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Compatibility of Carbon Nanotubes for Biomedical Applications: A Review

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Because of their intriguing physicochemical properties, including as their huge surface area, remarkable mechanical and thermal robustness, electro-chemical reactivity, and more, carbon nanotubes (CNTs) are thought to be particularly interesting nanomaterials. CNTs were created using a variety of techniques, like discharge of arc, vaporization of laser, vapor deposition of chemicals, and growth of vapour phase. Each approach has advantages as well as disadvantages. The physical and chemical behaviour of manufactured carbon nanotubes were affected by the procedures used in the synthesis process. This review paper provides a succinct summary of the standard methods used for CNTs and their application in medication administration for the treatment of cancer. The recent developments with great promise as biomaterials for the domains of biotechnology and agriculture are also the main topic of this review study.

Keywords: Carbon Treatment; Carbon Nanotubes; Characterization; Drug Delivery; Synthesis.

Nanotechnology is the main field for all professions and is essential to the advancement of new inventions. A technique for producing intricate structures, like those utilized in tissue engineering, is provided by nanotechnology[1]. The main appeal in nanotechnology, especially for its industrial applications and implementations, is carbon nanotubes (CNTs). Depending on the number of layers present, the CNTs were divided into single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs).

They are highly regarded for their attractive properties[2], such as mechanical[3], electrical[4], and thermal features[5], which make them suitable for a variety of applications across different sectors. The SWCNTs are composed of a single layer of graphene (diameter range: 0.4 to 2 nm), while the MWCNTs are composed of multiple layers of graphene (outer diameter ranges from 2 to 100 nm and inner diameter ranges from 1 to 3 nm). Because a high aspect ratio is required, carbon nanotubes (CNTs) are ideal for energy applications[6] and biological applications[7]. Initially, the majority of CNT research was conducted on electronic devices[8,9], screens[10], transistors[11], and other applications that took advantage of this nanomaterial's electrical characteristics. However, CNTs are generally thought to be the ideal material for a variety of uses, starting with biomedical applications[12].

Nanoparticles smaller than 100 nm have great properties, that brings new applications in a variety of industries. Because nanoparticles have unique optical or electrical characteristics that

allow for greater control over bodily functions, as well as applications as bio-catalysts and drug delivery, their usage in bioengineering applications offers substantial advantages. Numerous studies demonstrate how crucial CNTs are for encouraging bone development by enhancing the mechanical properties of polymers[13,14]. The majority of current research on the use of CNTs, graphene, and fullerene as biomaterials in biological applications focuses on developing a technique for long-term interactions with live tissues and cells. However, research has shown that interactions between cells and CNTs may have negative consequences, potentially endangering human health[15]. This review paper provides a succinct summary of the synthesis and use of carbon nanotubes (CNTs) in biomedical applications, particularly medication delivery for the treatment of cancer. This review also discusses the different characterisation strategies.

MATERIALS AND METHODS

Preparation of carbon nanotubes

Multiple methods were existed for preparations both CNTs using various carbon sources. Every method possesses its own merits and drawbacks. In this section, various methods used for the synthesis of CNTs were discussed.

Arc-discharge process

The CNTs were created by using an arc-discharge technique. The evaporation of graphite metal is a part of their process, and they use the following sequential technique[16]. A graphite rod of is 8.2 ϕ mm, length of 140 mm over 3.2 mm drilled channel that was filled with catalyst made up the anode. A 25 mm long and 10 mm diameter graphite rod served as the cathode. Ni, Co, and Fe metals (sizes ranging from 2 to 5 ìm) were ground with an elemental S in a mortar to create the catalyst, which was then heated for one hour at 500 °C in an inert gas atmosphere. After being further ground into micron-sized particles in a ball mill, the conglomerate was well combined with carbon powder. This combination is packed tightly in a 3.2-mm tube that was dug in graphite anode. The composite anode's atomic percentages of Ni 2.6, Co 0.7, Fe 1.45, and S 0.75 were its elements in respect to carbon.

