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Review Article

CARBON NANOTUBES AND ITS APPLICATIONS: A REVIEW

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ABSTRACT

Carbon nanotubes (CNTs) are allotropes of carbon with a nanostructure that can have a length-to-diameter ratio greater than 1,000,000. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology. Their unique surface area, stiffness, strength and resilience have led to much excitement in the field of pharmacy. Nanotubes are categorized as single-walled nanotubes and multiple walled nanotubes. Techniques have been developed to produce nanotubes in sizeable quantities, including arc discharge, laser ablation, chemical vapor deposition , silane solution method and flame synthesis method. The properties and characteristics of CNTs are still being researched heavily and scientists have barely begun to tap the potential of these structures. They can pass through membranes, carrying therapeutic drugs, vaccines and nucleic acids deep into the cell to targets previously unreachable. Overall, recent studies regarding CNTs have shown a very promising glimpse of what lies ahead in the future of medicines.

KEYWORDS Carbon nanotubes, Single and multiple walled nanotubes, Nanomedicines.

INTRODUCTION

The last few years have witnessed the discovery, development and, in some cases, large-scale manufacturing and production of novel materials that lie within the nanometer scale. Such novel nanomaterials consist of inorganic or organic matter and in most cases have never been studied in the context of pharmaceuticals. Carbon nanotubes (CNTs) are one of them. CNTs are allotropes of carbon. They are tubular in shape, made of graphite. CNTs possess various novel properties that make them useful in the field of nanotechnology and pharmaceuticals. They are nanometers in diameter and several millimeters in length and have a very broad range of electronic, thermal, and structural properties. These properties vary with kind of nanotubes defined by its diameter, length, chirality or twist and wall nature. Their unique surface area, stiffness, strength and resilience have led to much excitement in the field of pharmacy [1].

HISTORY

In 1952 Radushkevich and Lukyanovich published clear images of 50 nanometer diameter tubes made of carbon in the Soviet Journal of Physical Chemistry [2].

A paper by Oberlin, Endo, and Koyama published in 1976 clearly showed hollow carbon fibres with nanometer-scale diameters using a vapor-growth technique[3]. Furthermore, in 1979, John Abrahamson presented evidence of carbon nanotubes at the 14th Biennial Conference of Carbon at Penn State University. The conference paper described carbon nanotubes as carbon fibers which were produced on carbon anodes during arc discharge[4]. In 1981 a group of Soviet scientists published the results of chemical and structural characterization of carbon nanoparticles produced by a thermocatalytical disproportionation of carbon monoxide. Using TEM images and XRD patterns, the authors suggested that their "Carbon multi-layer tubular crystals" were formed by rolling graphene layers into cylinders[5].

In 1987, Howard G. Tennent of Hyperion Catalysis was issued a U.S. patent for the production of "cylindrical discrete carbon fibrils" with a "constant diameter between about 3.5 and about 70 nanometers, length 10^2 times the diameter, and an outer region of multiple essentially continuous layers of ordered carbon atoms and a distinct inner core"[6].

A large percentage of academic and popular literature attributes the discovery of hollow, nanometer sized tubes composed of graphitic carbon to Sumio Iijima of Nippon Electric Company in 1991. A 2006 editorial written by Marc Monthioux and Vladimir Kuznetsov in the journal Carbon has described origin of the carbon nanotube[7].

STRUCTURE AND MORPHOLOGY

The bonding in carbon nanotubes is sp^2, with each atom joined to three neighbours, as in graphite. The tubes can therefore be considered as rolled-up graphene sheets (graphene is an individual graphite layer) [8]. This bonding structure, which is stronger than the sp^3 bonds found in diamond, provides the molecules with their unique strength. Under high pressure, nanotubes can merge together, trading some sp^2 bonds for sp^3 bonds, giving the possibility of producing strong, unlimited-length wires through high-pressure nanotube linking[1, 9]. Structure of nanotubes is as shown in FIG 1.

