Indian Journal of Advances in Chemical Science

Review Article

# The Carbon Nanotube Revolution in Health care: A Review

**Ancey Abraham*, Sonika Bhatia***

*Department of Chemistry, Isabella Thoburn College, Lucknow, Uttar Pradesh, India*

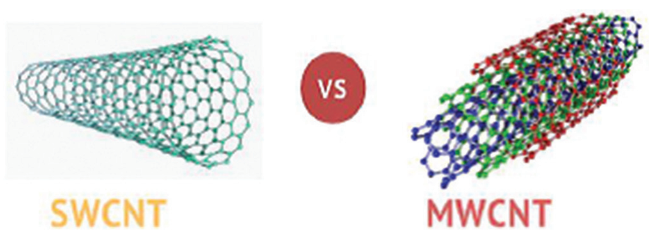
**ABSTRACT**

The discovery of carbon nanotubes (CNTs) has revolutionized an engineer's approach to design. CNTs measuring on the nanometer scale have found extraordinary applications in the field of nanotechnology due to their novel properties. CNTs have found varied applications in the field of medicine as drug delivery carriers, biosensors, and artificial implants. CNT has also been efficiently used in genetic engineering. CNTs have grown to be a popular tool and proved to be a promising nanomaterial for cancer diagnosis and treatment. In this article, the varied applications of CNT in health care are extensively reviewed.

**Key words:** Biomedical, Carbon nanotubes, Drug delivery.

## 1. INTRODUCTION

In recent years, significant progress has been made in the field of nanomaterials given their high potential in biomedical applications [1]. The novel properties of carbon nanotubes (CNTs) make them potentially useful in the field of nanotechnology and biomedicine. CNT is a hexagonal grid of carbon atoms rolled into a long, thin, hollow cylinder that is noted for its size, shape, and extraordinary physical capabilities [2]. In the $sp^2$ [2] hybridization, elemental carbon can form a number of fascinating forms [3]. Carbon, in addition to the well-known graphite, may form closed and open cages with a honeycomb atomic configuration. Kroto *et al*. discovered the C60 molecule in 1985 [4], which was the first of its kind. Although many carbon cages had been examined, tubular carbon structures were the first to be seen by Lijima in 1991. The nanotubes were made up of tens of graphitic shells (so-called multiwalled carbon nanotubes [MWNTs]) separated by 0.34 nanometers, with diameters of 1 nanometer and a high length/diameter ratio [5]. CNTs come in a variety of sizes, ranging from 1 nm to 50 nm in diameter. Nanotubes are normally measured in micrometers, however, recent improvements have allowed them to be measured in centimeters [5]. These nanotubes have a wide range of electrical, optical, mechanical, and thermal properties, and these properties differ depending on the type of nanotube defined by their diameter, length, chirality, degree of twist, and nature of the wall [6]. Due to their differences in electrical properties, they operate as either metals or semiconductors. Their distinct surface area, stiffness, strength, and resilience have all sparked a lot of curiosity and research in the field of pharmacy [6]. CNTs can be visualized as a sheet of graphene that has been rolled into a tube. Since, a graphene sheet may be rolled in multiple ways to produce distinct types of CNTs [7], CNT can be classified based on their structure. Two types of CNTs are observed – single-wall nanotubes and multiwall nanotubes have been summarized in Table 1.




The most promising method of industrial scale production of high purity CNT is chemical vapor deposition. In this method, a carbon-containing precursor gas, such as methane ($CH_4$), is introduced and heated in a vacuum chamber. The bonds between the carbon and hydrogen atoms begin to decompose as the temperature rises inside the chamber. Thereafter, the carbon diffuses into a melted metal catalyst substrate. This then transforms into a metal-carbon solution, which eventually becomes carbon supersaturated. At this point, the carbon begins to precipitate out and form CNT, while the hydrogen byproduct is vented out of the chamber to prevent explosion. Other methods for the synthesis of single- and multi-wall CNT are as illustrated in Figure 1.

