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Review Article

# An overview of carbon nanotubes and their approaches

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ABSTRACT

Nanotechnology has made tremendous strides in recent years, particularly in the creation of sensors with a wide range of applications. The basic components of nanotechnology are nanomaterials, which can be measured at the nanoscale. Materials with sizes measured in nanometres that resemble carbon tubes are known as carbon nanotubes (CNTs). They are made of graphite sheets, which resemble a continuous, rolled-up, indestructible hexagonal mesh structure with carbon molecules at the apexes. Carbon nanotubes are classified as single-walled (SWCNTs), double-walled (DWCNTs), or multi-walled (MWCNTs) based on the number of carbon layers they contain. Carbon nanotubes (CNTs) can be produced using three basic methods: chemical vapour deposition, electric arc deposition, and laser accumulation. Low density, chemical inertness, high elasticity, and thermal conductivity are only a few of the many characteristics of carbon nanotubes. The study of materials in nanotechnology, electronics, optics, and other domains has benefited greatly from the unique properties of carbon nanotubes. Carbon nanotubes have several useful applications, including drug delivery, water filtration, and sensing. Surface functionalisation can be used to create highly soluble chemicals, which can then be derivatised with active molecules to be used in biological systems. Surface functionalisation enables the adsorption or attachment of different chemicals or antigens, which can then be targeted towards a certain cell type for immunological awareness or therapeutic effects. This article discusses the characteristics of carbon nanotubes and their therapeutic uses in medication delivery and medical diagnostics. Additionally discussed are carbon nanotubes' antifungal and antibacterial properties.



## 1. Introduction

Nanotechnology is a vast field of research that has become a state-of-the-art industrial technique global. It covers a broad spectrum of materials produced at the nanoscale through a variety of physical and chemical processes.[1] Nanostructured materials, the building blocks of nanotechnology, are becoming more and more well-liked. Nanomaterials are smaller than 100 nm in diameter. Numerous new magnetic, mechanical, electrical, and optical properties are made possible by this wide diversity of materials. One possible class of nanomaterials is nanotubes. Although there has been much discussion on a number of different boron and molybdenum-based nanotubes, carbon nanotubes are currently by far the most significant class. Concentric graphite-like layers with diameters varying from 0.4 nm to tens of nanometres make up carbon nanotubes.[2] Through the early experimental findings of carbon nanotubes using transmission electron microscopy (TEM) and later reports of conditions permitting the synthesis of sizable quantities of nanotubes, Iijima advanced the area of carbon nanotubes in 1991.[1,2]

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Arc discharge, laser treatment, and chemical vapour deposition are the three different processes that can be used to create CNTs. Arc discharge produces both single-walled and multi-walled carbon nanotubes by evaporation carbon atoms into a plasma at temperatures above 3000 °C. While individual SWNTs require a catalytic agent, like cobalt, yttrium, nickel, iron, etc., MWNT does not require catalysis. Among the hydrocarbon sources used in the chemical vapour deposition method are cobalt, methane, ethylene, and others.[3,4]

Graphite is vaporised in an electrical furnace that is heated to 1200°C as part of the laser ablation process. The high conversion ratio and excellent purity of the finished products are ensured by the graphite purity. Macroscopic processing is used to improve the quality of carbon nanotube materials and obtain specific properties like length, alignment, and so forth since high purity levels are crucial for biomaterial applications. Iijima used the arc discharge method to discover MWCNTs. The oldest method for creating carbon fibres is this one.[5,6] Khan et al. (2016) effectively created carbon nanotube (CNT) composites in a colloidal environment with PS or poly (styrene) using in situ emulsion polymerisation to create nanostructured brushes. CNTs were salinised using (3- aminopropyl) triethoxysilane after first being functionalised with oleic acid to offer cross-linking properties.

Graphite sheets folded into cylindrical shapes are called carbon nanotubes. CNTs have a width of about 100 nm and a length of micrometres.[4,7] With molecules composed of 60 carbon atoms arranged in microscopic tubes, carbon nanotubes (CNTs) are a derivative of both carbon fibres and fullerene.[5,7] Two types of carbon nanotubes are distinguished by the number of carbon layers they contain. Hexagonally packed bundles of just one graphene sheet with a diameter of 0.4–2 nm are known as single-walled carbon nanotubes (SWCNTs). Two or more cylinders made of graphene sheets make up multi-walled carbon nanotubes, or MWCNTs. The diameter is between 1 and 3 nm. The SWCNT & MWCNT images are shown in (Figure 1).

