp^2bonds are stronger than sp^3 bonds and gives the structure unique strength. Carbon nanotube structure arrangement is dependable for the unique mechanical and chemical properties [1]. Armchair, zigzag, and chiral carbon nanotube configurations. While their diameter and chiral angle vary, armchair carbon nanotubes have electrical characteristics that are analogous to those of metals. The electrical characteristics of chiral and zigzag comparable to those of semiconductors [2].

Carbon nanotubes are categorized into two types in accordance with the number of layers: Single-walled carbon nanotubes (SWCNTs) and Multiwalled carbon nanotubes (MWCNTs).

Single-wall carbon nanotubes (SWCNTs)

Single-walled carbon nanotubes are covering with graphite which one atom thick layerrecognize as graphene into a seamless cylinder. The diameter of SWCNTs has 0.4 to 2nanometres, that's depends on temperature and usually emerge as hexagonal close packed bundles [2] [3]. As the result, that the growth temperature enhanced, the diameter of carbon nanotubes also become larger [23]. The length of SWCNTs is up to 1 mm. It requires catalyst for their synthesis. It gives less accumulation in the body [2] [3].

Multi-wall carbon nanotubes (MWCNTs)

Multiwalled carbon nanotubes are a consisting of multiple layers of graphene rolled up seamlessly into a tube shape. The diameter of MWCNTs is 7 to 100 nanometer and interlayer distance are 3.4 A°. The length of MWCNTs is up to 1 mm. It can be produced without catalyst. Product purity is high. It gives more accumulation in the body [2] [3]. MWCNTs, the aspect of sp^2 hybridization creates a shared electron cloud along the walls; as a result, interactions between the adjacent cylindrical layers of the nanotubes. These body, they have proven to be a highly effectivedrug interactions make MWCNTs less flexible and more structural defects [23].

When the graphene sheet is rolled up into a tube, tubule structures are induced. The molecules are doing rolling is contingent upon its direction: armchair, zigzag and chiral [2].

III. FABRICATION OF CARBON NANOTUBES

There are several methods of production of carbon nanotubes in particular arc discharge, laserablation process, chemical vapor deposition, flame synthesis, silane solution method. They can also be categorized into several groups. In physical processes include those arc discharge and laser ablation process. In chemical processes include chemical vapor deposition and in miscellaneous processes include such as flame synthesis and silane solution method [4].

Arc Discharge

This is the former methods of carbon nanotube production. This is the physical method of nanomaterial synthesis. This method is high temperature process. The product and yield are dependent on the atmosphere and catalysts [5]. The principle of this technique is to vaporizecarbon in the presence of catalysts underdiminished argon or helium environment of inert gas.carbon vapor, the rare gas and catalysts vapours are mixed together to generate a plasma thatis created when an arc is initiates between two electrodes. In the vaporization the energy transfer from the arc to the anode composed of graphite doped with catalyst. The power of the arc and additional experimental condition concern the anode erosion rate. Both a diffusion pump and argon or helium supply need to be connected to this technology by a vacuum line. The electrodes consist two graphite rods, typically high degree of purity. The anode is long rod and the diameter is 6 mm. The cathode is shorter rod and the diameter is 9 mm. It has been exhibited that the cathode releases superior in quality carbon nanotubes. Two carbon electrodes are assigned in a helium atmosphere with a DC bias of 20-30 V in the arc discharge technique. Carbon atoms are expelled from the anode and a mass as nanotubes on the cathode through a deposition process. Arc discharge generate narrower and shorter tubes than laser ablation [6] [7].

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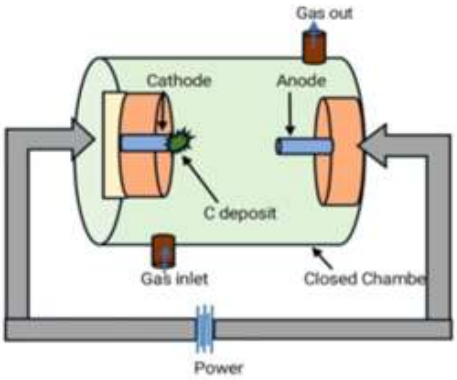

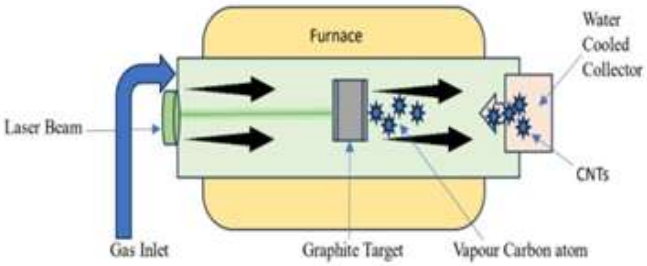

Schematic diagram of arc discharge method

Large scale synthesis of MWCNTs is achieved by arc discharge method. Multiwalled carbon nanotubes formed of coaxial graphene sheets and it is found only top surface of the cathode deposit. Methane was used in the synthesis process to produce MWCNTs characterized by high crystallinity and minimal coexisting carbon nanoparticles. The enhance efficiency of MWCNTs production using a hydrogen- containing gas, as opposed to inert gases like helium or argon, is likely attributed to the elevated temperature and increased reactivity of the hydrogen arc during the process. These MWCNTs contain 3 A° diameter tube and a linear carbon chain, both of which coexist within the same H2-arc MWCNTs [8].

Laser Ablation

Laser ablation method, a pulsed laser is employed to vaporize the carbon from graphite target within a high temperature reactor, with the assistance of an inert gas like helium, causing the graphite target to vaporize. The most feasible devices for gathering the nanotubes also have a surface that is cooled by water. They produce high yields approximate 70% and produce single wall carbon nanotubes [1][9][10]. This method involves a two-step ablation process where an initial laser vaporization pulse is succeeded by a second pulse, which accelerates the target vaporization, effectively reducing the deposition of carbon as soot. In this process, carbon nanotubes grow on catalyst atoms, continuing their growth until an excessive number of catalyst atoms conglomeration at the tubes end. As a result, the tubes produced using this method form a mat of ropes with diameters typically ranging from 12 to 20 nm and lengths extending up to 100 microns or even longer. The precise average diameter and length of the carbon nanotubes can be restrained by adjusting factors for instance temperature, catalyst composition and diverse process parameters [4].

