

## Research Article

# Carbon Nanotubes: An Ideal Candidate for Biomedical Applications

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## Abstract

Present review tells the importance of carbon nanotubes (CNTs) for biomedical applications. Various nanomaterials have widespread usage in biomedical applications on considering its tremendous superior properties. Silver nano particles, gold nano particles, carbon fibers, carbon nanotubes, nanowires, nanorods, quantum dots, graphene etc., are being widely investigated for various medicinal applications. Due to the multifunctional nature and unique physicochemical properties, carbonaceous materials (carbon nanotubes, fullerenes, graphenes etc) have extensive application in biomedical field. Among these, functionalized carbon nanotubes (f-CNTs) have great importance in biomedical field, since CNTs can interact with various biomacromolecules by physical adsorption. The improved solubility and biocompatibility of f-CNTs along with its unique optical, mechanical and electrical properties makes them as an efficient candidate for biomedical applications. Biomedical applications of CNTs have been progressing rapidly and it can be accepted as a potential biomedical agent for targeting, drug delivery, imaging, sensing, etc.

## INTRODUCTION

Recent developments showed that nanotechnology has great importance in the field of biomedical applications. Major biomedical application of nanomaterials involves targeting of damaged cells, drug delivery, especially for anticancer therapies, discovery of infectious microorganisms, DNA detection assays etc. The usages of nanomaterials in biomedical applications are increasing day by day. Due to their small size and increased surface area, it can interact with biomolecules easily. The commonly used nanomaterials are categorized to three types, like zero-dimensional materials (eg; quantum dots) one dimensional material (nanorods, nanowires, nanotubes etc), and two-dimensional materials (nanobelts, nanodisks, films and nanosheets etc). The major application of nanomaterials is for the drug delivery systems. The nanomaterials can target and deliver the drug specifically. Drug delivery by nanomaterials depends on certain factors such as morphology of the nanomaterials, the interaction between the materials and drug, mechanism of delivery, diffusion coefficient etc.

The nanotechnological application of diagnosis, imaging, curing and controlling of the biological system generally called as "Nanomedicine" or Nanotherapy. For biomedical usage the nanomaterials should be surface modified by chemical, physical and biological methods to improve the solubility of the nanomaterials in aqueous media and to become more compatible with biological systems. Thus nanomedicine involves the usage of modified nanomaterials as drug delivery vehicles, biosensors,

imaging agents, scaffold reinforcements labeling agents of cell and tissue, biomaterial reinforcements etc.

The commonly used nanomaterials for biomedical application involves silver nanoparticles, gold nanoparticles, carbon fibers, carbon nanotubes, nanowires, nanorods, quantum dots, graphene etc; and are being widely investigated for various medicinal applications. The main advantages of nanomaterials as biomedical tools involve reduced amount of the drug dose and less toxicity with enhanced stability after the surface functionalization.

Due to the multifunctional nature of carbon-based nanomaterials (CBNs), it acquired great importance for biomedical applications. Recently several works were reported based on the biomedical application of carbon based nanomaterials such as carbon nanotubes, carbon nanofibers, quantum dots, fullerenes, nanodiamonds, carbon, graphene, nanohorns [1-7]. These are broadly used for drug delivery and sensor applications with high selectivity due to its high aspect ratio, high surface to volume ratio, unique electrical and mechanical properties, biocompatibility properties etc; thus these nanomaterials can be used as diagnostic tools against diseases, since both the nanomaterials and most biological systems are in nanometer scale dimensions.

## CARBON NANOTUBES (CNTS)

CNTs are allotropes of carbon consist of a hexagonal layer of carbon atoms rolled to form cylindrical tubular structure

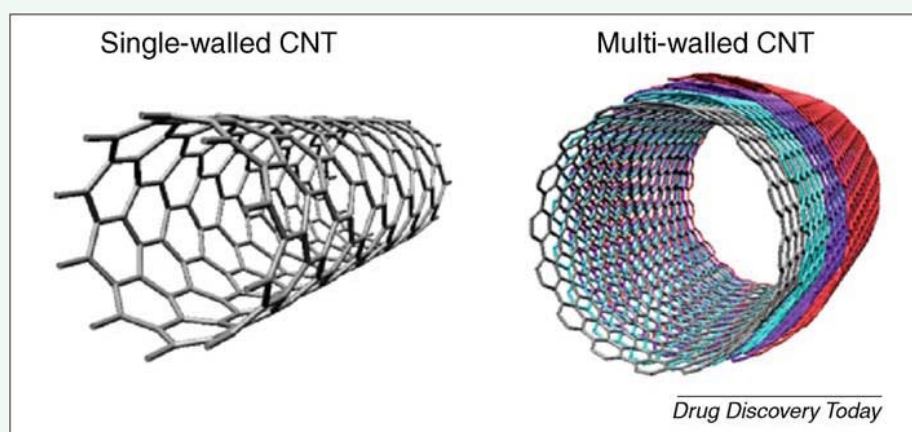
discovered by Iijima in 1991. They carbon atoms are connected through  $sp^2$  bonds. CNTs have the tensile strength in the range of 11-63 GPa and Young's modulus 1-1.8 TPa. They have the specific strength, 100 times greater than that of steel, and in addition they are highly elastic, light weight and are good thermal and electrical conductors. Because of their superior mechanical, electrical, thermal, and elastic properties, CNTs have been considered as an ideal nanomaterial in biomedical engineering. CNTs size, mode of synthesis, geometry, purity, and concentration have great role in governing their biological performance [3].