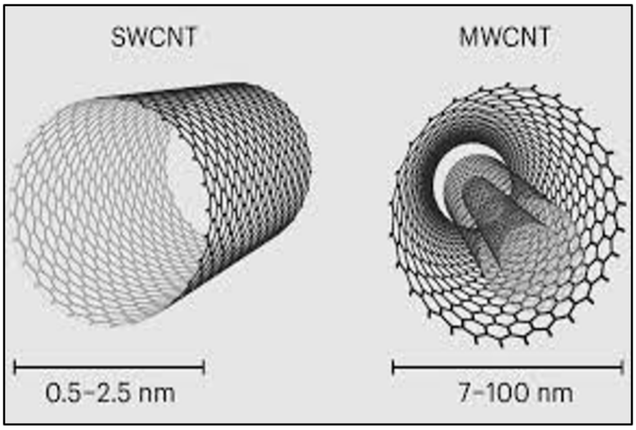


**Figure 1:** Carbon nanotubes.[1,2]

### 1.1. Properties of carbon nanotubes

Notable relatives of the fullerene is family are carbon nanotubes.[3,7] A number of factors influence CNT conductivity. The electrical conductivity of single carbon nanotubes is often between 104 and 107 S/m.[8,9] But more often than not, the MWCNT has a greater voltage, which leads to more electrical conductivity. Compared to other composites, MWCNT has a lesser percolation threshold. The electrical conductivity of carbon nanotubes is significantly influenced by their waviness.[10] The electrical conductivity of the material is effectively disrupted by wavy nanotubes because they possess larger associations than straight nanotubes. The material's increased electrical activity is made possible by the carbon nanotube's structural makeup.[7,10]

Electrical conductivity can be efficiently increased by the carbon nanotube's volume. Networks created by the SWCNT create contact blockages. The length, diameter, and geometry of nanotubes often dictate the generated contact blockage. The material's increased electrical activity is made possible by the carbon nanotube's structural makeup.[11]

Because of their cylindrical graphitic structure, carbon nanotubes exhibit exceptional mechanical properties. Compared to earlier measurements, carbon nanotubes having less average Young's modulus and tensile strength. According to theoretical research, SWNTs are stronger than MWNTs in terms of tensile strength. To enhance the physicochemical properties of various matrix systems, carbon nanotubes are added. For instance, new composite materials are made by combining carbon nanotubes with epoxy polymer systems. Since they dictate the system's long-term characteristics, carbon nanotube nanoscale diameters are crucial. CNTs are the strongest constituent with enhanced heat conductivity because of their high tensile force.[12]

Carbon nanotubes are a crucial carrier for the transportation of many active molecules, including medications and related chemicals, due to their ability to integrate substances like proteins and oligosaccharides. Concerns about the solubility of carbon nanotubes exist, however covalent functionalisation may provide a more comprehensive solution. Because of their inherent optical properties, such as NIR photoluminescence, CNTs make excellent bioimaging probes. The diameter and chirality of carbon nanotubes determine whether they are semiconducting or metallic. The increased electrical conductivity and high aspect ratio of carbon nanotubes are responsible for their field emission.[11,12]

## 2. Uses

### 2.1. Electronics and semiconductors

Transistors: Because of their rapidity and low power consumption, CNTs can be utilised as processors in nanoelectronic devices.Conductive Films: Applications for transparent conductive films include touchscreens and displays.

Interconnects: CNTs can serve as contributes in integrated circuits due to their conductivity, potentially taking the place of copper.[11,13]

### 2.2. Energy storage

CNTs improve the performance of lithium-ion batteries by fortifying the electrode material, increasing charge capacity, and extending cycle life.

Carbon nanotubes (CNTs) are used in supercapacitors to improve charge/discharge rates and energy storage.They improve the fuel cell electrodes' efficiency.

### 2.3. Composite materials

CNTs are utilised to strengthen, harden, and extend the durability of materials like metals, ceramics, and polymers. Automobiles, sports equipment, and aeroplanes all use these composites.

Lightweight constructions: CNT-based composites are ideal for lightweight, high-strength constructions because of their excellent strength-to-weight ratio.