## 2. PURIFICATION OF CNT

CNTs are less pure than other materials. They have impurities such as metal objects, amorphous carbon, and multishell, and have an average purity of roughly 5–10%. Purification is required before drug attachment to CNTs have been summarized in Table 2.

## 3. APPLICATIONS OF CNT IN HEALTH CARE

### *3.1. CNT in Drug Delivery*

Due to a lack of selectivity, conventional drug administration was frequently jeopardized by systemic toxicity [1]. Furthermore, drug administration was hampered by limited solubility, poor distribution among cells, and the inability of drugs to cross-cellular barriers. CNTs were discovered to be capable of overcoming these obstacles. CNTs have been used for targeted and controlled drug delivery due to the variable stimuli that CNT can control, such as magnetic stimuli,

***Corresponding author:**
*E-mail: ancey1@gmail.com; sonikaitc2@gmail.com*

**ISSN NO:** 2320-0898 (p); 2320-0928 (e)
**DOI:** 10.22607/IJACS.2021.904012

**Received**: 09th October 2021;
**Revised:** 13th October 2021;
**Accepted:** 23rd October 2021

electric stimuli, temperature changes, and others [9]. Due to the unique properties of CNT, particularly their ultrahigh surface area, beneficial molecules such as drugs, peptides, and nucleic acids can be integrated into their walls and tips [8], and has been summarized in Tables 3-5.

### *3.2. Artificial Implants*

Normally, the body reacts to implants with post-administration pain, but nanotubes and nanohorns attach to other proteins and amino acids, preventing rejection. They can also be used as implants in the form of artificial joints without causing host rejection. CNT filled with calcium and arranged/grouped in the structure of bone can also act as a bone substitute due to their high tensile strength [6,8]. Applications of Carbon Nanotubes as artificial implants has been summarized in Table 6.

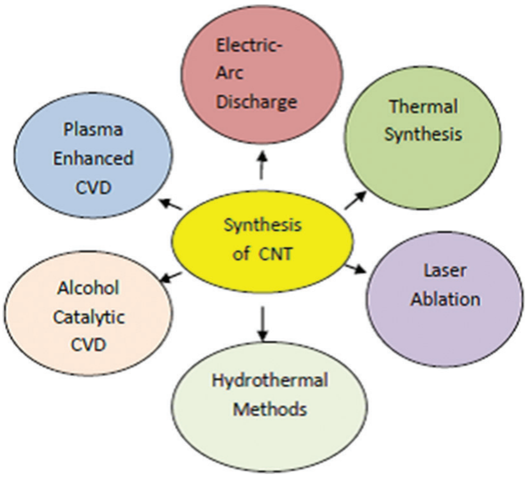



**Figure 1:** Various methods of synthesis of carbon nanotubes.

### *3.3. As Biosensors and Diagnostic Tool*

A biosensor is a diagnostic device that converts a biological event into a detectable electrical signal. CNTs provide a variety of appealing properties for the development of new generation probes in CNT-based sensors and are expected to bring about revolutionary changes. The applications of CNT based biosensors and diagnostic tools have been summarized in Table 7.

### *3.4. Biomedical Applications*

The inability of CNTs to dissolve in aqueous media was a major hindrance, hence, the development of covalent and non-covalent methods for producing water-soluble CNTs as well as procedures for attaching biomolecules to CNTs, enabled the development of biomedical applications of CNTs [4] have been schematically represented in

**Table 1:** Comparison between single-wall nanotubes and multiwall nanotubes [8].

| Single wall nanotube | Multi wall nanotube |
|---|---|
| Diameter of less than 1 nm | Diameter ranges between 10 and 20 nm |
| Single layer of graphene | Multiple layers of graphene |
| Resistivity – $10^{-4}$–$10^{-3}$ Ωm | Resistivity – $1.8*10^{-5}$–$6.1*10^{-5}$ Ωm |
| Bulk synthesis is difficult. Catalyst required for synthesis. Purity is poor | Bulk synthesis is easy. Can be synthesized without a catalyst. Purity is high |
| Characterization and evaluation is easy | It has a very complex structure |
| Easily twisted and are more pliable | Cannot be easily twisted |