Among the carbon-based nanomaterials (CBNs), Carbon Nanotubes have wide range of application on considering its large surface area, aspect ratio, unique electrical, mechanical, optical and thermal properties. Using the concept of nanotechnology, CNTs are widely used in the field of nanomedicine and the other applications include controlled drug delivery, hormone and enzyme delivery, targeting of damaged site and as a nanofluidic device in drug delivery systems. CNTs have an inevitable role as diagnostic tools like nanosensors, nanorobots, nanoprobe and actuators for detecting various diseases [8,9].

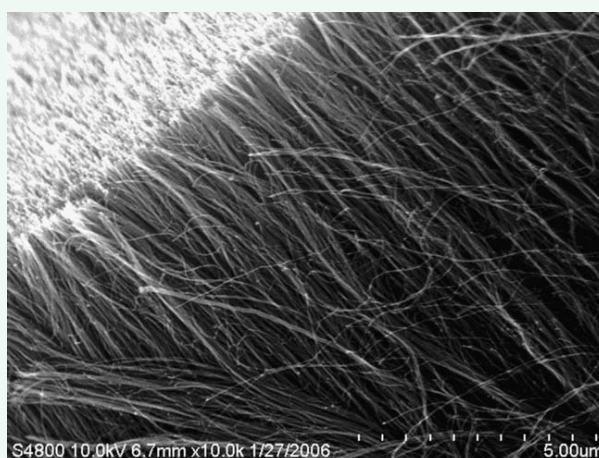
## Classifications

CNTs are classified into two, according to its structure, SWCNTs and MWCNTs (Figure 1). Carbon nanotubes composed of a single tube are commonly called a single-walled carbon nanotube (SWNT) and concentric cylinders of carbon are commonly referred to as multi-walled carbon nanotubes (MWNTs). MWCNTs are less stable than SWCNTs due to the structural defects [8,10].

**Single walled carbon nanotubes:** Single-walled carbon nanotubes (SWNTs) are formed by the rolling of single graphene sheet to form a cylindrical tube (diameters of between 0.4 and 2.5 nm) with excellent unique chemical, optical, electrical and physical properties. SWCNTs have better defined wall with ultrahigh surface area, which enables them to load multiple molecules by  $\pi$ - $\pi$  stacking interactions. Functionalized single wall carbon nanotubes can be used for treatment of cancer, central nervous system disorders, infectious diseases and enable applications in tissue engineering. SWNTs have unique optical properties and are highly absorbing materials with strong optical absorption in the near-infrared (NIR) range, hence it can be used



**Figure 1** Structure of single wall carbon nanotubes and multiwall carbon nanotubes [11].



**Figure 2** Scanning electron micrographs of multi-walled carbon nanotubes showing the tubular structure (diameter in nm and length in micro range) [10].

for molecular imaging and photothermal therapy. The biological imaging of SWCNTs is due to the photoluminescence in the NIR range and Raman scattering properties[12].

**Multiwalled carbon nanotubes:** Multi-walled carbon nanotubes (MWNTs) are formed by the rolling up of two or more graphene sheets laid one above the other to form concentric tubes with specific properties (diameters up to 100 nm). It also exhibits less rich and attractive optical properties than SWCNTs. But due to the large size of MWNTs than SWCNTs, their use in biological systems could be different from that of SWCNTs. Both MWNTs and SWCNTs show tendency to aggregate into a cluster or bundle form due to the weak van der Waal's force of attraction. This will induce toxic effect due to its insolubility in aqueous solvents. The solubility and biocompatibility can be improved by the surface modification of both the CNTs [13].

### Preparation and characterization

For the biomedical applications, the CNTs synthesized must be of good quality, free from impurities and carbonaceous materials and should have perfect structure. There are three main methods for the preparation of CNTs- Electric arc discharge (EAD), Laser ablation technique (LA) and Chemical vapor deposition method (CVD) –and are explained in detailed in Table 1. Among these methods CVD is the widely used method. The synthesis process involves metal catalysts, hence purification of prepared CNTs are important before of its biomedical applications. Among different purification methods, refluxing carbon nanotubes in an oxidizing acid is one of the most accepted method. This process oxidizes and removes the metal catalysts and other unwanted deposits from the inside and outside of the tubes.

The physical and mechanical properties of CNTs will depend on the preparation methods. Synthesized CNTs need to be characterized to get complete idea about its properties and is essential for its biomedical applications (Figure 2 and 3). Some instrumental techniques and the properties that can be studied from it are listed in Table 2.

### Modification of CNTs

CNTs can be made as an effective diagnostic tool by functionalization as it can enhance the solubility and compatibility

with biological systems. Several methods are reported based on the modification of CNTs with biomolecules which include both covalent and non-covalent modifications.