## 3. Medical Applications

1. **Drug Delivery**: Drugs can be delivered directly to sick cells using CNTs as carriers for targeted medication delivery.
2. **Biosensors**: CNTs improve the performance and sensitivity of biosensors that detect biomolecules like DNA or glucose.
3. **Tissue Engineering**: CNT scaffolds can promote tissue regeneration by promoting cell proliferation.

## 4. Environmental Applications

1. **Water Purification**: Heavy metals, germs, and organic pollutants are among the impurities that can be eliminated from water by CNT filters.
2. **Gas Storage**: Because CNTs can store gases like hydrogen, they can be used in fuel cell hydrogen storage devices.[11,14]

### 4.1. Advantages of carbon nanotubes

1. 1. The structure of carbon nanotubes makes them the perfect one-dimensional conductive pathway.
2. 2. Better control over channel formation
3. 3. High electron mobility
4. 4. High current density
5. 5. Small switch time

### 4.2. Biomedical applications of CNTs

The fact that carbon nanotubes (CNTs) are more biocompatible than other materials, have fast electron transfer kinetics, are ultra-light in weight, chemically inert, have a high tensile strength, have an extensive spectrum of antibacterial and antifungal properties, act as protein carriers, have exposed functional groups, and more makes them suitable for a wide range of applications. They are suitable for a variety of uses, such as environmental monitoring, food safety, and clinical diagnostics, due to their semi- and metal-based conductive properties. CNTs are also crucial for the creation of sensors that can detect a variety of harmful bacteria and to receive medical care of cancer. Additionally, CNTs have a variety of antimicrobial qualities.[13,14]

## 5. Sensors Based on Carbon Nanotubes

A wide range of biosensor applications find carbon nanotubes very appealing due to their remarkable qualities, which include strong tensile strength light weight, quick electron transfer kinetics, good biocompatibility, aiding in protein immobilisation, large surface area, organic inertness, numerous antibacterial and antifungal properties, the ability to be used as protein carriers, the presence of exposed functional structures, and more. Because multiwalled carbon nanotubes make it simple to immobilise proteins while maintaining their inherent activity, they hold great promise for use in biosensors. The following (Figure 2) is demonstration & Illustration of integration of MWCNTs in biosensor assembly which is generally utilized.[15–18].

### 5.1. Electrochemical biosensor

An integrated, self-contained device is an electrochemical biosensor.[19] The target molecule (analyte) in the sample is identified by converting the recognition event into a calculable electrical signal using an electrode (transducer) that is integrated into or closely related to a specific natural recognition element (bio-receptor).[20] With their precision, speed, portability, and affordability, biosensors offer promising prospects for a wide range of decentralised clinical applications, including bedside monitoring, emergency department screening, "alternative-site" testing (e.g., doctor's office), and home self-testing.[21] Amperometric, potentiometric, and conductometric are the three categories into which electrochemical biosensors fall.[15] Development today is concentrated on an electrochemical sensor that has an insulation base with an electrode encasing on it and a deformable material lid with a concave area in the middle. When the lid and base are