Schematic diagram of a laser ablation apparatus
Chemical Vapor Deposition

It is the popular method for producing carbon nanotubes. In contrast to the arc discharge and laser ablation methods, the Chemical Vapor Deposition method is more effective for large scale production of MWCNTs, as it exploits a hydrocarbon gases like methane as the carbon source, subjecting it to high temperature decomposition to yield carbon nanotubes [11]. To facilitate carbon nanotube growth, a typical step involves coating a chosen substrate, commonly made of materials like silicon, with catalyst materials such as iron, nickel or cobalt nanoparticles, which serve as nucleation sites in the chemical vapor deposition process. The substrate, along with the catalyst is heated to a high temperature usually maintained above 600 °C but below the catalyst melting point, enabling the decomposition of the introduced hydrocarbon gas to occur at the catalyst particle surfaces during MWCNTs growth [1]. The layer of the carbon atoms forms concentric cylinders, resulting in MWCNTs. This approach results in higher yields and purity, consequently reducing the need for costly purification processes, which remain necessary in the other methods. This method is referred to as thermal or catalytic chemical vapor deposition. Wang et al. amplified a nano agglomerate fluidized bed reactor, that can produce several kilograms of multi walled carbon nanotubes per hour with a reported purity of 70% by continuously decomposing ethylene gas on Fe/alumina catalyst at 700°C [8]. Chemical vapor deposition is mostly utilized for the industrial

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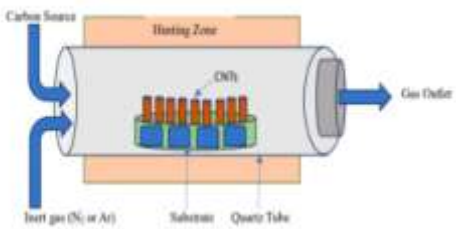
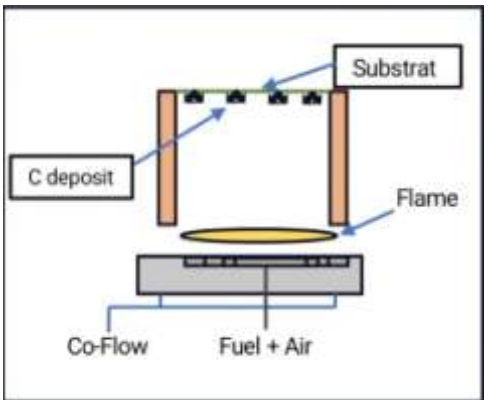
purposes due to the method is well examined and respectable results on the industrial scale [1].



Schematic diagram of a CVD setup

Flame Synthesis

Flame synthesis an efficient and scalable approach for producing nanotubes continuously, and it holds the promise of substantially lowering the production costs when compared to alternative methods. Still, achieving precise control over the synthesis of carbon nanotubes within a flame remain a significant challenge, primarily because of the intricate and multifaceted environment it presents. Furthermore, our understanding of the intricate growth mechanisms of CNTs in such conditions is still incomplete [12]. Flame based synthesis has proven effective in producing multi wall nanotubes and larger carbon nanotube structures. It utilized substrate type catalysts to ensure better control over the catalyst formation process. Different flame configuration, such as those mentioned earlier, have been employed with a range of fuel sources, including methane (CH4), ethylene (C2H4), acetylene (C2H2), propane (C3H8) and various alcohols along with oxidizer mixtures like air, O2-N2, and O2-Ar to achieve this diverse array of carbon nanostructure. Metal catalyst particles, such as iron or nickel, are intentionally added as tiny nanoparticles into the flame [13]. These nanoparticles play a crucial role by providing the initial points where carbon nanotubes start growing. The specific choice of catalyst can have a notable influence on the structure and properties of multi wall carbon nanotubes that ultimately form. The process by which multi-wall carbon nanotubes grow within flames is intricate. Essentially, it begins with hydrocarbons breaking down into carbon radicals in the flame. These carbon radicals then adhere to the catalyst nanoparticles. Subsequently, the MWCNTs form as carbon radicals undergo catalytic decomposition on these nanoparticles. In control way of fuel gas is moderately burned to gain the right temperature range is 600 °C to 1000°C for multi wall carbon nanotubes. As optimization parameters the fuel gas composition, catalyst and temperature can be control to produce MWCNTs with the desired quality and properties [1] [4] [13].



Schematic diagram of a Flame Synthesis

Silane Solution Method

In the establishment of carbon nanotubes, a silane method is employed, where a substrate like carbon paper or stainless-steel mesh is dipped in a silane solution containing a metal catalyst, typically in a 1:1 ratio of Co to Ni. Then, a feedstock gas with a carbon source, such as ethylene is passed via the substrate and electrical current is applied to heat it [1]. This process facilitates a reaction between the catalyst and gas, resulting in the formation of carbon nanotubes that adhere to the conductive substrate.

IV. PURIFICATION OF CARBON NANOTUBES

There are various stages in purification of carbon nanotubes. Nanotubes commonly include large number of impurities for instance metal particles, amorphous carbon, graphitic sheets and multishell structure.

Oxidative Treatment

The most frequently implement a system for purification of carbon nanotubes is oxidation using various techniques, treatment with different acids and calcination. To ensure that carbon nanotubes are free from impurities and unreacted reagents [14]. These impurities have quite more defects or a more open structure. This process is favored because these impurities are frequently connected to the metal catalyst, which also aids in the oxidation. The prosperity of this procedure relies on different factors, including the amount of metal, the duration of oxidation, the environment,

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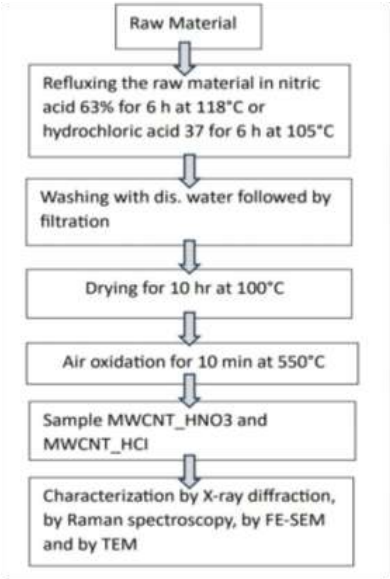
the oxidizing agent and temperature [1]. For example, Multi wall carbon nanotubes were purified using two diverse methods. The first method intended to eliminate the metal catalyst, achieved through refluxing the nanotubes in nitric acid (63%) for 6 hours at 118°C and in hydrochloric acid (37%) for 6 hours at 105°C, as illustrated I figure 4.1a and the second method is illustrated in figure 4.1b, involved the removal of amorphous carbon by subjecting the nanotubes to air oxidation for 10 minutes at 550°C. As result, samples were labelled as MWNT_HNO for those purified with nitric acid and MWNT_HCl for those purified with hydrochloric acid [14].