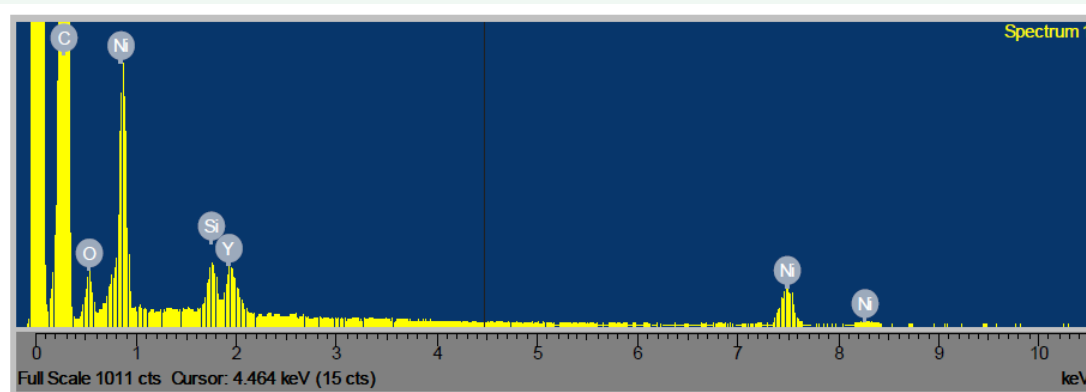
**Covalent modification:** In covalent modification chemical bonds are formed through chemical reactions. The schematic representations for different covalent functionalizations and are shown in Figure 4.

**Modification by oxidation reaction:** Oxidation process by strong oxidizing agent is an important method for the surface modification of CNTs, in which the defective carbon atoms on side walls or at the end of CNTs are oxidized to carboxyl groups which can be further modified by amidation or esterification to avoid the chance of aggregation caused by charge screening effects. In this method defective carbon atoms are undergo modification, hence it also known as defect functionalization. These covalently modified CNTs have increased biocompatibility with biological systems.

**Modification by addition reaction:** Among the addition reactions, cycloaddition reaction has great importance. This can be conducted by photochemical reactions of CNTs with azide and carbene generating compounds (Bingel reaction). The cycloaddition reactions occur mainly on the side walls of CNT.

**1,3-dipolar cycloaddition:** The 1,3-dipolar cycloaddition on CNTs is a another technique for functionalization and are widely used, in which pyrrolidine rings are formed at the end of the tubes and sidewalls. In the case of covalent modification there will be a chance for structural changes in CNTs thereby the optical, physical and electrical properties are often destroyed [12,16,17] (Figure 4).

**Non-covalent modification:** Non-covalent modification involves physical interactions of CNTs with amphiphilic surfactant molecules or polymers.  $\pi$ -  $\pi$  stacking interactions are taking place between the biomolecules and CNTs. It can be noted that the non-covalent functionalization involves two major methods, first one is the wrapping of polymers around the CNT side walls and second one is the  $\pi$ -  $\pi$  stacking interactions between loaded materials and the graphene sheets of the CNTs. The aromatic hydrophobic surface makes CNTs as an ideal candidate for non-covalent interaction. In addition, there is a hybrid method for the



**Figure 3** EDX spectrum, Ni and Y belong to metallic catalyst particles [15].

**Table 1:** Different methods for the preparation of CNTs [14].

Method	Electric arc discharge (EAD).	Laser ablation techniques (LA)	Chemical vapor deposition method(CVD)
	Connect two graphite rods with few millimeters apart to a power supply, and switch on. At 100 amps, carbon vaporizes in a hot plasma	Blast graphite with intense laser pulses rather than electricity to generate carbon gas under various conditions until hit on the one that produces prodigious amounts of SWNTs.	Place substrate in oven heated to 600°C, followed by the passage of a carbon-bearing gas like methane. As gas decomposes carbon atoms formed recombine in the form of NTs.
Advantages	CNTs prepared from this method have higher Young's modulus with least defects as compared with other methods	As compared with EAD technique, LA can yield both SWNTs and MWNTs	The most economical method for production of CNTs, forming nanotubes with least production variables
Disadvantages	Inability to produce SWNT/MWNTs with uniform diameter, and mostly a time-intensive method	CNTs obtained are very narrow in diameter and form tangled ropes and bundles along with impurities.	This method is found to have broad spectrum of advantages, hence advantages outweigh disadvantages
Method of choice	Not useful for industrial scale	Mostly used for laboratory scale and rarely for industrial scale	This is regarded as the method of choice for industrial scale

**Table 2:** Different analytical techniques and the properties studied [14].

Instrumental methods	Characteristics properties
Thermo gravimetric analysis (TGA)	Quantitative determination of the amount of carbon and non-carbon matter in CNTs, helps in assessment of purity, thermal stability and nanotubes homogeneity
Transmission electron microscopy (TEM)	(a) Determines the morphology (b) Qualitative assessment of purity (c) Allows understanding of the structural arrangement of CNT-drug composites and also identifies the CNTs after cellular uptake
Scanning electron microscopy (SEM)	For preliminary evaluation of CNTs (figure 2)
Scanning electron microscopy with energy dispersive X-ray analysis (SEM-EDX)	Most widely useful method for routine estimation of metallic content in CNT (figure 3)
Raman spectroscopy	(a) Novel technique for characterization and evaluation of SWNTs (b) Gives information about radial breathing mode (RBM) of nanotubes, which includes various vibrational transitions like radial movements, expansions and contractions
H1 NMR	Provides information about the presence of functional groups on CNTs by assigning characteristic peaks. Determines diameter of Nanotubes
IR spectroscopy	Acts as a qualitative tool for identification of functional groups, helps in assessing the effect of functionalization on CNT properties

modification of CNTs, which involves two steps, first one involves a non-covalent approach of an anchor molecule to CNTs and the second step follows its covalent linkage to the biomolecules [11]. No structural changes of CNTs have occurred during the non-covalent approach and hybrid approach; hence CNTs can maintain its unique electrical, optical and physical properties as such. Hence the non-covalent functionalization is preferable than covalent modification. The schematic representation of CNTs modifications are shown in Figure 5. By the functionalization process CNTs can be directly link with biomolecules specifically and is a key parameter of drug delivery systems [11,12,18].