Table 1- Comparison between SWNT and MWNT

Sr. No.	SWNT	MWNT
1.	Single layer of graphene.	Multiple layer of grapheme
2.	Catalyst is required for synthesis.	Can be produced without catalyst.
3.	Bulk synthesis is difficult as it requires proper control over growth and atmospheric condition.	Bulk synthesis is easy.
4.	Purity is poor.	Purity is high.
5.	A chance of defect is more during functionalization.	A chance of defect is less but once occurred it's difficult to improve.
6.	Less accumulation in body.	More accumulation in body.
7.	Characterization and evaluation is easy.	It has very complex structure.
8.	It can be easily twisted and are more pliable.	It can not be easily twisted.

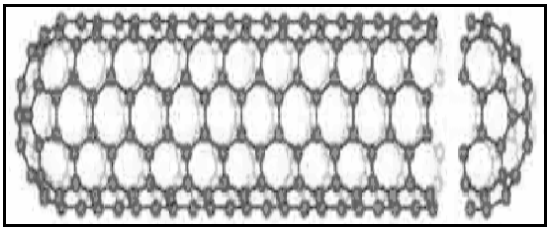

FIG 1. Structure of carbon nanotube

CLASSIFICATION OF CARBON NANOTUBES

Carbon nanotubes are classified in following two types, [1, 9]

- SWNTs- Single walled carbon nanotubes
- MWNTs- Multiple walled carbon nanotubes

Comparision between SWNT and MWNT is as presented in TABLE 1.

METHODS OF PRODUCTIONS OF CNTs:

A. Arc Discharge Method[10-13]

Arc Discharge method has been reported for producing carbon nanotubes. In this method, as shown in FIG 2 nanotubes are produced through arc-vaporization of two carbon rods placed end to end with a distance of 1mm in an environment of inert gas such as helium, argon at pressure between 50 to 700 mbar. Carbon rods are evaporated by a direct current of 50 to 100 amps driven by 20V which will create high temperature discharge between two electrodes. Due to this, anode will get evaporated and rod shaped tubes will be deposited on cathode. Bulk production of CNTs depends on uniformity of plasma arc and temperature of deposition.

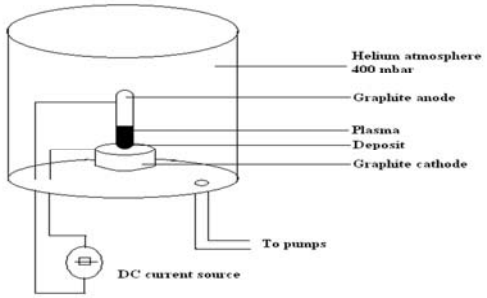

FIG. 2. ARC DISCHARGE METHOD

1. Production of SWNTs:

In the production of SWNTs anode is dipped with a metal catalyst such as Fe, Co, Ni, Y, or Mo. It produces SWNTs with a diameter of 1.2 to 1.4nm. Efficiency of SWNT production by arc discharge method is improved with,

a) Inert Gas

Argon with a lower diffusion coefficient and thermal conductivity has given nanotube with smaller diameter (1.2nm) and 0.2nm diameter decrease with 10% increase in argon: helium ratio, when Nickel and Yttrium is used as a catalyst (4.2: 1).

b) Optical Plasma Control

As the distance between anode and cathode increases, anode vaporization increases, due to which strong visible vortices around cathode is occurred. With a nickel and yttrium catalyst (C/Ni/Y is 94.8:4.2:1) the optimum nanotubes were produced at a pressure of 660 mbar for pure helium and 100 mbar for pure argon. The nanotubes diameter ranges from 1.27 to1.37 nanometer.

c) Catalyst

By changing metal catalyst, nanotubes with a diameter of 0.6 to 1.2nm are produced. Catalysts used are Co and Mo.

d) Open Air Synthesis With Welding Arc Torch

This method is specifically used for SWNTs with graphite rod containing metal catalyst. Ni and Y (3.6: 0.8 at %) are fixed at side wall of water cooled, steel based electrode, torch arc aimed at the edge of target and soot is deposited on substrate behind the target. The arch is operated at 100 amp current and shielding Ar gas flowed through torch to enhance arc jet formation. This method is very convenient and inexpensive with Ni:Y(3.6: 0.8). Nanotubes produced by this method are of diameter of 1.32nm.