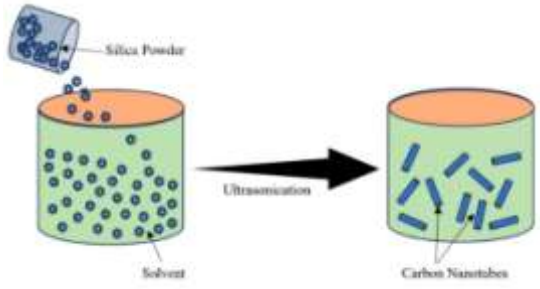
Oxidative treatment

Acid Treatment

Usually, Acid treatment is employed to eliminate the metal catalyst, a process that begins with either oxidation or sonication to expose the metal surface, which is subsequently solvated by the acid [1]. In this process using sulfuric acid and nitric acid. Each cycle of this acid treatment process consisted of 10 seconds of sonication and take two hours of treatment. The residual acidic materials on the CNT surface were removed through filtration and the CNTs were further washed with water before being dried in an oven for 24hours. Multiwall carbon nanotubes after acid treatment, resulting inreduced thickness and weight of the CNTs [15].

Ultrasonication

In this purification method, particle is separated with the use of ultrasonic vibrations, which disperse agglomerates of various nanoparticles. The efficacy of particle separation relies heavily on the choice of surfactant, solvent and reagent [1]. In the presence of appropriate solvent like dichloromethane and O-dichloromethane, has proven effective in removing amorphous impurities from carbon nanotubes. During sonication, solvent molecules interact with CNTs, promoting solubilization and improving the isolation of multiwall carbon nanotubes while preventing carbon nanoparticle agglomeration. The range of structural damage depends on the solvent used, perhaps as a result of variations in energy transfer efficiency during cavitation. Sonicated CNTs emerge shorter due to nanotube cutting, exhibitopened tips and prepare uniform surface functional groups, making ultrasonic treatment an effective method for functionalizing multiwall carbon nanotube surface [16].



Schematic diagram of ultrasonication

V. FUNCTIONALIZATION

Pristine carbon nanotubes insoluble in water as a result of their highly hydrophobic surfaces. To make them suitable for medical applications with low toxicity and biocompatibility, CNTs require to undergo surface functionalization [2]. Functionalization plays a major role in making CNTs soluble and increasing their biocompatibility qualities [1]. This process includes two fundamental approaches:

1.Covalent attachment, somewhere chemical bonds are formed and

2.Noncovalent attachment, involve physical adsorption of biomolecules to the CNTs [2].

Covalent Functionalization

In covalent functionalization, chemical reactions are utilized to form bonds with the sidewalls of nanotubes. This technique includes oxidation and carboxyl-based couplings, somewhere strong acids are used to open tube caps, form holes in the sidewalls and initiate carboxylic groups. These carboxylic groups not just raise CNT

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solubility in water however also enable covalent connections with another molecules over amide and ester bonds [1] [17]. The sidewalls of carbon nanotubes show various defect sites, containing structures like stone-wales blemish with pentagon-heptagon pairs, sp3- hybridized defects, and vacancies within the nanotube lattice [18]. In the process of covalent functionalization, functional groups such as OH, COOH and NH2 are linked to the sp2 carbon framework on the surface of carbon nanotubes [19] [20] [21].

Noncovalent Functionalization

Non-covalent functionalization initially relies on van der waals forces and π- π interactions to stabilize the interaction between molecules and carbon nanotubes [22]. The sidewalls of carbon nanotubes show sp2 hybridization [24]. This functionalization offers the main advantage of preserving the conjugated structure of carbon nanotube sidewalls, therefor maintaining their original structural properties [18]. It is a productive technique for adjusting the interfacial properties of nanotubes, employing aromatic compounds, surfactants and polymers that interact through π-stacking or hydrophobic interactions. In these proceed, non-covalent modifications of CNTs ease maintain their desired properties while significantly enhance their solubility [1]. They can be classified as aromatic small molecule absorption, polymer wrapping, surfactants, biopolymers and the endohedral method [18].

VI. PHARMACOKINETICS AND METABOLISM OF CARBON NANOTUBES

Research in pharmacokinetic and metabolism of various compose of carbon nanotubes have been investigated and some recent review literature also reported [2] [25] [27]. The biodistribution and pharmacokinetics of nanoparticles are influenced by physicochemical attribute like surface functionalization, solubility, shape, aggregation and chemical composition. Water soluble multi-walled carbon nanotubes in mice were perform as per literature [25]. Multiwalled carbon nanotubes showed similar outcomes, with Tween 80- dispersed MWCNTs aggregate in the liver and spleen although having a low blood circulation time, while serum-dispersed MWCNTs gathered in the lungs [28] [27]. However, these simply dispersed carbon nanotubes could be valuable in diagnostics and thermal therapy. The carbon nanotubes can be established by lymph cells, imply their potential use in sentinel lymph node detection crucial for cancer therapy [27]. Despite, all the types of carbon nanotubes were promptly cleared from tissues, with a maximal blood circulation half-life of 3.5 hours [25] [2]. Multiwalled carbon nanotubes were excreted via the renal route and found to be integral in the excreted urine under transmission electron microscopy. After all, recent research disputes the previous belief that carbon nanotubes remain intact in the body, as some scientists demonstrated that myeloperoxidase (MPO), an enzyme in mouse neutrophils, can break down carbon nanotubes. They explore, contradicting prior opinions, signifies a breakthrough in nanotechnology and nanotoxicology by show that endogenous MPO has the capability to decompose carbon nanotubes into water and carbon dioxide, potentially impacting medical applications [2].

VII. TOXICITY

The toxicological finding on carbon nanotubes from recent literature emerge contention, with initial in vitro tests suggesting benign effects on specific cells, although subsequent studies, especially on raw materials, indicate potential dangers to various living systems [2] [29] [30]. It is considerable to note that despite the pharmacological potential of carbon nanotubes conjugated with therapeutic molecules, their application in humans has not been enforced and as a result, their clinical toxicity remains is not estimate. There are three toxicological studies of carbon nanotubes.

1.In Vitro Toxicological Studies of Carbon Nanotubes
2.In Vivo Toxicological Studies of Carbon Nanotubes
3.Human Toxicity of Carbon Nanotubes

In Vitro Toxicological Studies of Carbon Nanotubes

Meanwhile, examination into water soluble multi-walled carbon nanotubes in rat glioma cells revealed that smaller sized multi-walled carbon nanotubes exhibited higher toxicity, probably linked to enhanced oxidative stress [34]. While insoluble pristine carbon nanotubes proved highly toxic in vitro across various cell types, including keratinocytes, brain neuronal cells, embryonic kidney cells, and lung cancer cells [2]. In studies assessing water-dispersible single walled carbon nanotubes on human lung cells, there is no

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intracellular localization of single-walled carbon nanotube was observed. As an alternative, indirect cytotoxicity was noted, attributed to alterations in the call culture medium, inclining towards a false-positive toxic effect [31] [32] [33]. Researcher found that water soluble single wall carbon nanotubes, conspicuous with fluorescein, were non-toxic to mouse B- and T- lymphocytes as well as macrophages, maintaining the function of these immune cells [2]. It is crucial to note that these insoluble pristine carbon nanotubes are not appropriate for drug and gene delivery in the therapeutics and are primarily associated with workplace exposure in carbon nanotube production.