## BIOMEDICAL APPLICATIONS OF CNTS

Now a days nanotechnology has acquired widespread applications in biomedical field, precisely drug delivery has benefited greatly from the advances in nanotechnology by using a variety of nanomaterials. Due to the multifunctional nature and unique physicochemical properties carbonaceous materials

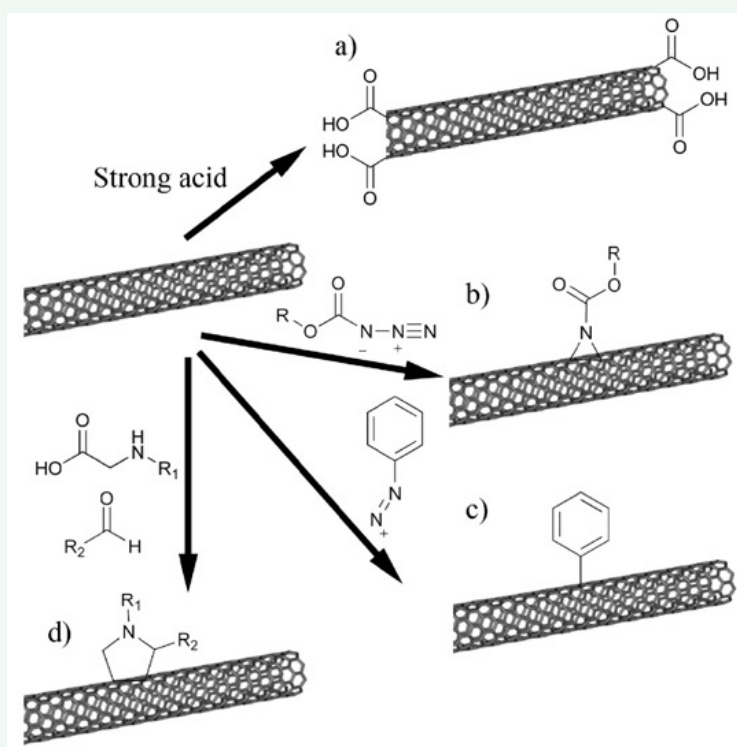
(carbon nanotubes, fullerenes, graphenes etc) have extensive application in biomedical field. The schematic representations of biomedical applications of carbonaceous materials are given in Figure 6.

Among the different nanomaterials, functionalized carbon nanotubes have great importance in biomedical field since CNTs can interact with various bio macromolecules by physical adsorption [14] (Figure 7).

## CNTS IN TISSUE ENGINEERING

Tissue engineering is mainly for the replacement of damaged or diseased tissue with suitable substitutes, which can maintain the normal functions of damaged organs. Scaffolds are mainly used for the organ transplantation which are mechanically very strong in nature. It was reported that CNTs can be considered as an effective material for scaffolds. Due to its large surface area it can bind with large amount of biomolecules. But for unmodified CNT's, the surfaces are hydrophobic in nature, and hence it shows





**Figure 4** Common methods for covalent functionalization of carbon nanotubes: (a) oxidation by strong acids, (b) nitrene cycloaddition, (c) arylation using diazonium salts, and (d) 1,3-dipolar cycloadditions [17].

a tendency to aggregate in the cell culture process and there by inducing toxicity effects. Biomodification of CNTs surface with various bioactive molecules such as carbohydrates or peptides will improve the biocompatibility and bioactivity of scaffolds. The increased application of CNTs in the field of tissue engineering was due to its high mechanical strength. Several studies were reported that CNTs are good additives to improve the mechanical strength of the tissue scaffolds. CNTs with biodegradable polymers are very good scaffolds since it can achieve good mechanical and electrical properties. Zang et al., prepared nano-composite scaffolds of poly lactic glycolic acid and CNTs using the electrospinning technique. They observed that there was a 54% increase in the strength of the scaffold in the presence of only about 0.5% of multi-walled carbon nano-tubes. Similarly Jeong et al., also got a mechanically strong scaffold with the incorporation of CNTs (1%) to polyvinyl alcohol [21,22].

Zarei M and S. Karbasi fabricated poly (3-hydroxybutyrate) /Carbon nanotube PHB/CNTs scaffolds by electrospinning with improved mechanical properties than the pure PHB scaffold (Figure 8). They observed that the uniform distribution of CNTs may be the reason for the enhancement in tensile strength (Figure 8). Figure 9 shows the TEM images of the prepared composite. It is reported that CNTs could improve the wettability, bioactivity and cell ability of the scaffolds to be used in tissue regeneration [23].