The arc-discharge method consists of PREP and an anode spinning at a speed of 5000 rev/min[17]. 12 mm and 15 mm graphite anode, and cathode were used to create the carbon plasma. With a voltage of about 20 to 30 V, the change of current was varied from 80 to 120 A. A 3 mm inter-electrode spacing was maintained. In a traditional arc-discharge, the carbon vaporized at an anode was deposited on the cathode surface, but for PREP method. Chamber pressure was used to be 500 Torr and an inert helium gas rate of 5 lit/min. Consequently, PREP makes it easier to continue synthesizing CNTs. By varying speed of separation between the amount and yield of CNTs were controlled. Heating the CNTs in an atmosphere at 700 °C was used to purify them.

In order to create the CNTs, the arc-discharge approach involved placing two graphite electrodes vertically with a 1-2 mm space between them[18]. After that, a rarefied ambient gas is introduced and the chamber is emptied using a diffusion pump. When a direct current discharge is applied between the two graphite rods, the anode is exhausted, which causes CNTs to develop in the chamber soot. This method, which used an anode, and cathode prepared of 99.999% of graphite[19]. In one experiment, a diameter of 6 mm, and length of 80 mm rod type carbon anode was used in conjunction with a cube type carbon cathode that was 40 mm long, 40 mm high, and 10 mm thick. By advancing the depleted anode 0.5-2 mm spacing over graphite electrodes is manually adjusted. Arc-plasma was created using voltages between 18 and 30 V and currents between 40 and 80 A. With a constant supply of dry air, the chamber pressure was methodically increased from 100 Torr to 760 Torr in steps of 100 Torr. A cold-water line was used to cool the carbon cathode and apparatus. Products were collected from the top cold-water line, the soot flakes around the cathode, and the canter region of the carbon cathode, among other places within the device.

The CNTs were synthesized using an arc-discharge technique, and it contains 3× 70 mm hole was drilled in 6× 300 mm spectrally graphite, and the rod is filled with a 1:1 ratio of graphite, and Y-Ni alloy to prepare them[20]. To reduce the build-up of cathode deposits, cathode was 10 mm graphite over pointed end pointing in direction of the anode. Helium environment with a pressure between 100 and 700 Torr, the arc was created with a current

between 40 and 100 A. By continuously translating the anode during discharge distance through two electrodes were prepared at roughly 5 mm, soot on inside wall of chamber was collected after an arc discharge.

The SWCNTs were created by using the direct current arc-discharge method[21]. With 6×150 mm² graphite rod and 4×100 mm² drilled hole, the anode was filled with a powdered mixture of graphite and Y–Ni alloy (or CaC_2/Ni) while keeping the metal/C atomic ratio between 3 and 10. In a static helium atmosphere of 500 or 700 torr, an arc was created at about 40 A between the anode and a sharp-tipped graphite cathode. Throughout the arc operation, the anode was continuously adjusted to maintain the electrode gap separation at roughly 10 mm. 5 g of soot was typically produced in 2 hours using a 10 cm anode rod. Direct fabrication of the composite rods using a mixture of graphite and catalyst powder might produce about 60 g of soot each day.

Laser vaporization

One technique used to turn a material into vapor using a laser is called laser vaporization. The laser vaporization apparatus for the synthesis of CNTs[22] contain the lateral surface of carbon rod placed inside 70 mm T-shaped tube was exposed to radiation from a Nd:YAG laser. When the target is completely exhausted, the system can run continually until its diameter is around 6 mm closer to the laser beams. In an environment of 0.5 bar Ar or Ar with 5% vol. of H_2, vaporization took place at an oven temperature of 1150 °C, flowing at about 80 sccm.

CNTs were created by using an electric tube furnace at temperatures below 1450 K[23]. Under 250 sccm, argon moves through a regulated environment under 500A, and 45 mm quartz tube with a water-cooled collector and pumping port at one end and a Brewster window and gas entry was used to generate Torr pressure. The Nd:YAG laser (Spectra-Physics Pro290-30) with nanosecond pulses operating at 1064 or 532 nm and 30 Hz, producing about 2 or 1 J/cm² each pulse, made up the laser vapour. The secondary laser, which is primarily a Nd:YAG laser (Spectra-Physics Tornado S240-TN50-106Q), is used as an excitation laser. It operates continuously at a frequency of 20 kHz, with wavelength of 1064 nm. Its average power outputs are 50 and 48 W, respectively.