In Vivo Toxicological Studies of Carbon Nanotubes

In recent review literature concluded that, various in vivo toxicological assessments of carbon nanotubes involving intravenous or subcutaneous injections and gastrointestinal exposure with functionalized or dispersed single walled carbon nanotubes and multi-walled carbon nanotubes in various animals such as rats, mice that revealed low toxicity across various biomedical exposure pathways [27]. The toxicity of single walled carbon nanotubes emerged linked to oxidative stress, irrespective of administration routes [36]. Especially, significant toxicity was observed only at very high dosages around 60 mg/kg with polyethylene-Glycol- multiwalled carbon nanotubes administered in mice [2] [35]. When used in tissue engineering for cell growth through subcutaneous implantation, CNTs demonstrated excellent biocompatibility with minimal inflammation [37]. Meanwhile, conflicting findings were reported, indicating oxidative DNA damage after oral gavage and inflammation with implanted single-walled carbon nanotubes and multi-walled carbon nanotubes [36 37]. There have been conflicting findings on the pathogenicity of carbon nanotubes when injected into the mouse abdominal cavity, despite some research recommending their biocompatibility with skin following subcutaneous implantation [27, 2]. Carbon nanotube toxicity in vivo was impacted by a number of parameters, including chemical functionalization and metal impurities; pure and chemically modified carbon nanotubes showed higher biocompatibility. The general conclusion, which states that functionalized CNTs are typically biocompatible and decreased in toxicity for biological applications, emphatic the demand for further toxicity assessments to determine safety limits and clarify toxicological pathways [27].

Human Toxicity of Carbon Nanotubes

As the use of functionalized carbon nanotubes (CNTs) linked with therapeutic molecules in clinical studies is even to be explored in humans, numerous publications indicate that pristine CNTs could pose a risk of occupational lung diseases for workers in carbon nanotube industries, reminiscent of the asbestos-related pathology observed in the past [27, 38,39]. Awareness from rodent studies administering carbon nanotube test dusts denote that manufactured carbon nanotubes can stimulate inflammation, epithelioid granulomas, fibrosis, and biochemical changes in the lungs when administered intratracheally or intrapharyngeally [2, 38, 40, 41]. Recent research considered though the asbestos-like reactivity and pathogenicity associated with long, pristine nanotubes can be mitigated through surface modification and effective length reduction via chemical treatment, as tri (ethylene glycol) (TEG) [2]. But discussions concerning the possible risks of coming into contact with immaculate carbon nanotubes and any remaining metal contaminants in them continue. Concerns over the safety profile of multi-walled carbon nanotubes (MWCNTs) have been raised because to their apparent resemblance to asbestos fibers. Despite the potential therapeutic benefits of carbon nanotubes, it is still imperative to comprehend and manage their toxicity.

VIII. BIOSAFETY OF CARBON NANOTUBES

Numerous attempts have been made to confirm the biological effects of carbon nanotubes both in vivo and in vitro since its discovery in 1991.

In Vitro Biosafety

There has been much debate regarding carbon nanotubes biological application despite a plethora of research addressing their biosafety. There are number of studies on the in vitro biosafety of carbon nanotubes. Recent research indicates that there may be dose-dependent toxicity for both SWCNTs and MWCNTs, which could be caused by a number of mechanisms. Researchers intended a workable model for MWCNT cell uptake [114]. The findings indicate that cellular translocation pathways may differ between bundled and single MWCNTs, as bundled MWCNTs can be

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attributed into cells through an energy-reliant endocytosis procedure, although single MWCNTs can penetrate cells directly. In mouse embryonic stem (ES) cells, showed that the carbon nanotube causes damage to DNA and increases the frequency of mutations [115]. Furthermore, reported that carbon nanotubes interfere with metabolic activity and membrane integrity, as well as induce free-radical generation, oxidative stress, cell-cycle arrest, and inflammation in fibroblastic cells [114]. On the other hand, indicating that carbon nanotube can enhance as well cell adhesion and growth apart from differentiation through the large-scale adsorption of proteins [114,116]. Furthermore, studies have shown that CNT-based substrates can enhance the cellular activities of a variety of cell types, containing osteoblasts, fibroblasts, neural cells, and smooth muscle cells. Because of this, the biosafety of carbon nanotubes is still not entirely understood, and their biological effects vary greatly depending on a wide range of factors, such as type, size, surface functional group, concentrations, exposure time, and more. It is especially more in-depth research is unquestionably required. Carbon nanotubes are still being actively researched and discussed today due to their special qualities and broad application potential. It is clear that CNTs are class of carbon-based nanomedicines [114].

In Vivo Biosafety

The biological effects of carbon nanotubes in vivo have been examined and documented in a number of studies; however, there has not been as much evidence of carbon nanotube biosafety in vivo as there has been in vitro. Regarding intratracheal instillation, Lam et al. assessed the pulmonary toxicity of carbon nanotubes in a mouse type [114]. Their results show that CNTs are far more toxic than quartz and carbon black because they induce granulomas and further pulmonary lesions in mice. They proposed that the reason for carbon nanotubes pulmonary toxicity is their insolubility and nonbiodegradability, which prevents the lung's macrophage–mucociliary clearance mechanism from eliminating them. Furthermore, in a mouse model with a fibrogenic response and granulomas, Shvedova et al. showed another pharyngeal aspiration of SWCNTs causes pulmonary inflammation and damage [114, 117]. Using a mouse model, researcher investigated the in vivo biodistribution of pristine SWCNTs and proposed that the liver, lung, and spleen are where the SWCNTs are primarily accumulated [114]. The in vivo behaviors of SWCNTs and MWCNTs in a rat's skeletal muscle. They found that while the two carbon nanotubes physicochemical characteristics such as length, size, shape, and surface chemistry are substantially diverse, they even so exhibit biocompatible qualities by demonstrating the ability to regenerate muscle in a short acute state, appropriate enzyme activity in the muscle, and the lack of tissue capsules [118]. Furthermore, using a mouse model to track the translocation pathways of MWCNTs, researcher assessed the hepatic toxicity of MWCNTs in vivo. They demonstrated that although important serum biochemical indices, such as LDH, total bilirubin (TBIL), total bile acid (TBA), alkaline phosphatase (ALP), and alanine aminotransferase (ALT), depend on exposure duration and dose, MWCNTs exhibit good biocompatibility and no overt toxicity in mice given intravenously injected MWCNTs. Therefore, there is still debate regarding the in vivo biosafety of carbon nanotubes, and more thorough research is required to gain a essential knowledge of them [114].