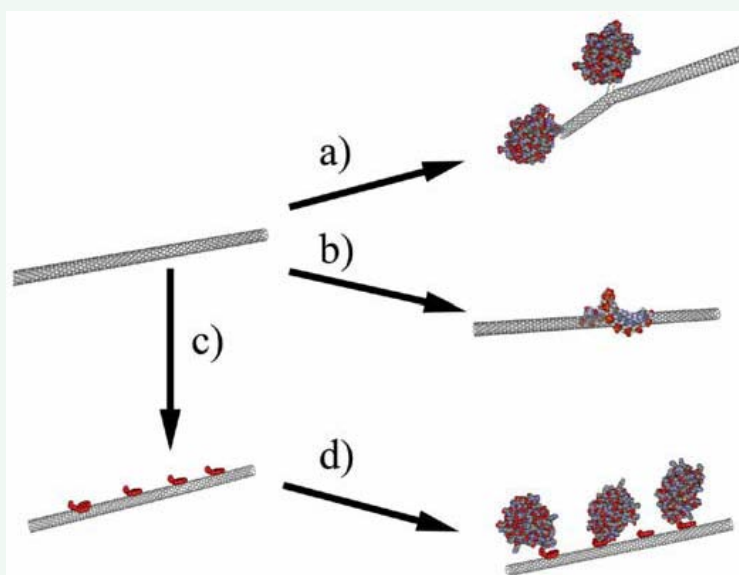
CNTs exhibit a wide range of electrical properties and have great potential as a scaffold component. Electrical properties such as high conductivity of CNTs make them as a potentially candidate for bone tissue engineering purposes. The conductive

substrates can be used for cell electrical stimulation and they can accelerate bone formation and regeneration. These advantages give the potential of satisfying the required criteria for a bioactive biomaterial to CNT [24]. The CNT reinforced naturally derived polymers were used as promising scaffold materials, MacDonald et al., prepared a collagen- carbon nanotube composite material as scaffolds in tissue engineering [25].

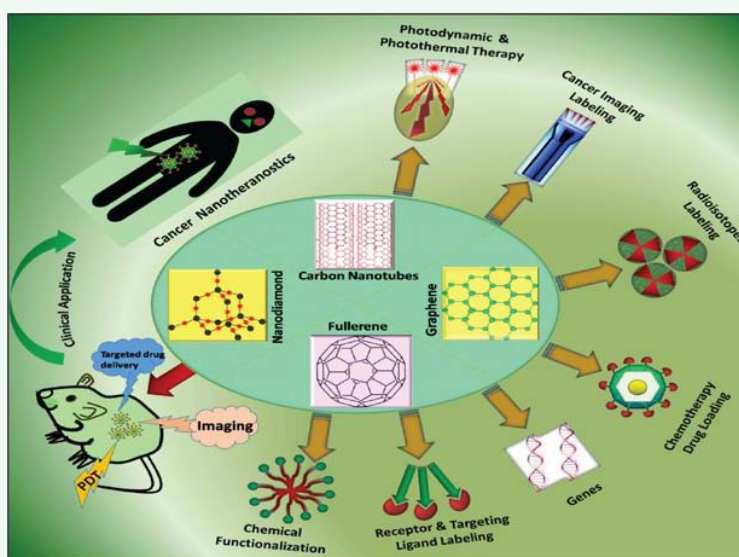
The four areas where the carbon nanotubes can be used for tissue engineering are cell tracking and labeling, sensing cellular behavior, augmenting cellular behavior and enhancing tissue matrices. The ability to track implanted cells and to monitor the progress of tissue is important in tissue-engineered constructs of clinically applicable sizes. Labeling implanted cells help to evaluate the viability of the engineered tissue and to understand the biodistribution and migration pathways of transplanted cells. Several literatures reported that carbon nanotubes are feasible as imaging contrast agents for optical, magnetic resonance, and radiotracer modalities. Thus the CNT incorporated polymer scaffolds have many applications in the medical field as nano devices, molecular level building blocks, scaffolds etc. Also polymer coated CNTs have optimistic impact on cell proliferation and differentiation.

## CLINICAL APPLICATIONS OF CNTS

CNTs are broadly used for biomedical applications on taking account of its nanoscale size, shape, structure, ultra light weight, thermal stability, unique electrical, optical and physical properties. Even though CNTs have specific appreciable properties, its lack of solubility in aqueous media was a major



**Figure 5** The main modification methods of carbon nanotubes with biomolecules: (a) the covalent approach, (b) non-covalent approach and (c) and (d) hybrid approach (c. an 'anchor' non-covalently absorbed to the carbon nanotubes d. chemical reaction between the anchor and the biomolecules) [17].



**Figure 6** Schematic representation of biomedical applications of carbonaceous materials [19].

problem facing towards the biomedical application of CNTs. But these limitations can be minimized by suitable functionalization methods.