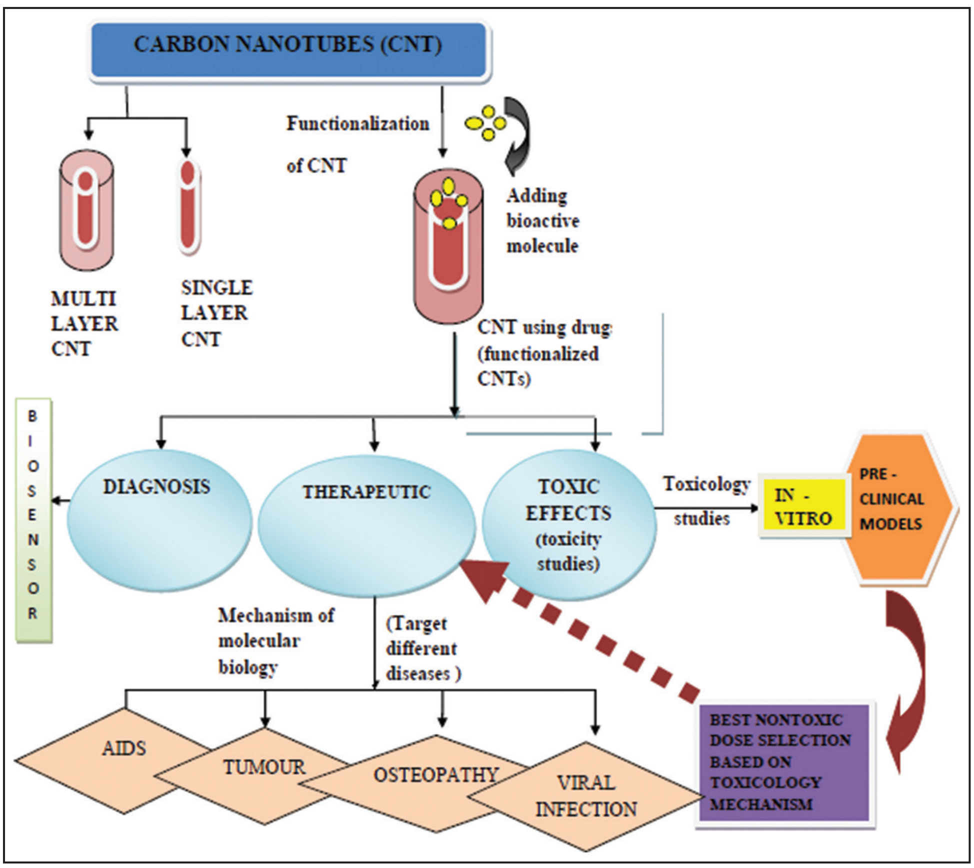



**Figure 2:** Schematic illustration of biomedical applications of carbon nanotubes [9].

**Table 2:** Summary illustrating various purification methods employed for CNT [5,6,8].

| Phase | Method employed | Condition | Expulsion/reduction |
|---|---|---|---|
| Air oxidation | Dynamic oxidation | Oxidation at 673 K for 40 min | Carbonaceous contaminants |
| Acid refluxing | Refluxing | Refluxing in strong acid – HCl (ideal), $HNO_3$, $H_2SO_4$ | Metal particles and amorphous carbon |
| Sonication filtration and annealing | Surfactant-assisted sonication | SDBS-aided sonication with ethanol (or methanol) | Carbon and catalyst particles, untangling |
| | Filtration | Ultrafiltration | Carbon & metal particles |
| | Annealing | Annealed in $N_2$ for 4 h at 1273 K | Carbon and metal particles |