IX. PROPERTIES OF CARBON NANOTUBES

Carbon nanotubes have exceptional characteristics like incredibly high surface areas, high biocompatibility, chemical inertness, light weights, impressive mechanical strength and large aspect ratios [46]. They present an extraordinary tensile strength, exceeding that of steel by 100 times. Furthermore, their large electrical and thermal conductivities intimately related those of copper, which are appropriate for different applications [42] [43]. The distinctive properties of carbon nanotubes state them as good choices to filler in a range of polymers and ceramics to carry out agreeable consumer products [44,45]. To employ the capability ofCNT, it becomes essential to fully understand their chemical and physical characteristics.

Physical Properties

Carbon nanotubes demonstrate physical properties; however, they can be in controlled fabrication, precisely characterizing them remains a challenge. Multi-walled nanotubes and single-walled nanotubes share same exceptional electrical, thermal and mechanical strengths, forming them subjects of comprehensive study for applications including microelectronic interconnects, heat sinks and structural composites. Insignificantly, carbon nanotubes anisotropic nature, displaying different property values along various directions, also their appeal in diverse fields [42].

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Properties	SWNT	MWNT
Diameter	1to 2 nm	5 to100 nm
Length	100 to 1000 nm	15,000 nm
Elastic Modulus	1000 to 3000 GPa	300 to 1000 GPa
Band Gap	0 to 0.5 eV	2.9 to 3.7 eV
Density	2600 p(Kg/m3)	1600 p (Kg/m3)
Melting Point	3527 °C	3527 °C
Tensile Strength	22.2+2.2 GPa	11 to 63 GPa
Thermal Conductivity	3000 to 6000 W/mK	2000 to 3000 W/mK

Physical Properties of SWNT and MWNT [42]

Electrical Property

The chiral configurations of carbon nanotubes (CNTs) give rise to a variety of electrical characteristics. The idea that carbon nanotubes exhibit special conductive properties has been supported by research; they represent the evidence that geometric variations as defects, chirality, diameter differences, and the degree of crystallinity in the tubular structure—play a significant role in the electronic properties of CNTs [44,47,48]. The electronic structure of a carbon nanotube (CNT) can be derived from 2D graphite, but as one-dimensional structures, CNTs illustrate electronic properties directly influenced by their diameter and helicity. With an especially low electric resistance, electrons within a carbon nanotube experience minimize scattering because of the small diameter and high aspect ratio, only facing resistance when colliding with defects in the crystal structure, such as impurities in atoms or the crystal lattice [42]. Carbon nanotubes has an acutely high current carrying capacity excelled superconductors. They can exhibit metallic or semiconducting properties, facilitation the formation of semiconductor-semiconductor and semiconductor-metal junctions important for device fabrication. While armchair nanotubes are metallic, others may be metallic or semiconducting, though high curvature in small diameter tubes can affect electrical properties. The electrical conduct of CNTs is intricately tied to their treatment method and aggregation state. Theoretically, ideal nanotubes demonstrate ballistic conduction for micron-range distances, offering efficient electron conduction with zero resistance [42,49,50]. CNTs in particular offer answers to problems with traditional copper and aluminum wires, which makes them viable options for use in electrical wiring applications. Additionally, the use of nanotubes in electron guns for cathode ray tubes (CRT) in field emission displays (FED) is promising, and the fact that they can function as diodes raises the prospect of using nanotubes exclusively in electronic computer circuit construction [42, 47, 48].

Thermal Property

Carbon nanotubes (CNTs), parallel rolled-up sheets of graphene. It is important and interest also for their electronic and mechanical properties as well as important for their thermal properties. Despite them micro size, quantum effects become crucial, evident in how their low-temperature specific heat and thermal conductivity directly reflect the 1-D quantization of the phonon band structure in CNTs [51,52]. The thermal conductivity of CNT is impacted by both internal and external temperatures of the tubes. Various factors, including atomic arrangement, tube diameter and length, structural defects, morphology, and impurities, play pivotal roles in determining the thermal properties of CNT [53]. When individual multi-walled nanotubes (MWNTs) were tested, their thermal conductivity was measured at 3,000 W/K at room temperature, surpassing that of graphite. Generally, this value was proved to be two orders of magnitude higher than the thermal conductivity observed in bulk MWNTs. A parallel study on single-walled nanotubes (SWNTs) revealed a remarkable thermal conductivity exceeding 200 W/m K for SWNTS [54,44].

Mechanical Property

Measuring the mechanical properties of nanotubes is challenging due to the difficulties in acquiring pure, consistent CNT samples. Both theoretical predictions and experimental findings reveal that CNTs follow diamond in stiffness, boasting an impressive Young's modulus of carbon nanotubes spans from 270 to 950 GPa, coupled with a substantial tensile strength ranging from 11 to 63 GPa. Eventually, reports consistently highlight that CNTs exhibit relative softness in the radial direction [42, 44]. Prior to experimental investigations, researchers conducted early theoretical calculations to anticipate the mechanical properties of carbon nanotubes (CNTs) [55-57]. They employed transmission electron microscopy (TEM) to measure thermal vibrations, revealing an

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average Young's modulus ranging from 1 to 1.8 TPa, significantly surpassing the stiffness of commercially available carbon fibers (≥ 800 GPa). Subsequent studies by various research groups, using atomic force microscopy (AFM), directly measured bending forces of MWNTs, yielding Young's modulus values spanning from 0.32 to 1.47 TPa. Researchers noted that multi-walled nanotubes (MWNTs) could withstand bending at sharp angles without experiencing structural fracturing when subjected to an atomic force microscope (AFM) tip. Additionally, observations by Endo et al. revealed that when breaking vapor-grown CNTs in liquid nitrogen, an inner tubule could endure the applied pressure [44,58-66].

Chemical Properties

Carbon nanotubes, being consisting of carbon atoms, obtain the diverse properties of carbon, enabling the formation of various combinations and derivatives. They can undergo functionalization through various chemical reactions, broadening their applications in materials science and technology. The solubility of carbon nanotubes plays a crucial role in their processability, affecting reactivity, dispersion, and purification. Unfortunately, their hydrophobic nature renders them insoluble in water and stimulating to dissolve in various solvents, posing limitations to their utilization. While sonication aids dispersion in certain solvents, interruptions lead to rapid precipitation [42,67]. Carbon nanotubes demonstrate the ability to interact with various compounds, forming supramolecular complexes that improve their processing for the fabrication of nanodevices. Additionally, their capacity to undergo different chemical reactions further enhances their solubility, extending their relevancy across various fields [68].