2. Production of MWNTs

MWNTs are produced with the use of pure graphite arc with an inner diameter 1-3nm and outer diameter10nm (approx.). Since catalyst is not used in this process there is no need for a heavy acidic purification. So, MWNTs can be formed with a less number of defects. Different methods used to synthesize are,

a) Synthesis in Liquid Nitrogen[11]

MWNTs are formed by generating arc-discharge in liquid nitrogen. For which low pressure and expensive inert gas are not needed. Yield is about 70% of reaction product.

b) Magnetic Field Synthesis[12]

MWNTs formed by this method are defect free and having high purity. In this arc- discharge is controlled by a magnetic field around the arc plasma. Extremely pure graphite rods (purity > 99.999 %) are used as electrodes. Highly pure MWNTs (purity > 95 %) are obtained without further purification, which disorders walls of MWNTs.

c) Plasma Rotating Arc Discharge[13]

The centrifugal force caused by the rotation generates turbulence and accelerates the carbon vapor perpendicular to the anode and the rotation distributes the micro discharges uniformly and generates stable plasma. Consequently, it increases the plasma volume and raises the plasma temperature. At the rotation speed of 5000 rpm, a yield of 60 % was found at a temperature 1025 °c without the use of a catalyst. The yield can be increased up to 90% after purification if the rotation speed is increased and the temperature is enlarged.

B. Laser Ablation Method[13]

The equipment used for this method is as shown in FIG 3. A pulsed or continuous laser is used which will vaporize a graphite target in an oven at 1200 °c. The oven is filled with helium or argon gas in order to keep the pressure at 500 torr. Since the optimum background gas and catalyst mixture is the same as in the arc discharge process, this method is almost similar to arc discharge. This method is very expensive so it is mainly used for SWNTs. Laser vaporization results in higher yield of SWNTs with narrower size distribution than those produced in arc discharge process. Catalyst used for SWNTs is Ni: Y (4.2: 1 at %).

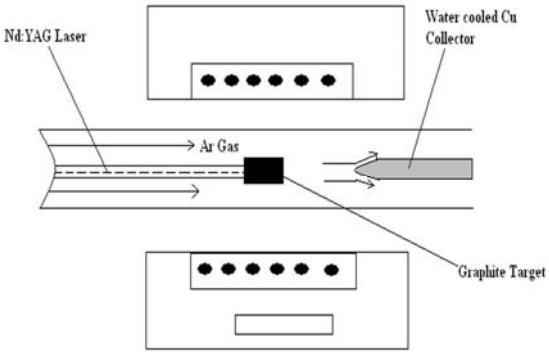

FIG. 3. LASER ABLATION METHOD

Different methods used to synthesize are,

a) Ultra Fast Pulses from a Free Electron Laser (FEL) Method:

In this method the pulse width is ~ 400 fs. The repetition rate of the pulse is increased from 10 Hz to 75 MHz. The intensity of the laser bundle is ~5 x 10^{11} w/cm^2. A jet of preheated argon gas is located near the rotating graphite target. In that argon gas deflects the ablation 90^0 away from incident beam direction, clearing carbon soot from front of target. If this system is upgraded with full power a yield of 45gm/ hr can be achieved. Catalyst used is Ni, Co or Ni, Y.

b)Continuous Wave Laser-Powder Method

In this method, CO_2 laser is used in an argon stream. Laser ablation of mixture of graphite and catalyst powder is carried

out, due to which thermal conductivity losses are significantly reduced. The catalyst used is Ni: Co (1:1) and yield is 5 gm/hr.

MWNTs can be also produced with pure graphite.

C. Chemical Vapors Deposition Method[14-15]

It is carried out in two step process:-

- Catalyst is deposited on substrate and then nucleation of catalyst is carried via chemical etching or thermal annealing. Ammonia is used as an etchant. Metal catalysts used are Ni, Fe or Co.
- Carbon source is then placed in gas phase in reaction chamber. Then carbon molecule is converted to atomic level by using energy source like plasma or heated coil. This carbon will get diffused towards substrate, which is coated with catalyst and nanotubes grow over this metal catalyst. Carbon source used is methane, carbon monoxide or acetylene. Temperature used for synthesis of nanotube is 650 – 900^0 C range. The typical yield is 30%.