To create SWCNTs laser-ablation approach was considered[24]. By employing a certain wavelength to strike graphite embedded with catalytic components like Ni and Co, this method produces energy. After transition metals were first combined with a catalyst to create graphite and then placed inside a reactor, the target's surface was exposed to laser radiation at 2000 °C while being protected by an inert atmosphere, which produced carbon nanotubes.

The laser method for used CNT production[25]. Their method uses a 24-inch-long, 2-inch-diameter quartz tube that is placed within a 12-inch-long hinged tube furnace that operates at 1000 °C. In order to maintain a pressure of 500 Torr, argon gas was fed close to this window and controlled at 100 sccm. A 1.6 mm, annular spot target was focused the ablation laser beam. The target received 140 mJ from simultaneous use of 1.06 μm and the 532 nm.

Chemical vapor deposition

By introducing chemical precursors into a reaction chamber, where they react to form a solid film on the surface, the process known as chemical vapor deposition (CVD) is used to deposit thin layers of materials onto a substrate. To synthesize CNTs using the CVD technique, a supporting catalyst is needed. When heat and plasma are applied, used gas breaks down and carbon nanotubes are created.

The Ar atmosphere with a temperature range of 500–850 °C and a flow velocity of 300 sccm were used to prepare the CNTs[26]. Carbon sources were added by either thermally breaking down solid hydrocarbons (naphthalene and anthracene) or passing 100 sccm of Ar through liquid hydrocarbons (hexane, cyclohexane, and benzene) in an evaporator kept at about 150 °C for 30 minutes. To get rid of the catalyst, the synthesized carbon soot was sonicated with 37% HCl and then water.

Using MgO (Vel) in an ethanol solution containing metal salts (Co, Ni, Fe) or a mixture of metal salts (Co-Fe) at the necessary concentration used the CVD technique to create CNT[27]. After an hour of sonication, the material is subjected to a rotary evaporator to remove the ethanol. After 12

to 15 hours of drying at 130 °C, the material is ground into a fine powder. Each catalyst's section was hydrogenated in H_2/N_2 (flow rates of 30 ml/min for H_2 and 80 ml/min for N_2).

Given that the vaporization temperatures of ferrocene and toluene are 175 °C and 110 °C, respectively, the furnace was warmed to around 200 °C in accordance with the method described to ensure the vaporization of the solution upon injection[28]. After that, the vapor was sent into the second stage furnace, where it formed aligned nanotube films from the nearby reaction tube (14 mm inner diameter) as well as flat quartz substrates. Using a motorized syringe pump, the injection feed rate was continuously maintained at 1.2 ml/h throughout all trials, with a total gas flow rate of 750 ml/min. Through the CVD method, Ni catalyst was placed and used in the reactor at 900 °C and without Ni at 546 °C , both in Ar atmosphere[29]. CVD technique to create CNTs. After the temperature stabilized, the airflow was stopped. At the same time, an ethylene flow of 10 Sccm was started. Argon was utilized as carrier gas, and about 50 mg of pyrene precursor in kept at 200 °C in the furnace.

The main use of hydrocarbon material for carbon root is described[30]. The carbon root is transformed into carbon agglomerates on the surfaces of the catalyst particles and then reassembled when it interacts with the carbon source gas in the quartz tube at the proper temperature. Findings show that the size of the metal-catalyst particles mostly determines the inner and outer diameters of CNTs. Transition metals, such as Fe, Co, Ni, molybdenum, niobium, and tantalum, are commonly used as catalysts.

Vapor phase deposition

The reaction produces carbon nanotubes (CNTs) depending on the reaction gasses. The size of the CNTs on the fragmented catalyst mostly determines their presence on the graphite surface, whereas the catalyst crystal face has a significant impact. According to[31], this method offers a lead in preparation of CNTs.

In methods explained by[32], the gas flow of C_2H_2 linked over H_2 is immediately released once the argon flow is stopped and the first furnace is turned on until 150 °C. Responses were made for the allotted amount of time. The Catalytic Chemical Vapour Deposition (CCVD) technique for CNT synthesis was explained[33]. The CNT synthesis process is demonstrated[34], who use hydrocarbon gas as the carbon source. A quartz tube is placed within a furnace that is heated by a radio frequency heater to high temperatures (500-900 °C). A tungsten-organic precursor and acetylene gas were used in a catalytic reaction[35] to deposit carbon nanotubes in the vapor phase. High-purity MWCNTs with an interior hollow structure made up the deposits.