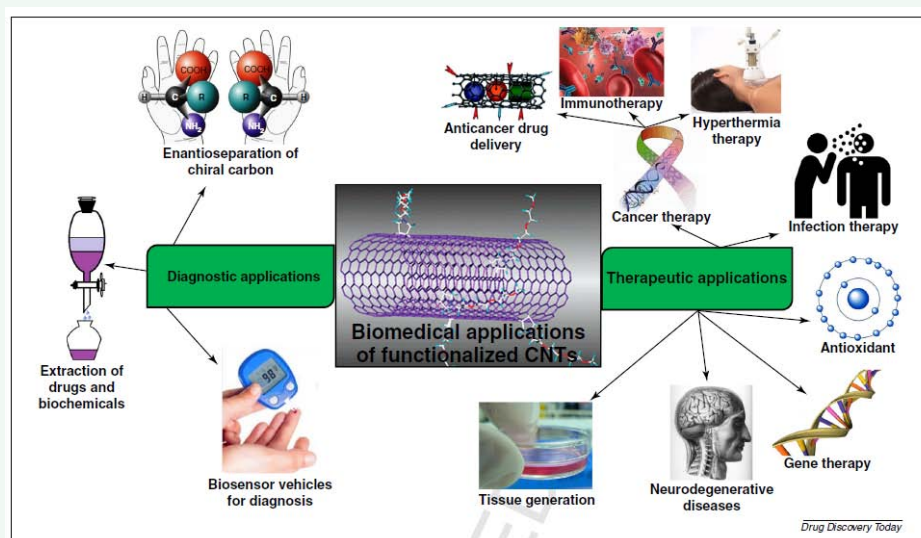
### Drug delivery applications

In this era of nanotechnology several nanomaterials are used for biomedical application, especially for target and drug delivery for cancer treatment. Even though CNTs have large lengths ranging from several hundreds of nm to micrometer; it can be shortened for making them suitable as a drug carrier. The basic requirement of CNTs to consider as a drug carrier is its solubility in aqueous medium. As already discussed the weak van der Waals forces between the tubes leads to the aggregation of

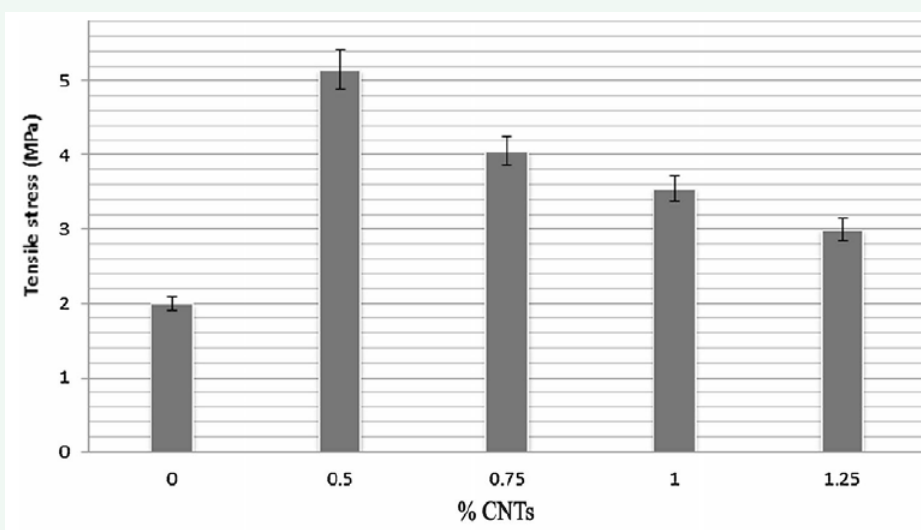
CNTs in to a bundle form and it will cause insolubility in aqueous medium. And hence its dispersion in an aqueous medium become difficult, as a result, it cannot attain a biocompatibility between the biomolecules. The better dispersion of CNTs in aqueous medium and biocompatibility can be improved by the most effective functionalization methods [11,26].

### Cancer therapy

Now a days due to the large surface area and unique physicochemical properties, CNTs are selected as a promising material for the treatment of diseases. The ability of functionalized CNTs to penetrate the plasma membrane and to carry large amount of drugs makes its increased use in treatment of diseases.



**Figure 7** Schematic representation of biomedical applications of functionalized carbon nanotubes [20].



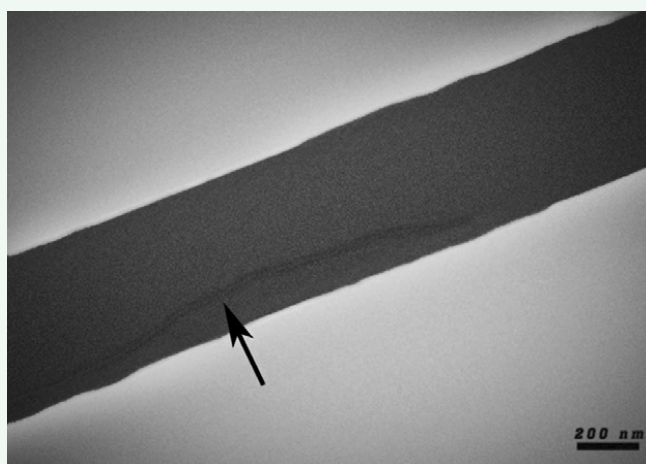
**Figure 8** Changes in the tensile strengths of PHB-CNT scaffolds with various CNTs loading [23].