D. Flame Synthesis Method:

SWNTs are formed in controlled flame environment from hydrocarbon fuels and small aerosol metal catalyst[15-16]. Single-walled nanotubes have been observed in the post-flame region of a premixed acetylene/oxygen/argon flame operated at 50 Torr (6.7 kPa) with iron pentacarbonyl vapor used as a source of metallic catalyst. Between 40 and 70 mm heights above burner (~30 milliseconds), nanotubes are observed to form and coalesce into clusters[17].

E. Silane Solution Method:

Carbon nanotubes were produced using a silane solution method, in which a substrate such as carbon paper or stainless steel mesh was immersed in a silane solution of a metal catalyst, preferably Co: Ni in a 1:1 ratio; and a feedstock gas containing a carbon source such as ethylene was fed through the substrate and the catalyst deposited thereon while the substrate was heated by applying an electrical current thereto. Thus, a reaction occurs between the catalyst and the gas to yield CNTs supported on the conductive substrate[18].

PURIFICATION OF CNTs[19]

Nanotubes usually contain a large amount of impurities such as metal particles, amorphous carbon, and multishell. There are different steps in purification of nanotubes.

1) Air Oxidation:

The carbon nanotubes are having less purity; the average purity is about 5-10%. So purification is needed before attachment of drugs onto CNTs. Air oxidation is useful in reducing the amount of amorphous carbon and metal catalyst particles (Ni, Y). Optimal oxidation condition is found to be at 673 k for 40 min.

2) Acid Refluxing

Refluxing the sample in strong acid is effective in reducing the amount of metal particles and amorphous carbon. Different acids used were hydrochloric acid (HCl), nitric acid (HNO_3) and sulphuric acid (H_2SO_4), but HCl was identified to be the ideal refluxing acid.

3) Surfactant aided sonication, filtration and annealing

After acid refluxing, the CNTs were purer but, tubes were entangled together, trapping most of the impurities, such as carbon particles and catalyst particles, which were difficult to remove with filtration. So surfactant-aided sonication was carried out. Sodium dodecyl benzene

sulphonate (SDBS) aided sonication with ethanol (or methanol) as organic solvent were preferred because it took the longest time for CNTs to settle down, indicating an even suspension state was achieved. The sample was then filtered with an ultra filtration unit and annealed at 1273 k in N_2 for 4 h. Annealing is effective in optimizing the CNT structures. It was proved the surfactant-aided sonication is effective to untangle CNTs, thus to free the particulate impurities embedded in the entanglement. Nanotube can also be purified by multi-step purification method.

CHARACTERISATION AND PROPERTIES OF CNTs[20]

- RAMAN Spectroscopy suitable for the quick and reliable screening of the presence of SWCNT
- Transmission electron microscopy allowing for the assessment of detailed structures.
- Scanning electron microscopy providing overviews of sample structures while less sensitive to sample preparation and homogeneity than TEM.
- Thermogravimetric analysis giving information about relative abundance of catalyst particles, nanotubes and other carbonaceous structures.

CNTs have very interesting physicochemical properties such as ordered structure with high aspect ratio, ultralight weight, high mechanical strength, high electrical conductivity, high thermal conductivity, metallic or semi-metallic behaviour and high surface area[1].

FUNCTIONALISATION OF CNTs

For biological and biomedical applications, the lack of solubility of carbon nanotubes in aqueous media has been a major technical barrier. To overcome this problem the modification of the surface of CNT i.e. functionalisation is done[21]. With different molecules it is achieved by adsorption, electrostatic interaction or covalent bonding of different molecules and chemistries that render them more hydrophilic. Through such modifications, the water solubility of CNT is improved and their biocompatibility profile is completely transformed. Moreover, the bundling/aggregation of individual tubes through vander Waals forces are also reduced by the functionalisation of their surface[22].