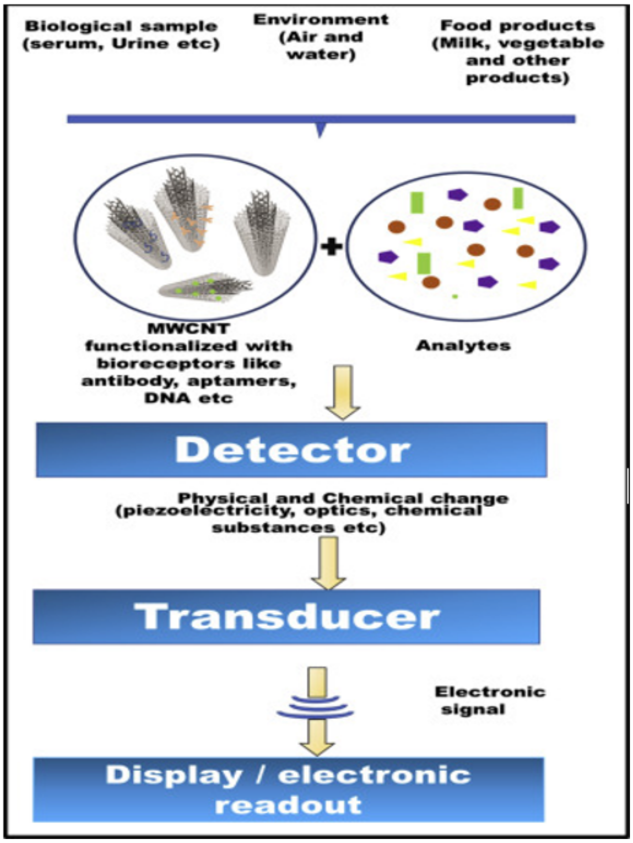


**Figure 2:** Illustration of integration of MWCNTs in biosensorassembly.[15–18]

combined, they create a capillary space that contains the electrode layer.[16] Nanoscale carbon materials have many improved characteristics that make them perfect for creating electrochemical biosensors. This area has continuously improved during the past two centuries.[17] When used as inverters for screen-printed carbon electro transducers (SPCEs), multiwalled carbon nanotubes (MWCNTs) produced enhanced properties that were comparable to those of bare SPCEs.[18]

Beden et al. (2015) used electroactive adducts to develop a sensor with electrochemical activity for sub-nanomolar dopamine detection. MWCNTs and AuNPs were added to the sensor to improve its analytical capabilities. Using nano-hybrids to replace the electrodes improved the sensors' response. The sensor showed a low threshold of detection and a good linear range.[22] Gutierrez et al. (2016) used MWCNTs on the surface of a glassy carbon electrode (GCE) to demonstrate qualitative as well as quantitative albumin, glucose, and amino acid detection. Their probe's limit of detection for glucose was 182 nM. In real samples, the sensor detected albumin, amino acids, and carbohydrates. The sensor's commercial potential was demonstrated by its use in real samples (Gutierrez et al. 2016). Li & Lee et al. (2016) integrated functionalised multi-walled carbon nanotubes to raise the detection limit of sensing while reducing manufacturing time. By using MWCNT, they were able to achieve a low limit of detection.[23,24]

### 5.2. *Piezoelectric sensor*

Khan and associates (2017) used the electromechanical properties of MWCT to develop a stretchy sensor. Researchers found that a stretchable sensor with MWCNTs on polydimethyl siloxane (PDMS) showed exceptional stability, sensitivity, linearity, and detection limit. Additionally, SEM analyses demonstrated that a consistent and compact CNT network can be produced using the spray coating method. When designing a stretchable sensor, uniformity and compactness are crucial factors to take into account.[25] Ali and associates used graphene, carbon nanotubes, and graphene-CNT composites to develop a piezoresistive sensor. Composites were shown to have a higher percentage drop in resistance and a lower sensitivity than pure graphene but higher than pure carbon nanotubes.[26,27] The similar flexible wearable sensor was developed by Park et al. in 2019 utilising MWCNT on PDMS as a substrate. They employed this sensor for two purposes: 1) rehabilitation through the construction of robotic hands, and 2) tissue characterisation by strain sensing in needles. Additionally, they found that the sensor is small, flexible, biocompatible, affordable, easy to build, and very selective.[28,29]

### 5.3. *Gas sensor*

Hieu and associates used nanocomposites, specifically MWCNTs and tin oxide particles, to develop an extremely sensitive sensor for ammonia gas detection. The sensor reacted far more quickly, even at room temperature.[30,31] Gas sensors are created to meet the requirements of numerous applications, such as environmental, medicinal, and industrial. Although there are a number of traditional gas detecting techniques, they require large equipment and a skilled operator. Since small-scale sensors were substantially less expensive, they were a good choice. The sensitivity and selectivity of gas sensors are significantly improved by using nanomaterials as sensing interfaces.[32,33] A MWCNT-based highly effective transistor style sensor for selective NOx evaluation was disclosed by Kim et al. in 2016. Gold was applied to the silicon wafer's surface after MWCNTs were adhered to it. The sensor is intrinsically capable of detecting NOx gas at a range of gateway source voltages. The sensor method is predicated on the observation that resistivity falls with increasing absorbed NOx gas concentration.[34,35]