**Table 3:** Summarized applications of CNT-based drug delivery system [10].

| Drug delivery system | Application |
|---|---|
| Cisplatin-incorporated oxidized SWNHs | Terminates the growth of human lung cancer cells |
| CNT-functionalized carrier system | Successful oral alternative administration of erythropoietin |
| Functionalized carbon nanotubes | Targeting of amphotericin B to cells |
| Anticancer drug polyphosphazene platinum given with nanotubes | Enhanced permeability, distribution, and retention in the brain due to controlled lipophilicity of nanotubes |
| Gelatin CNT mixture (hydrogel) | Potential carrier system for biomedical |

**Table 4:** Tumor targeted drug delivery system (CNT based) [1].

| CNT Type | Drug | Tumor targeted |
|---|---|---|
| SWNT | Taxoid | Leukemia |
| SWNT | Doxorubicin | Colon cancer, breast cancer, glioblastoma |
| SWNT | Radionuclide | Burkitt lymphoma |

SWNT: Single-wall nanotube

**Table 5:** CNT-based nucleic acid delivery system [8].

| CNT type | Nucleic acid | Application |
|---|---|---|
| SWNT | siRNA | Increase suppression of tumor growth |
| SWNT | siRNA | Enhance the efficiency of siRNA-mediated gastrin-releasing peptide receptor (GRP-R) gene silencing |
| SWNT | SOCS1siRNA | Reduced SOCS1 expression and retarded the growth of established B16 tumour in mice |

**Table 6:** Application of carbon nanotubes as artificial implants [8].

| Nanotube type | Natural/ synthetic material | Cell/tissue | Application |
|---|---|---|---|
| MWNT | Poly (acrylic acid) | Human embryonic system | Enhance cellular differentiation towards neurons |
| MWNT | Polyurethane | Fibroblast cells | Increase the interaction between the cells and the polyurethane surface |
| SWCNT | Polycarbonate membrane | Osteoblast-like cells | Increase cytoskeletal extensions |

MWNT: Multiwall nanotube

**Table 7:** CNT-based biosensors and diagnostic tools and their applications [5].

| CNT-based sensors | Application |
|---|---|
| Glucose sensor | Track glucose levels in the blood without having to prick fingers |
| CNT-incorporated sensor | Monitoring of hazardous radiation exposure in nuclear plants/reactors, chemical laboratories, or industries |
| Implantable sensors | Monitor pulse, temperature, and blood glucose levels, as well as diagnose diseases |
| Protein/enzyme encapsulated nanotube | Implantable biosensors |
| Radioisotope enzyme, magnetic material encapsulated nanocapsule | Biosensors |
| Nanosize robots and motors with nanotubes | In studying cells and biological systems |

Figure 2. Bianco *et al*. synthesized soluble CNTs and covalently linked them to biologically active peptides [5]. CNT being light weight, chemically inert, more biocompatible in comparison to other substances and possessing high tensile strength, number of antibacterial and antifungal properties makes for an appropriate material for biomedical applications [9]. In chemotherapy, drug-embedded nanotubes attack and kill viruses directly on viral ulcers. There were no antibodies produced against the CNT backbone, indicating that the nanotubes have no inherent immunogenicity [5]. *In vitro* studies revealed that hyperthermia due to the thermal conductivity of CNTs internalized into those cells and caused selective cancer cell killing. Their semi and metallic conductive properties make them suitable for various applications such as clinical diagnostics, food safety, and environmental monitoring [9]. Overall, CNTs have their contributions in diagnostics, bioinspired fabrication, molecular electronics, bioinspired materials, molecular devices, tissue engineering, and therapeutics.

### *3.5. Genetic Engineering*

CNTs are used as a carrier for genes (gene therapy) to treat cancer and genetic disorders due to their unique cylindrical structure and properties. Due to their tubular structure, they have proven to be effective vectors in gene therapy. The CNT based applications in Genetic Engineering have been summarized in Table 8.