RESULTS

XRD analysis

The CVD method was used by[36] to create the CNT. Tetraethoxysilane and nickel nitrate were used to create a binary solution, which was then stirred in ethanol for 24 hours at room temperature

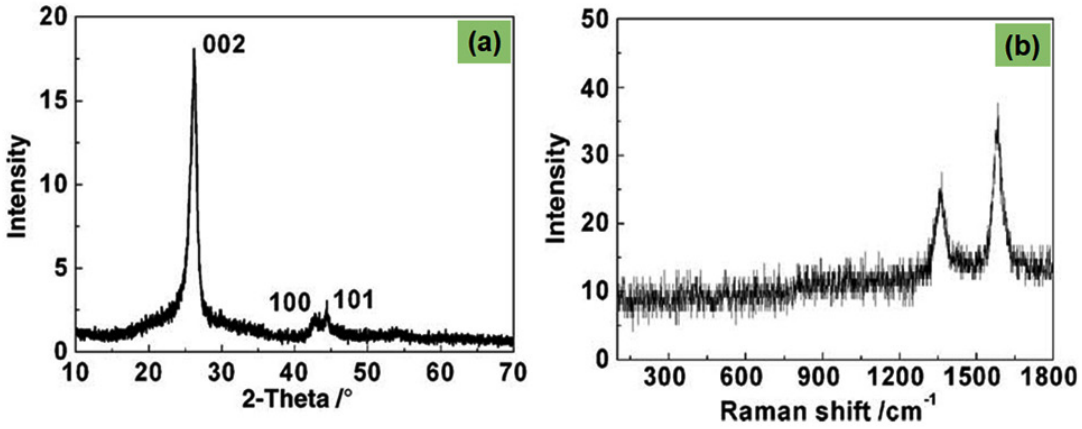

Fig. 1. XRD of CNT, and Raman spectra[36]

before being placed in an autoclave and heated for 30 min at 250 °C and 7.5 MPa of pressure. The solution was then cooled using nitrogen gasses, and the nickel-silica aerogel catalyst was observed. **Fig. 1(a)** provides an illustration of the CVD deposition process, which was carried out using a quartz tube that was controlled by gas flow. The sample's CNTs' XRD pattern is similar to that of highly oriented pyrolytic graphite (HOPG) [36]. At roughly 26°, the (002) peak emerged, suggesting an inter-planar spacing of 0.342 nm, which is marginally more than that of HOPG, which is roughly 0.336 nm. The cobalt as a catalyst in a catalytic CVD process to create CNTs[37]. For the