X. CARBON NANOTUBES IN DRUG DELIVERY SYSTEM

The purpose of a drug delivery system is to enhance how a drug works and its generally effectiveness in treating medical conditions [69]. With their ability to easily enter cells, carbon nanotubes enable the direct delivery of drugs to the cytoplasm or nucleus. This targeted drug delivery enhances the overall effectiveness and therapeutic effect of the drug, while also reducing the prospect of affecting unintended targets [70]. In the province of medical research today, carbon nanotubes play a crucial role, especially in exploring more effective drug delivery and tissue engineering techniques. Originally, pure carbon nanotubes were not soluble, but breakthroughs came with the development of methods to make them soluble by adding organic molecules. This innovation enables the surface engineering or functionalization of these tubes, making them more dispersible in water and allowing them to bind to specific therapeutic substances or target tissues, thereby triggering therapeutic effects [1,71,72,73]. Furthermore, carbon nanotubes offer the possibility of multi-drug therapy by loading them with exceeding one drug. Further, they can serve as a controlled release system, gradually releasing drugs over an extended period for sustained therapeutic effects [1]. Continuing the quest for advanced drug delivery systems, researchers are examining the potential of functionalized carbon nanotubes (f-CNT) to act as carriers for small drug molecules, though their application in delivering anticancer, antibacterial, or antiviral agents is not fully understood. The advancement of delivery systems capable of transporting therapeutic agents with recognition capabilities, optical signals for imaging, and specific targeting holds significant promise, especially in the treatment of conditions like cancer and infectious diseases. In pursuit of this, a novel strategy involves the multi functionalization of carbon nanotubes, combining a fluorescent probe for monitoring cellular uptake with an antibiotic component as the active molecule [74].

XI. APPLICATIONS OF CARBON NANOTUBES

a. Carbon Nanotubes in Therapeutic Treatment

Carbon Nanotubes in Cancer Treatment

Carbon nanotubes are used in blood cancer, brain cancer, breast cancer, colon cancer, lymph node, liver cancer, kidney cancer, cervical cancer by using various drugs such as paclitaxel, daunorubicin, amphotericin B, Doxorubicin etc [75, 79]. Multiwalled carbon nanotubes have been employed in cancer diagnosis furthermore treatment. Researcher discovered that narrow multiwalled nanotubes, bluster an average diameter of 09.2 nm, demonstrated a heightened affinity for tissue especially non-reticular endothelial tissues compared to their broader counterparts with an average diameter of 39.5 nm [76]. The use of multiwalled carbon nanotubes to assist in the delivery of the anticancer drug methotrexate, utilizing an enzymatic cleavage release mechanism within in vitro breast cells. As well, they dominated dendrimer-modified multiwalled carbon nanotubes

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for the targeted delivery of the drug doxorubicin under low pH conditions [77, 78]. Combining multi-walled carbon nanotubes with tumor lysate protein, also known as a tumor cell vaccine, has shown significant and specific improvements in the effectiveness of anti-tumor immunotherapy. This was observed in a mouse model with H22 liver tumors [80]. The potential contribution of carbon nanotubes activation of the complement system and their adjuvant effects is thought to enhance antitumor immunotherapy, although the exact mechanism behind these effects is unknown [81].

Carbon Nanotubes in Gene Therapy

CNTs discover extensive use in therapeutics, acting as carriers for genes in gene therapy for genetic disorders and cancer treatment. They prove effective in gene slicing technologies, where RNA fragments encapsulated within nanotubes can hinder protein production required for virus multiplication, offering potential treatments for respiratory syncytial virus (RSV), severe bronchitis, and asthma [82]. They wrap around the intended DNA, assist its delivery to the target site, present potential cure for genetic disorders by rectify missense gene sequences [84,75]. They offering the ability to manipulate genes and atoms for the advancement of bioimaging, genomics, proteomics, and tissue engineering applications [83]. Further medical applications, nanotubes are reported for their crucial role in helical crystallization of proteins and the growth of embryonic rat brain neurons. They also assist as a platform for immobilizing proteins and antigens, making them a potential source for vaccine development, offering a safer alternative to traditional methods involving dead bacteria [85]. Because of their exceptional properties, such as their wide surface distribution and extreme purity, CNTs hold great promise for the delivery of peptides, drugs, and nucleic acids. Carbon nanotube tips and walls can be used to affix the desired gene or drug to effectively target particular cancer-causing receptors on cell structures. This makes it possible for the nanotubes to enter mammalian cells by endocytosis or other workable processes. This capability alters carbon nanotubes to more safely and reliably identify genes and therapeutic drugs within afflicted cells that were previously difficult to access using traditional membrane mechanisms [86].

Carbon Nanotubes in Infection Therapy

In response to the challenges posed by the resistance of infectious agents to various antiviral and antibacterial drugs, as well as issues with vaccine effectiveness, carbon nanotubes (CNTs) have been attempting to determination this issue. Specifically, functionalized CNTs have shown promise as carriers for antimicrobial agents, exemplified by their ability to transport the antifungal drug amphotericin B [2, 88]. Furthermore, our research group has executed success by combining the antimicrobial agent Pazufloxacin mesilate with amino-functionalized multi-walled CNTs, known for their high adsorption capabilities. This combination will be applied in experimental assays purpose at infection treatment [2, 89]. Carbon nanotubes demonstrate antimicrobial properties by disrupting intracellular glutathione, leading to enhanced oxidative stress in microbial cells and causing the natural death of pathogens. Furthermore, CNTs play a role in vaccinations, activating the immune response by triggering MHC-II and promoting the production of natural antibodies to combat infections [75, 87]. In recent study they capable to delivered siRNA molecules linked to carbon nanotubes (CNTs) to human T cells and primary cells. The findings exposed that nanotube efficiently facilitated RNA interference (RNAi), effectively silencing CXCR4 and CD4 receptors on human T cells and peripheral blood mononuclear cells (PBMCs). The siRNA sequences employed in the research efficiently suppressed the expression of CD4 and CXCR4 receptors critical for HIV entry and infection in T cells. Although still in the initial stages, these promising results suggest the ability utilize of CNTs for HIV treatment [78].