By patterning MWCNTs onto NOA 63 polymer and powering it with an integrated super capacitor, Changhoon Song et al. (2019) developed a NO2 gas sensor. The created sensor was able to identify the flaws in the skin. Because of the integrated interface, the distortion brought on by elbow movement or other interventions has no effect on the device's sensing capabilities. Therefore, the sensor could be converted into a wearable device that can detect NO2.[36] George et al. used silver ink and MWCNTs adhered to a poly (3,4 ethylene dioxythiophene) and polystyrene (PEDOT: PSS) substrate to create a sensor for detecting volatile organic compounds. The theoretical idea and proof of concept of the radiofrequency sensor were validated by electrical characterisations conducted in the presence of volatile organic compounds.[58] In 2019, Duong et al. used MWCNTs and tungsten oxide nanobricks to create an ammonia gas sensor.[37] To detect ammonia gas, hydrothermally generated nanocomposites were used. Nonetheless, both the CNT-modified electrode and the tungsten oxide (WO3) nanobrick-modified electrode displayed gas sensing properties. When used as a nanocomposite (MWCNT-WO3) for biosensor construction, the sensor demonstrated improved performance.[38] A flexible gas sensor developed by Kim et al. (2018) has the ability to simultaneously detect hazardous gases like chlorine, sulphur dioxide, and ammonia. The dye-functionalized matrix that was attached to MWCNTs was used to construct the sensor. The sol-gel method was used to make the dye-functionalized matrix. The electrical and optical signals generated when the matrix comes into touch with a gaseous material form the basis of the detection mechanism. The developed sensor is highly adaptable and may be shaped into any shape while maintaining the high conductivity of the device.[8,9,39]

### 5.4. *Antibacterial activity of CNTs*

A flexible gas sensor that can simultaneously detect hazardous gases like ammonia, sulphur dioxide, and chlorine was developed by Kim et al. (2018). Using a dye-functionalized matrix attached to MWCNTs, the sensor was constructed. Using a sol-gel method, the dye functionalised matrix was produced. When a gaseous material comes into contact with the matrix, electrical and optical signals are generated, which form the basis of the detection mechanism. While maintaining the device's exceptional conductivity, the developed sensor is incredibly adaptable and can be shaped into any shape.[40]

MWCNTs were found to have a strong antibacterial potential by researchers. Numerous factors, including as density, diameter, length, surface functional molecules, and carbon nanotube purity, influence MWCNTs' antibacterial properties.[41] Since small tubes allow for more interaction with germs than long tubes do, the aspect ratio of MWCNTs significantly affects their antibacterial effects. The osmolarity of the cell membrane is altered by shorter tubes' increased interaction with it.[42] In contrast, the process is reversed in a liquid medium. Short tube aggregates have fewer cells than long tube aggregates in liquid media. More cells may be able to fit into long tube aggregates during the aggregation process. Additionally, diameter is important since a small diameter facilitates a tighter relationship with bacteria while a large diameter permits a less intimate interaction with germs. Consequently, one of the most important factors influencing MWCNTs' antibacterial qualities was their aspect ratio.[43]

The antibacterial activity of iron oxides and single-walled carbon nanotubes against E. coli bacteria was examined by Engel et al. (2018).For both bacterial capture and inactivation, a CNT-based filter has been created.The antibacterial activity against a variety of bacteria, such as Shigella flexiner, Salmonella, E. coli, and Klebsiella, was assessed using carbon nanotube-coated membrane filters. Ag-Fe3O4-treated single-walled carbon nanotubes showed antibacterial activity, according to Bhaduri and colleagues (2018). Su et al. (2013) discovered that silver-doped multiwalled carbon nanotubes has antibacterial properties. Additionally, multiwalled carbon nanotubes doped with silver and cyclodextrin shown enhanced antibacterial activity, according to Rananga and Magadzu (2014). Multiwalled carbon nanotubes were employed by Vecitis et al. (2011) to eliminate and deactivate bacteria. Additionally, the researchers demonstrated a multiwalled carbon nanotube filter that eliminates and deactivates bacteria and viruses from drinking water.[44,45]