The recent expansion in methods to chemically modify and functionalize carbon nanotubes has made it possible to solubilize and disperse carbon nanotubes in water, thus opening the path for their facile manipulation and processing in physiological environments. Equally important is the recent demonstration that biological and bioactive species such as proteins, carbohydrates, and nucleic acids can be conjugated with carbon nanotubes.

These nanotube bioconjugates will play a significant role in the research effort toward bioapplications of carbon nanotubes. One focal point has been the development of nanoscale bioelectronics systems based on carbon nanotubes, which has been driven by the experimental evidence that biological species such as proteins and DNA can be immobilized either with the hollow cavity of or on the surface of carbon nanotubes[21].

Concerning the intrinsic toxicity of CNT, in vitro studies had indicated that SWNT functionalised by a covalent method with phenyl-SO_3H or phenyl-$(COOH)_2$ groups produced less cytotoxic effects than aqueous dispersions of pristine SWNT stabilised with a surfactant— 1% of Pluronic F108 . Moreover, in the same study, the cytotoxicity of covalently modified SWNT has been reported to be further decreased with the increase in the degree of sidewall fictionalization[23].

PHARMACOLOGY OF CNTs

The biodistribution and pharmacokinetics of nanoparticles rely to a large extent on their physicochemical characteristics such as size, shape, aggregation, chemical composition, surface functionalisation and solubility [24-25]. Two studies have been reported so far concerning the biodistribution of CNT. Both studies were performed with water-soluble CNT, which are biocompatible with the body fluids. None of the studies report toxic side effects or mortality.

Wang et al.[26] have used ^{125}Iodine-labeled multiple hydroxylated SWNT (^{125}I-SWNT-OH), functionalized by oxidation of the nanotubes, and radiotraced their distribution in mice after administration by, primarily, intraperitoneal (i.p.) administration. Other routes of administration were compared to i.p. such as subcutaneous, oral (by stomach intubation) and intravenous. This study reported that the CNT biodistribution was not significantly influenced by the administration route and that the ^{125}I-SWNT-OH distribute quickly throughout the whole body. The preferred organs for accumulation were the stomach, kidneys and bone. Most importantly from the safety point of view, 94% of the nanotubes were excreted into the urine and 6% in the feces as observed in this study. No tissue damage or distress was reported.

Second study, focusing on the intravenous route of administration and using functionalised SWNT and MWNT following a different surface chemistry (i.e. via the 1, 3-dipolar cycloaddition reaction) compared to the SWNT used in the study by Wang et al., was performed[27]. The CNT were functionalised with the chelating molecule diethylene triaminepentaacetate (DTPA) and radiolabeled with ^{111}Indium ([^{111}In] DTPA-CNT). In this study, the effect on biodistribution and blood circulation half-lives of different degrees of surface functionalisation with DTPA was also studied, using 100% and 60% surface functionalisation with DTPA (the remaining 40% functional group were amino functions). The biodistribution profiles obtained were found very similar for both types of functionalised [^{111}In] DTPA-SWNT which showed an affinity for kidneys, muscle, skin, bone and blood 30 min after administration. However, all types of nanotubes were found to be rapidly cleared from all tissues and a maximum blood circulation half-life of 3.5 h was determined. The excretion of DTPACNT, both SWNT and MWNT functionalised with 100% DTPA were found to be excreted through the renal route into the bladder and urine following intravenous administration. Moreover, both types of DTPA-CNT were observed intact in the excreted urine by transmission electron microscopy.

TOXICITY OF CNTs

Generally, the harmful effects of nanoparticles arise from the combination of various factors, two of which are particularly important: (a) the high surface area and (b) the intrinsic toxicity of the surface[24]. In contrast with conventional particles of larger mean diameter, nanoparticles under 100 nm can potentially be more toxic to the lung (portal of entry), can redistribute from their site of deposition, can escape from the normal phagocytic defences and can modify the structure of proteins. Therefore, nanoparticles can activate inflammatory and immunological responses and may affect the normal tissue function[28]. CNT, in the context of toxicology, can be classified as ‘nanoparticles’ due to their nanoscale dimensions, therefore unexpected toxicological effects upon contact with biological systems may be induced. The nanometer-scale dimensions of CNT make quantities of milligrams possess a large number of cylindrical, fibre-like particles, with a concurrent very high total surface area. This total surface area will also

depend on their degree of bundling and aggregation of nanotubes in solution[22].