Several studies were reported that CNTs are promising drug carriers for cancer therapies [26]. Cancer is a dangerous disease, increasing day by day and chemotherapy is the one of the present diagnostic methods against cancer. The usual cancer treatments are painful and it kills not only the cancer cells but also it kills the normal cells. In the current era the drug delivery systems with liposomes, conjugate polymers, dendrimers, cyclodextrins, nano particles etc. have opened new advanced possibilities which get targeted only on defective areas in which the CNTs based drug carriers are considered as the most potential drug carrier. Biocompatible based CNTs, loaded with drugs are effective in targeting and killing cancer cells specifically with less toxicity and much effective than the other conventional drugs [11].

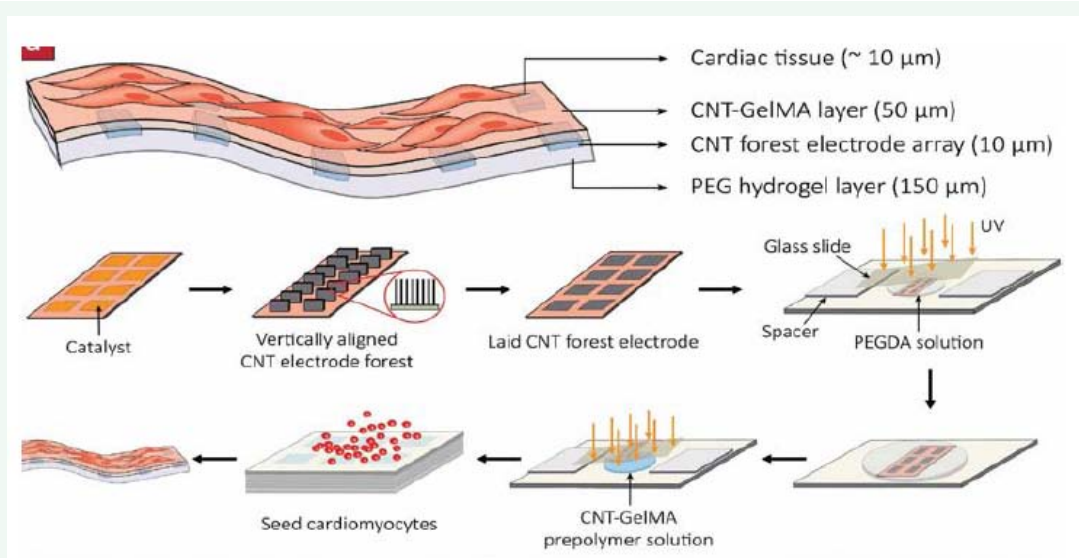
### Optical imaging

Optical imaging has also attracted great importance for diagnostics and biomedical imaging. Carbon nanotubes have the

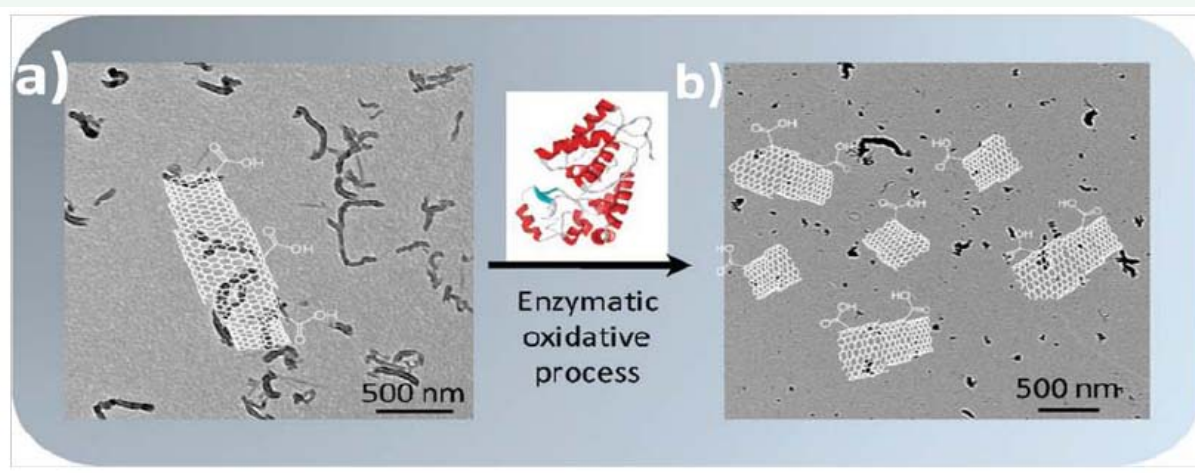
required property needed for optical detection. They possess optical transitions in the near infrared (NIR), the IR between 900 and 1300nm is an important optical window for biomedical applications because of the lower optical absorption and small auto-fluorescent background. Also carbon nanotubes show good photo stability. Normally Raman scattering and fluorescence spectroscopy are used for tracking carbon nanotubes in cells over long durations of time. Carbon nanotubes can also be modified with radiotracers for gamma scintigraphy. CNTs functionalized with heavy elements could serve as X-ray contrast agents. From literature it was come to the notice that carbon nano tube-based materials can be used as NIR fluorescent labels, MRI contrast agents, and radiolabels since it can provide image enhancement. The literature works based on the biomedical application of CNTs suggests that functionalized CNTs have good biocompatibility and can be used as a vehicle for carrying imaging agents [10].