Carbon Nanotubes in Tissue Generation

Tissue engineering, a rapidly advancing interdisciplinary field, integrates medicine, bioengineering, material sciences, pharmaceutical sciences, and life sciences. Its primary goal is to change diseased or impaired tissue with biological substitutes, derived from the patient's own cells or tissues, to restore and maintain normal functioning. This innovative approach not only addresses the challenges of transplantations from donors but also holds the potential to significantly decrease associated risks [91]. Carbon nanotubes have become a preferred choice in tissue generation due to their biocompatibility, resistance to biodegradation, and ability to enhance organ generation, as highlighted in recent studies [83]. When integrated into scaffolds, CNTs contribute to improved cell adhesion, reduced degradation rates, and enhanced mechanical properties, morphogenesis, and cell signaling. Notably, CNTs

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demonstrate a periodic release of growth factors and nutrients at a controlled rate, facilitating the progression of cell division and the evolution of functionalized tissues [91,92]. Labelling cells through implants not only allows for assessing the viability of engineered tissue but also enhances our understanding of cell migration, bio-distribution, movement pathways, and cell relocation. Non-invasive techniques, gaining popularity over traditional methods like cytometry due to practical challenges and time consumption, find CNTs to be a more feasible choice as contrast imaging agents. Carbon nanotubes show promise for optical resolution, magnetic resonance behavior, and simulating radio tracer models in tissue engineering applications [86]. Researchers are working on developing carbon nanotubes (CNTs) for bone regeneration, incorporating negatively charged functional groups with bonded calcium. This creates a scaffold that allows hydroxyapatite, a key inorganic component of bone, to adhere. The remarkable strength, rigidity and resilience of CNTs induce them a promising alternative to traditional titanium or ceramic bone scaffolds, as indicated by studies [75,90]. In addition to their various applications, carbon nanotubes (CNTs) play a crucial role in enhancing tissue matrices. These matrices, acting as scaffolds, are vital in tissue engineering as they provide structural support for new tissue, define its spatial occupation, and facilitate the tissue development process [23]. Studies suggest that CNT-based scaffolds, especially when combined with materials like chitosan in a polymer matrix, exhibit superior biocompatibility both in vitro and in vivo compared to other materials commonly used in tissue engineering [23]. Research indicates that multi-walled carbon nanotubes (MWCNTs) are more effective than single-walled carbon nanotubes (SWCNTs) due to their lower defects, straighter structure, and reduced tendency to disperse. In fact, the mechanical properties of a 100% MWCNTs monolith closely resemble those of human bone [91,93]. The unique features of carbon nanotubes (CNTs), including their extensive surface area, DNA or protein immobilization capacity, and distinctive electronic structures, position them as key elements for nano sensing devices with applications in monitoring cell activities within engineered tissue patterns [86]. While materials like PLA and PLGA have been applied in tissue engineering, they require the inherent mechanical strength and functionalizability of synthetic polymer compounds, in contrast to CNTs which show potential as tissue scaffolds, providing structural reinforcement. However, a drawback lies in their non-biodegradability. Mixing CNTs with polymeric substances enhances mechanical strength, and combinations like MWNTs with chitosan or SWNTs with natural collagen show promise for improving specific properties and cell growth in tissues [86, 94].

Carbon Nanotubes as Antioxidants

Additional investigation into various forms of carbon nanotubes is necessary to uncover their valuable potential as efficient free scavengers [95]. The ability use of carbon nanotubes (CNTs) as free-radical scavengers is even in its early stages, despite ongoing research. As per certain scientists' recent research, CNTs, also referred to as carboxylate SWCNTs, possess antioxidant characteristics and hold great potential in biomedicine. These applications may include the prohibition of chronic illnesses, aging, and even food preservation [2, 96]. COOH groups enhance the free radical scavenging ability of SWCNTs, indicating that carboxylate SWCNTs may outperform their radical nonfunctionalized counterparts [2]. The antioxidant properties of carbon nanotubes, especially carboxylated SWCNTs, have produced effects on the anti-aging cosmetics and sunscreen cream industries. These products are designed to shield the skin from damaging free radicals created by the body and UV radiation exposure [2,97]. Only with the use of carbon nanotubes is it possible to investigate various forms of their effective free radical scavenger capabilities in both biomedical and environmental applications. Given that free radicals are recognized to be extremely harmful, it is imperative to comprehend this [2,96].

Carbon Nanotubes for Neurodegenerative Disease and Alzheimer Syndrome

Biomedical materials that have been utilized in neuroscience include diseases and Alzheimer's syndrome [2, 97, 98]. CNTs can effectively act as delivery carriers for the target brain by crossing the blood-brain barrier through a variety of targeting mechanisms, being their small size and modifiable external modifications [2, 100]. CNTs, are superior electrical conductors, they are very helpful in the regeneration of neurons. Successful neuron growth can occur on CNT beds, and the length and degree of branching of the neurons can be enhanced by surface modification with 4-hydroxyonoenal, which is known to be involved in neuron growth [75]. According to Yang et al. [98], acetylcholine was successfully delivered

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by SWCNTs with a high safety range in mice's Alzheimer's disease-affected brains. Numerous other functionalized SWCNTs or MWSCNTs have been effectively employed as appropriate delivery systems for the treatment of brain tumors or neurodegenerative diseases [2, 29]. Overall, these studies' findings suggest that CNT conjugates with medicinal compounds have a greater impact on neuronal growth than do drugs taken on their own.

b. Carbon Nanotubes in Diagnosis and analysis

Biosensor

Different biomolecules, including DNA and protein, can be functionalized onto carbon nanotubes [101, 102, 103]. Biosensors are different from other sensors in that they have a sensing element composed of biological material, as proteins, oligo- or polynucleotides, or microorganisms. Biosensors are utilized to mention biological processes or to recognize biomolecules. Carbon materials have been utilized in electrochemical biosensors, the most common type of biosensor, for a very long time. Due to their ease of use and relatively simple calibration, electrochemical biosensors are widely used for the detection of biomolecules in solutions. These sensors are typically dependent on the enzymatic catalysis of a reaction that either generates or consumes electrons. Enzymes have been produced to detect glucose and other biomolecules using CNT-based biosensors [23]. For instance, many researchers have composite carbon nanotubes (CNTs) with glucose-oxidase biosensors [2, 104] to control blood sugar in diabetic patients with higher accuracy and less complicated manipulation than biosensors alone. For various therapeutic monitoring and diagnostic purposes, additional CNT-enzyme biosensors have also been advanced, such as carbon nanotubes-based dehydrogenase biosensors or peroxidase and catalase biosensors [2, 29]. Numerous research groups have shown that CNT bundles [102], carbon nanotubes membranes, polymer-CNT composites [42, 105], and carbon nanotube-modified electrodes can be used as efficient electrochemical biosensors based on these special qualities, which include the high electron transfer rate and the high electrocatalytic activity [106, 42]. The primary benefits of carbon nanotubes lie in the sensing element's nanoscale and the correspondingly low material requirement for a detectable response. As RNA sensors, enzyme sensors, DNA sensors, glucose sensors, and even protein sensors, well-aligned carbon nanotubes arrays have been used [107,108,42]. For the purpose of detecting biological species, carbon nanotubes configured as field effect transistors (FETs), or CNTFPETs, give the benefits of potential biocompatibility, size compatibility, and sensitivity to minuscule electrical perturbations. Owing to its distinct features, the CNTFET biosensor has found extensive application in the biological domain, encompassing molecules such as protein, glucose, enzymes, antigens and antibodies, DNA, bacteria, and hormones. Metal electrodes that serve as the source and drain electrodes in a CNTFET biosensor are prepared on the silicon substrate's surface and covered in an insulating layer of silicon dioxide. A gate electrode is introduced and a conductive channel is created by connecting a particular carbon nanotube between the two electrodes. This allows the gate's source voltage to be imported and controlled, thereby controlling conduction. The CNTFET biosensor's mechanism is possible to coat particular antibodies with carbon nanotubes. An electric signal that is seen and recorded may result from the particular adsorption of antigen and anti-body [42, 108].