The intrinsic toxicity of CNT depends on the degree of surface functionalisation and the different toxicity of functional groups. Batches of pristine CNT (non-purified and/or non-functionalised) readily after synthesis contain impurities such as amorphous carbon and metallic nanoparticles (catalysts: Co, Fe, Ni and Mo), which can also be the source of severe toxic effects[22]. Donaldson et al.[29] have shown that the structural characteristics of nanomaterials, such as the fibre shape, the length and the aggregation status of the CNT, can also influence their local deposition in the lungs and the immunological response following exposure to CNT.

Another important factor is the bioavailability of CNT in the body. The mechanism of CNT metabolism, degradation or dissolution, clearance and bioaccumulation requires attention and study in order to obtain a clearer idea of the limitations of such nanomaterials as components of pharmaceuticals. So far the vast majority of reports published on the administration of CNT are primarily concerned with the toxicology of CNT, addressing the possible negative side-effects of this nanomaterial on human health and environment, and particularly from the point of view of public health and safety for CNT production plant workers. As large-scale manufacturing gradually becomes routine for the production of CNT, handling and exposure (dermal and pulmonary) of workers to CNT brings exposure-risk issues to the surface[22].

Maynard et al.[30] have studied the release of particles from unrefined SWNT material into the air and the potential routes of exposure of the workers in a small-scale production facility. They have found that handling of unrefined material produces airborne particle concentrations of 53 μg/m^3 and glove deposits of 0.2–6 mg per hand.

APPLICATIONS OF CNTs

Various applications of CNTs are as follows:

1) Carrier for Drug delivery**:** Carbon nanohorns (CNHs) are the spherical aggregates of CNTs with irregular horn like shape. Research studies have proved CNTs and CNHs as a potential carrier for drug delivery system.
2) Functionalised carbon nanotubes are reported for targeting of Amphotericin B to Cells[31].
3) Cisplatin incorporated oxidized SWNHs have showed slow release of Cisplatin in aqueous environment. The released Cisplatin had been effective in terminating the growth of human lung cancer cells, while the SWNHs alone did not show anticancer activity[32].
4) Anticancer drug Polyphosphazene platinum given with nanotubes had enhanced permeability, distribution and retention in the brain due to controlled lipophilicity of nanotubes[33].
5) Antibiotic, Doxorubicin given with nanotubes is reported for enhanced intracellular penetration[33].
6) The gelatin CNT mixture (hydro-gel) has been used as potential carrier system for biomedicals.
7) CNT-based carrier system can offer a successful oral alternative administration of Erythropoietin (EPO), which has not been possible so far because of the denaturation of EPO by the gastric environment conditions and enzymes[33].
8) They can be used as lubricants or glidants in tablet manufacturing due to nanosize and sliding nature of graphite layers bound with van der waals forces[33].

2. Genetic Engineering

In genetic engineering, CNTs and CNHs are used to manipulate genes and

atoms in the development of bioimaging genomes, proteomics and tissue engineering[33]. The unwound DNA (single stranded) winds around SWNT by connecting its specific neucleotides and causes change in its electrostatic property. This creates its potential application in diagnostics (polymerase chain reaction) and in therapeutics. Wrapping of carbon nanotubes by single-stranded DNA was found to be sequence-dependent, and hence can be used in DNA analysis. Nanotubes due to their unique cylindrical structure and properties are used as carrier for genes (gene therapy) to treat cancer and genetic disorders. Their tubular nature has proved them as a vector in gene therapy. Nanotubes complexed with DNA were found to release DNA before it was destroyed by cells defense system, boosting transfection significantly. Nanostructures have showed antiviral effect in respiratory syncytical virus (RSV), a virus with severe bronchitis and asthma[34]. The treatment is generally done by combining nanoparticles and gene slicing technologies. Here RNA fragments capable of inhibiting a protein (which is needed for virus multiplication) is encapsulated within nanotubes and administered in the form of nasal sprays or drops. The promising results have been noted inhibiting further growth of virus[34]. Nanotubes are reported for helical crystallisation of proteins and growth of embryonic rat brain neurons. Streptavidin protein is successfully immobilized on CNT via 1-pyrene butanoic acid and succinimidyl ester[32]. Nanotubes and nanohorns can adhere various antigens on their surface, hence act as source of antigen in vaccines. Hence, by use of nanotubes, use of dead bacteria as source for antigen which is sometimes dangerous can be avoided.