Nanotubes complexed with DNA were discovered to release DNA before it was destroyed by the cell's defense system, significantly increasing transfection. Nanostructures have been shown to have antiviral activity against respiratory syncytial virus, a virus that causes severe bronchitis and asthma [5]. In most cases, the treatment combines nanoparticles and gene slicing technologies. In this case, RNA fragments capable of inhibiting a protein (which is required for virus replication) are encapsulated within nanotubes and administered as nasal sprays or drops. Positive results have been noted in inhibiting virus growth [6].

### *3.6. In Cancer Diagnosis and Therapy*

CNT transport capabilities, combined with appropriate surface modifications and their unique physicochemical properties, can lead to a new class of nanomaterials for cancer therapy. Many distinct protein biomarkers are frequently overexpressed in cancer cells, and they serve as an input and primary source of information for early diagnosis, prognosis, maintaining surveillance after curative surgery, monitoring therapy in advanced disease, and predicting therapeutic response [8]. Many important tumor markers have been applied and used extensively in the diagnosis of various forms of cancer as summarized in Table 9.

### *3.7. Preservative*

CNT and nanohorns are naturally antioxidants. As a result, they are used to preserve drug formulations that are prone to oxidation [5]. Their antioxidant property is used in anti-aging cosmetics and as a dermatological sunscreen with zinc oxide to prevent oxidation of important skin components [6].

**Table 8:** CNT-based applications in genetic engineering [5].

| Nanotube | Application in genetic engineering |
|---|---|
| Carbon nanotube and carbon nanohorns | Manipulate genes and atoms in the creation of bioimaging genomes, proteomics, and tissue engineering |
| Single-stranded DNA wound around single-wall nanotube | Diagnostics (polymerase chain reaction), therapeutics, and DNA analysis |
| Nanotubes complexed with DNA | Increases transfection |
| Nanostructures (nanotubes) | Antiviral activity against respiratory syncytial virus |

**Table 9:** Summary illustrating detection of cancer biomarkers by CNT-based detection systems [11-14].

| CNT type | Biomarker | Cancer |
|---|---|---|
| SWNT-horseradish peroxidase | Prostate-specific antigen | Prostate cancer |
| Multiple enzyme layers assembled multiwall carbon nanotubes (MWCNTs) | Alpha-fetoprotein | Various forms |
| Carbon nanomaterial | Carcinoma antigen-125 | Carcinoma |
| Multiwalled carbon nanotube-chitosan matrix | Human chorionic gonadotropin | Various forms |

## 4. CHALLENGES AND LIMITATIONS

Residual metal particles are a standard impurity in CNT samples. If these impurities are not removed properly, they can significantly alter the behavior of a CNT-based device. Due to their inert nature, CNTs do not disperse in organic matrices and form bundles with each other. Furthermore, the general concerns raised about the toxicity of CNT pose a potential risk to the environment if not carefully monitored. The manufacturing process of nanotubes being a relatively expensive one is a major limitation.

## 5. CONCLUSION

CNTs have the potential to find novel applications in a wide range of clinical settings providing a very promising glimpse into the future of medicine. CNTs have enormous potential in tumor molecular diagnosis and targeted therapy of tumors. Furthermore, the encapsulation of other materials in CNT would pave the way for their bioapplications in medicine. The properties and characteristics of CNT are still being heavily researched, and scientists have only begun to realize the potential of these nanotubes. They can pass through membranes, delivering therapeutic drugs, vaccines, and nucleic acids to previously inaccessible targets. Without a doubt, CNTs are a material with enormous potential, with the potential for breakthroughs in a new generation of devices, electric equipment, and biofields.

## 6. ACKNOWLEDGMENTS

The authors acknowledge to Dr. (Mrs.) V. Prakash, The Principal, Isabella Thoburn College, Lucknow, for their support.