**Figure 9** TEM photomicrograph of PHB/CNTs nano-composite scaffold with 0.5% CNTs [23].



**Figure 10** Schematic showing the concepts behind the fabrication of the hybrid bioactuator [28].



**Figure 11** Degradation of functionalised MWCNTs by oxidative enzymes.



## MISCELLANEOUS APPLICATIONS

Still then there are several other biomedical applications for CNTs. Current blood glucose monitoring methods by patients suffering from diabetes are normally invasive and often painful. High electrochemically accessible surface area, high electrical conductivity and useful structural properties have demonstrated the potential use of SWCNT and MWCNTs in highly sensitive non-invasive glucose detectors. Recently, Nitrogen doped carbon nanotubes found potential applications in the development of sensors for the sensitive determination of glucose content.

The attractive properties of CNTs make them as an ideal component for nanosensors, to immobilize DNA or other proteins, analysis of redox-active proteins and amino acids allowing cell monitoring in engineered tissues. By assembling carbon nanotubes between two electrodes, a field effect transistor (FET) can be formed and can be used for detection [10]. CNT-based sensors are used to detect biological species including proteins and DNA, on considering its optical properties. CNTs can be utilized as optical tags or contrast agents for various biological imaging techniques. Properly functionalized CNTs are able to enter cells without toxicity, shuttling various biological molecular cargoes into cells.

As already discussed the Raman scattering and photoluminescence properties of CNTs make them as an ideal candidate for tracking, detecting and imaging diseased cells or tissues. CNTs have applications to deliver genes to cells due to its great affinity for DNA, RNA and other polynucleotide molecules. CNTs have been considered as components for DNA and protein biosensors, ion channel blockers and as bioseparators and biocatalysis. Moreover some researchers were reported that CNTs can be used as a detector for DNA and antibodies associated with human autoimmune disease with high specificity [27].

Carbon-based nanomaterials can be incorporated into a hydrogel network to increase its electrical conductivity and mechanical stiffness in which CNTs and graphene layer have great attention in recent years because of their formidable structural, mechanical, thermal and electrical properties. Recently Mehrali et al., investigated the application of graphene and CNTs in the development of composite hydrogels for designing and engineering of electro active organs and tissues such as nerve, cardiac, and skeletal muscle. They reported that unique properties of CNTs and graphene makes them as a promising candidate for developing conductive hydrogels for use as bioactuators, biosensors and tissue-engineering scaffolds. In their study CNT incorporation within gelatin methacrylate (GelMA) hydrogel has resulted in a remarkable increase in compressive modulus and tensile modulus of more than 300% and 400%, respectively, without impacting the hydrogel microstructure or cellular in growth due to the improved structural integrity formed by the formation of ordered nanofiber networks inside the hybrid hydrogels [28]. The schematic representation of CNTs incorporated GelMA hydrogel and its fabrication is shown in Figure 10. Thus CNTs have been used as nanofillers in hydrogels intended for use in neural, cardiac, and skeletal-muscle tissue engineering.

## BIODEGRADATION OF CNTS

Since the applications of CNTs have been developed and is progressing day by day it is necessary to study the toxicity and biodegradability completely. The studies based on the toxicity and biodegradability is still going on, the complete idea of mechanism based on the toxicity and biodegradation is not fully understood yet due to the insufficient data and experimental evidence. Several studies reported that the biocompatibility, solubility and toxicity can be controlled by the functionalization of CNTs. The removal or elimination of CNTs from organs is a considerable question for its biomedical application, since there will be a chance to accumulate the CNTs in tissues or cells causing serious issues to living system. To avoid this type of side effects, the biodegradation and elimination of CNTs from the living organs are yet to be encountered. But the degraded product may also make toxic effects on tissues and cells. Controlled degradation of CNTs and the elimination of degraded product is a demanding objective for the biomedical application of CNTs. Some studies were reported that catalytic activity of natural enzymes and some internal fluids can degrade the CNTs intracellularly. The degraded aromatic fragments will eliminate as carbon dioxide from the organs without any side effects. It was reported that horseradish peroxidase (HRP) and phagolysosome milieu (PSF; phagolysosomal simulating fluid), have the capacity to degrade the CNTs in the presence of small amount of hydrogen peroxides. TEM images of carboxylated-MWCNTs before and after treatment with HRP in the presence of  $H_2O_2$  for 60 days [29], is given in (Figure 11).

Both SWCNTs and MWCNTs are undergoing catalytic degradation, but MWCNTs will take more time than SWCNTs due to its large size and multi concentric tubes. The degradation rate will depend on the degree of functionalization and type of functionalization. Studies based on the degradation of CNTs within the cell, were reported but its mechanisms were not completely understood. The process of biodegradation of CNTs, are yet to be considered in detail due to the increased application of CNTs in the biomedical field [29].

## CONCLUSIONS

CNTs with modified surfaces have great importance in the biomedical field. The improved solubility and biocompatibility of f-CNTs along with its unique optical, mechanical and electrical properties make them as a potential candidate for biomedical applications. According to the available literatures it can be understood that biomedical applications of CNTs has been progressing rapidly and it can be considered as a promising biomedical agent for targeting, drug delivery, imaging, sensing, etc., when compared with than other nanomaterials still in use. More studies on the biodegradability and toxicity of CNTs are yet to be encountered without fail.

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