3. Biomedical applications

Bianco et al. [35] have prepared soluble CNTs and have covalently linked biologically active peptides with them. This was demonstrated for viral protein VP1 of foot mouth disease virus (FMDV) showing immunogenicity and eliciting antibody response. In chemotherapy, drug embedded nanotubes attack directly on viral ulcers and kills viruses. No antibodies were produced against the CNT backbone alone, suggesting that the nanotubes do not possess intrinsic immunogenicity. Combination of all the described features of the vaccine system with the fact that the capacities of the anti-peptide antibodies to neutralize FMDV have been enhanced has indicated that CNT can have a valuable role in the construction of novel and effective vaccines[34].

In vitro studies by Kam et al.[36] showed selective cancer cell killing obtained by hyperthermia due to the thermal conductivity of CNT internalised into those cells. The work developed regarding the use of CNT as gene therapy vectors have shown that these engineered structures can effectively transport the genes and drugs inside mammalian cells. The CNT-transported genetic material has conserved the ability to express proteins[33].

4. Artificial implants

Normally body shows rejection reaction for implants with the post-administration pain[35]. But, miniature sized nanotubes and nanohorns get attached with other proteins and amino acids avoiding rejection. Also, they can be used as implants in the form of artificial joints without host rejection reaction. Moreover, due to their high tensile strength, carbon nanotubes filled with calcium and arranged/grouped in the structure of bone can act as bone substitute[37].

5. Preservative

Carbon nanotubes and nanohorns are antioxidant in nature. Hence, they are used to preserve drugs formulations prone to oxidation. Their antioxidant property is used in antiaging cosmetics and with zinc oxide as sunscreen dermatological to

prevent oxidation of important skin components[33].

6. Diagnostic tool

Protein-encapsulated or protein/enzyme filled nanotubes, due to their fluorescence ability in presence of specific biomolecules have been tried as implantable biosensors[37]. Even, nanocapsules filled with magnetic materials, radioisotope enzymes can be used as biosensors[38]. Nanosize robots and motors with nanotubes can be used in studying cells and biological systems[38].

7. As catalyst

Nanohorns offer large surface area and hence, the catalyst at molecular level can be incorporated into nanotubes in large amount and simultaneously can be released in required rate at particular time. Hence, reduction in the frequency and amount of catalyst addition can be achieved by using CNTs and CNHs[38].

LIMITATATIONS OF CNTs[22]

- Lack of solubility in most solvents compatible with the biological milieu (aqueous based).
- The production of structurally and chemically reproducible batches of CNTs with identical characteristics.
- Difficulty in maintaining high quality and minimal impurities.

CONCLUSION:

With the prospect of gene therapy, cancer treatments, and innovative new answers for life-threatening diseases on the horizon, the science of nanomedicine has become an ever-growing field that has an incredible ability to bypass barriers. The properties and characteristics of CNTs are still being researched heavily and scientists have barely begun to tap the potential of these structures. Single and multiple-walled carbon nanotubes have already proven to serve as safer and more effective alternatives to previous drug delivery methods. They can pass through membranes, carrying therapeutic drugs, vaccines, and nucleic acids deep into the cell to targets previously unreachable. They also serve as ideal non-toxic vehicles which, in some cases, increase the solubility of the drug attached, resulting in greater efficacy and safety. Overall, recent studies regarding CNTs have shown a very promising glimpse of what lies ahead in the future of medicine.

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