### 5.5. *Antifungal activity of CNTs*

This suggests that ZnO:CNT loaded with Ag could be a promising treatment for fungal infections68. Using the poisoned food technique, the antifungal potential of Ag-loaded ZnO:CNT was examined. Rathore et al. (2000) showed antifungal activity in vitro using the agar well diffusion method. This method shows antifungal efficacy against fungi like A. niger, C. trobicalis, and C.neoformans by using chitosan derivatives in conjunction with MWCNT. With polymer chitosan preventing spore germination, germ tube elongation, and radial development, the nano-composites have demonstrated impressive promise. Chitosan inhibits the growth of fungi by promoting the morphogenesis of the cell wall. Microscopic study revealed that chitosan's small size allows it to penetrate the cell wall and mingle with DNA. The production of enzymes and proteins necessary for the development of fungal hyphae is impacted by conjugation with DNA, which suppresses transcription and translation. When juxtaposed with the parent chitosan, polymer derivatives incorporating MWCNT demonstrated unique antifungal activity. MWCNTs can alter the permeability of the cell membrane by electrostatically interacting with it. It was demonstrated that MWCNTs and chitosan derivatives were more effective against C. Trobicalis than C. neoformans, with A. niger exhibiting the highest efficacy. It has been shown that functionalised carbon nanotubes work well against certain strains of Candida.[46,47]

The antifungal effect against a number of fungi, such as A. niger, A. fumigatus, C. albicans, P. chrysogenum, S. cerevisiae, F. culmorum, M. canis, T. mentagrophytes, T. rubrum, and P. lilacinum, was demonstrated in a study by Zari et al. (2013). Tetra-arylbimesityl derivative-dispersed single-walled carbon nanotubes activated with a carboxy group were used to show antifungal activity against S. aureus, C. albicans, and E. coli.[48]

### 5.6. *Cancer diagnosis and treatment*

The detection and treatment of cancer have both made use of multiwalled carbon nanotubes. The Wang et al. (2014) discovered that compared to bigger multiwalled carbon nanotubes (39.5 nm average diameter), short multiwalled nanotubes (09.2 nm average diameter) exhibited a greater affinity for non-reticular endothelial tissues. Because thin multiwalled nanotubes accumulate more tissue, the scientists came to the conclusion that larger aspect ratios of these nanotubes would be advantageous in biological applications.[49] In 2010, Samori et al. employed an enzymatic cleavage release method to deliver the anticancer drug methotrexate to in vitro breast cells using multiwalled carbon nanotubes. Similarly, the drug doxorubicin (DOX) was transported at low pH using dendrimer-modified multiwalled carbon nanotubes.[50]

Since peptides, proteins, and DNA are rapidly broken down by enzymes present on the cell's surface or within, multiwalled carbon nanotubes provide excellent carriers for these macromolecules. In 2015, Guo and colleagues synthesised carrier cationic multi walled carbon nanotubes-NH3+, which were used to directly inject apoptotic siRNA against polo-like kinase (siPLK1) into calu6 tumour xenografts.[49,50]

## 6. Discussion

The special qualities of carbon nanotubes have been extremely helpful in the investigation of stuff in the use of nanotechnology electronic devices, imaging, and other fields. Among the many practical uses for carbon nanotubes include sensing, water purification, and medication delivery. Very soluble compounds can be produced by surface functionalization and subsequently derivatized with interacting molecules for usage in systems of life. In order to target a particular kind of cell for immunologic monitoring or medical purposes, surface functionalization makes it possible for various substances or antigens to adhere to or adsorb to the surface. The properties of nanotubes composed of carbon and their curative applications in drug transport and medical diagnostics are covered in this article. The antifungal and antibacterial capabilities of carbon nanotubes are also covered.

## 7. Conclusion

Carbon nanotubes are cylindrical, rolling structures. Multiwalled carbon nanotubes have improved electrical conductivity, mechanical strength, surface area, and chemical consistency. Carbon nanotubes are ideal for the effective transport of biomolecules such proteins, lectins, DNA, RNA, antibiotics, and immunoactive compounds because of their special characteristics. Carbon nanotube-based biosensors have shown themselves to be more dependable, sensitive, reproducible, and cost-effective. MWCNTs enhance the sensitivity, specificity, and usability of biosensing technologies for cancer detection and treatment. MWCNT-based biosensors have been used to detect a wide range of analytes, such as pyridoxine, dopamine, ascorbic acid, uric acid, and many more. Carbon nanotubes have also demonstrated antibacterial qualities. Future studies should therefore concentrate on developing more effective CNT-based tools to enhance human health.

## 8. Conflict of Interest

None.

## 9. Source of Funding

None.

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