Enantioseparation of Chiral Drugs and Biochemical

Eighty-eight percent of the most recent drugs marketed in the pharmaceutical industry are racemates, which are collected of an equimolar mixture of two enantiomers. Currently, 56 percent of drugs in utilize are chiral products. [2,109] The US Food and Drug Administration (FDA) has recommended assessing each enantiomers activity for racemic drugs in the body and promoted the creation of novel chiral drugs as single enantiomers. [2] As a result, numerous novel technologies, including carbon nanotechnology, have been developed for chiral separation. A chiral stationary phase of MWCNT cross-linked with hydroxypropyl-ß-cyclodextrin has been developed by researcher for the enantioseparation of racemic clenbuterol, a bronchodilator, with a high-resolution factor. The helical winding of the graphitic rings around the tube axis notifies us that carbon nanotubes are chiral forms as well. They might not, however, work well as enantiospecific adsorbents. On the other hand, it has been effectively tested to divided enantiomers from numerous racemic drugs using chiral selector-modified carbon nanotubes [2]. Chromatographic separation is one of the many fields where MWCNTs with electrical and sorption attributes have found widespread application. Carbon nanotubes have a racemic chiral structure, which

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has been confirmed by physical studies, but this structure has not been utilized exclusively for enantioseparation [110].

Solid Phase Extraction of Drugs and Biochemicals

CNTs have excellent adsorption aptitude because of their strong interaction with other molecules, especially those containing benzene rings. For the analytical extraction of medications, pesticides, or natural compounds from a variety of media, including biological fluids, drug preparations, the environment, plants, animal organs, and non-functionalized or functionalized carbon nanotubes (CNTs) have been studied as Solid Phase Extraction (SPE) adsorbents. They can be utilized alone or in combination with classical SPE sorbents (C18 silica, XAD-2 copolymer) [2,111]. Comparative studies have shown that carbon nanotubes have an adsorption aptitude that is either high or comparable to that of silica-based sorbents or macroporous resins. Numerous recent review articles covering general topics have numerous applications of carbon nanotubes in solid phase extraction [2,112]. A novel molecularly imprinted magnetic solid phase extraction material rigid on magnetic carbon nanotubes has been developed recently by our group to support the extraction and resolution of the antibiotic gatifloxacin (GTFX) in serum samples in conjunction with high-performance liquid chromatography (HPLC). This new adsorbent phase's results demonstrated good specific recognition for GTFX. Additionally, it was effortlessly extracted from the suspension using an external magnet, providing the most effective and selective drug extraction from biological fluids [2].

Many other uses of CNTs in SPE have been carried out for the examination of various natural compounds (pepperrine), phenolic preservatives, and pesticides (carbofuran, iprobenfos, parathion-methyl, etc.). Additionally, carbon nanotubes can be used to prepare stationary phases for GC or LC columns, as well as to extract inorganic ions and organometallic compounds [2,111].

XII. LIMITATIONS OF CARBON NANOTUBE

•Insoluble in the majority of biologically acceptable solvents (aqueous based).
•The creation of identically characterized batches of CNTs that are reproducible both chemically and structurally.
•Maintaining minimal impurities and high quality can be challenging [113].

CONCLUSION

This article presents a review of the properties, toxicity, pharmacokinetics and applications of carbon nanotubes along with their structure, synthesis and purification techniques. Carbon nanoparticles have unique structural characteristics that make them useful for pharmaceutical nano delivery, especially their high aspect ratio and propensity to be functionally modified and then used as carrier vectors. The added benefit of carbon nanotubes is that they could be used as nanodevices for regulated drug delivery. Because carbon nanotubes are easily functionalized on both their sidewall and core, a wide range of drugs can be placed on them with ease, making them suitable as targets in drug delivery systems. The needle-like shape of functionalized CNTs allows them to have a higher tendency to cross cell membranes. Investigating the biological characteristics of CNT has been made easier by the introduction of organic functionalization. Scientists have only just started to fully explore the potential of carbon nanotubes, and their properties and characteristics are still the subject of intense research. It has already been displaying that single and multiple walled carbon nanotubes are safer and more efficient than earlier drug delivery techniques. They have the ability to cross membranes and deliver nucleic acids, vaccines, and therapeutic medications to previously inaccessible parts of the cell. Carbon cylinders biocompatibility has been established. Since insoluble and extremely toxic pure carbon nanotubes, it was crucial to confirm their solubility in physiological media. CNTs have shown to be great tools for therapeutic monitoring, disease diagnosis, and drug analysis in different fields when composite with biosensors or other materials. To maintain health, it is also advisable to develop functionalized CNTs capacity as a free radical scavenger. All things considered, nanotechnology has the ability to transform therapeutic concepts in the future and offer hope for the treatment of incurable diseases. Many of the challenges associated with this nanotechnology must also be addressed or clarified. When CNTs are tested in a clinic, the primary and most important consideration is their potential toxicity to humans in both the short and long term. Recently conducted preliminary toxicological studies in animals and in vitro have produced conflicting results. It is very

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advantageous to carefully optimize the physicochemical parameters to reduce the toxicity of CNTs. It is strongly advised to conduct additional toxicological studies on various CNT forms, such as pristine and functionalized CNTs, as well as their conjugates, before allowing them to be used successfully in clinical trials and subsequently exported globally. With innovative new treatments for life-threatening diseases, gene therapy, and cancer on the horizon, the science of nanomedicine is a rapidly expanding field with amazing barrier-breaking capabilities. All things considered, recent research on carbon nanotubes has provided a very encouraging look at what the future of medicine may hold.

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