## 7. REFERENCES

1. S. Ji, C. Liu, B. Zhang, F. Yang, J. Xu, J. Long, C. Jin, D. Fu, Q. Ni, X. Yu, (2010) Carbon nanotubes in cancer diagnosis and therapy, ***Biochimica et Biophysica Acta BBA Reviews on Cancer***, **1806**(**1**): 29-35.
2. S. Khanna, N. Islam, (2018) Carbon nanotubes-properties and applications, ***Organic and Medicinal chemistry international Journal***, **6:** 30-35.
3. R. Khare, S. Bose, (2005) Carbon nanotube based composites a review, ***Journal of Minerals and Materials***, **4**(**1**): 31-46.
4. H. W. Kroto, J. R. Heath, S. C. O'Brien, R. F. Curl, R. E. C. Smalley, (1985) Buckminsterfullerene, ***Nature***, **318:** 162-163.
5. K. Varshney, (2014) Carbon nanotubes: A review on synthesis, properties and applications, ***International Journal of Engineering Research and General Science***, **2**(**4**): 18.
6. R. Hirlekar, M. Yamagar, H. Garse, M. Vij, V. Kadam, (2009) Carbon nanotubes and its applications: A review, ***Asian Journal of Pharmaceutical and Clinical Research***, **4:** 11.
7. E. N. Ganesh, (2013) Single walled and multi walled carbon nanotube structure, synthesis and applications, ***International Journal of Innovative Technology and Exploring Engineering***, **2**(**4**): 10.
8. A. Eatemadi, H. Daraee, H. Karimkhanloo, M. Kouhi, N. Zarghami, A. Akbarzadeh, M. Abasi, Y. Hanifehpour, S. W. Joo, (2014) Carbon nanotubes: Properties, synthesis, purification, and medical applications, ***Nanoscale Research Letters***, **9**(**1**): 393.
9. N. Anzar, R. Hasan, M. Tyagi, N. Yadav, J. Narang, (2020) Carbon nanotube a review on synthesis, properties and plethora of applications in the field of biomedical science, ***Sensors International***, **1:** 100003.
10. A. Barroug, M. J. Glimcher, (2002) Hydroxyapatite crystals as a local delivery system for cisplatin: Adsorption and release of cisplatin *in*

vitro, ***Journal of Orthopaedic Research***, **20**(**2**): 274-280.
11. C. Ou, R.Yuan, Y. Chai, M. Tang, R. Chai, X. He, (2007) A novel amperometric immunosensor based on layer-by-layer assembly of gold nanoparticles-multi-walled carbon nanotubes-thionine multilayer films on polyelectrolyte surface, ***Analytica Chimica Acta***, **603**(**2**): 205-213.
12. N. Li, R. Yuan, Y. Chai, S. Chen, H. An, (2008) Sensitive immunoassay of human chorionic gonadotrophin based on multi-walled carbon nanotube-chitosan matrix, ***Bioprocess and Biosystems Engineering***, **31**(**6**): 551-558.
13. Y. Y. Lin, J. Wang, G. Liu, H. Wu, C. M. Wai, Y. Lin, (2008) A nanoparticle label/immunochromatographic electrochemical biosensor for rapid and sensitive detection of prostate-specific antigen, ***Biosensors and Bioelectronics***, **23**(**11**): 1659-1665.
14. S. Bi, H. Zhou, S. Zhang, (2009) Multilayers enzyme-coated carbon nanotubes as biolabel for ultrasensitive chemiluminescence immunoassay of cancer biomarker, ***Biosensors and Bioelectronics***, **24**(**10**): 2961-2966.

***Bibliographical Sketch**

Ms. Ancey Abraham obtained her M.Sc. degree in Chemistry from Isabella Thoburn College, Lucknow. She has co-authored 3 Research papers published in International Journals of repute and has peer reviewed a manuscript from the Journal of Child Health Care.

Dr(Mrs) Sonika Bhatia, Associate professor, Department of chemistry, Isabella Thoburn College, Lucknow. She received her PhD from Central Drug research Institute, Lucknow & has done post-doctoral research from department of chemistry IIT Kanpur. She has 8 papers, 3 book chapters & 1 patent to her credit. Dr.Bhatia has been awarded first place in the Broad Outlook learner Teacher award by Air India at the state level.