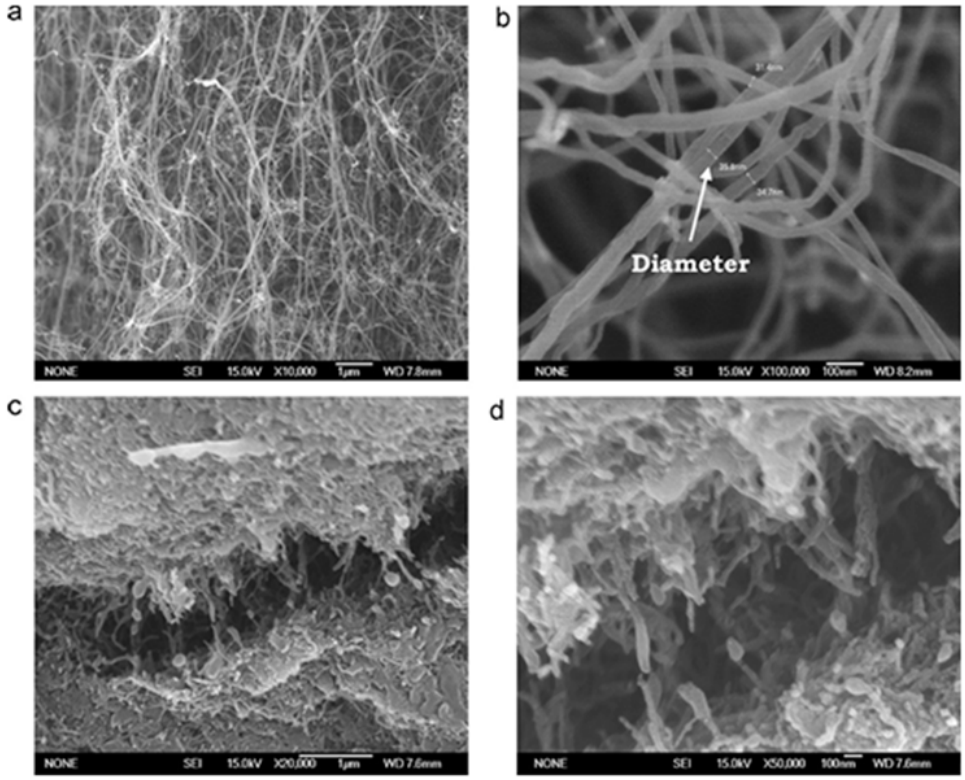

Fig. 2. SEM: (a, b) high magnification, and (c, d) low magnification[32]

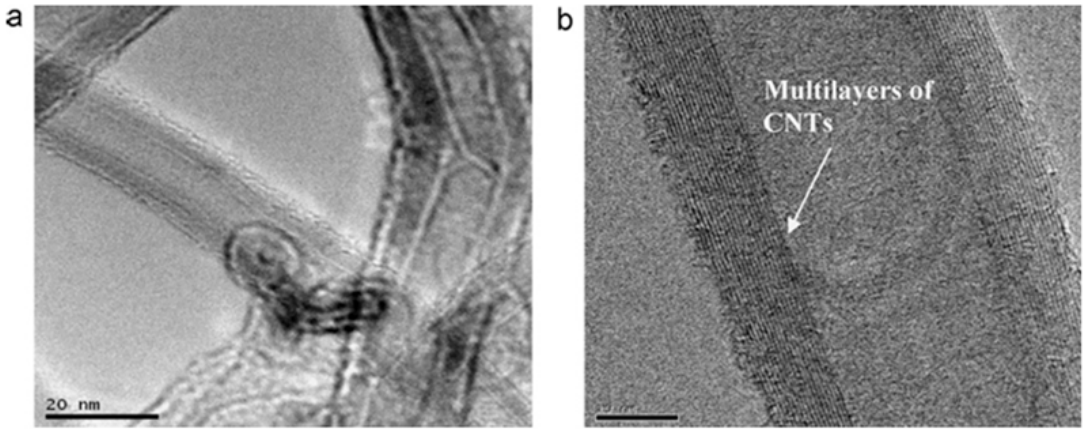

Fig. 3. TEM image: (a) SWCNT, and (b) MWCNT[32]

MWCNT synthesis, about 100 mg of catalyst was kept in tube inside reactor. After that, an Ar flow was used to heat the furnace to 800-1000 °C. Acetylene was then used to replace the Ar for 20-60 min at 100-500 ml/min flow rate. After that, the produced CNTs were annealed for one hour at 900 °C before being cooled.

Raman analysis

The Raman analysis by Zhang is shown in Fig. 1(b)[36]. The graphite E¬2g optical mode at 1582 cm{ ¹, which has been extensively studied in highly ordered pyrolytic graphite, was identified as a notable characteristic at 1580 cm{ ¹. In highly crystalline samples, the E2g intensity mode on graphitic is pronouncedly robust. In contrast, graphite and carbon that are not properly ordered showed a characteristic peak at around 1351 cm{ ¹. This suggests that the image may be the result of symmetry-lowering influence caused by fault or CNT caps, bending, and the presence of amorphous carbon.

The presentation of CNTs D and G band Raman spectra[38], it exhibits Sp^2. After analysing Raman frequency shift in CNT[39] discovered that it perfectly matched the typical Raman spectra. According to the Raman spectra, the D-band was found at 3.7 cm^{-1} and 1314 cm^{-1} [40], while G-band was found at 4.6 cm^{-1}, and 1603 cm^{-1} [41].

The G/D ratio, which[42] found to be 0.75, indicates a significant presence of CNT and provides several active sites for further functionalization. Raman spectra can be used to

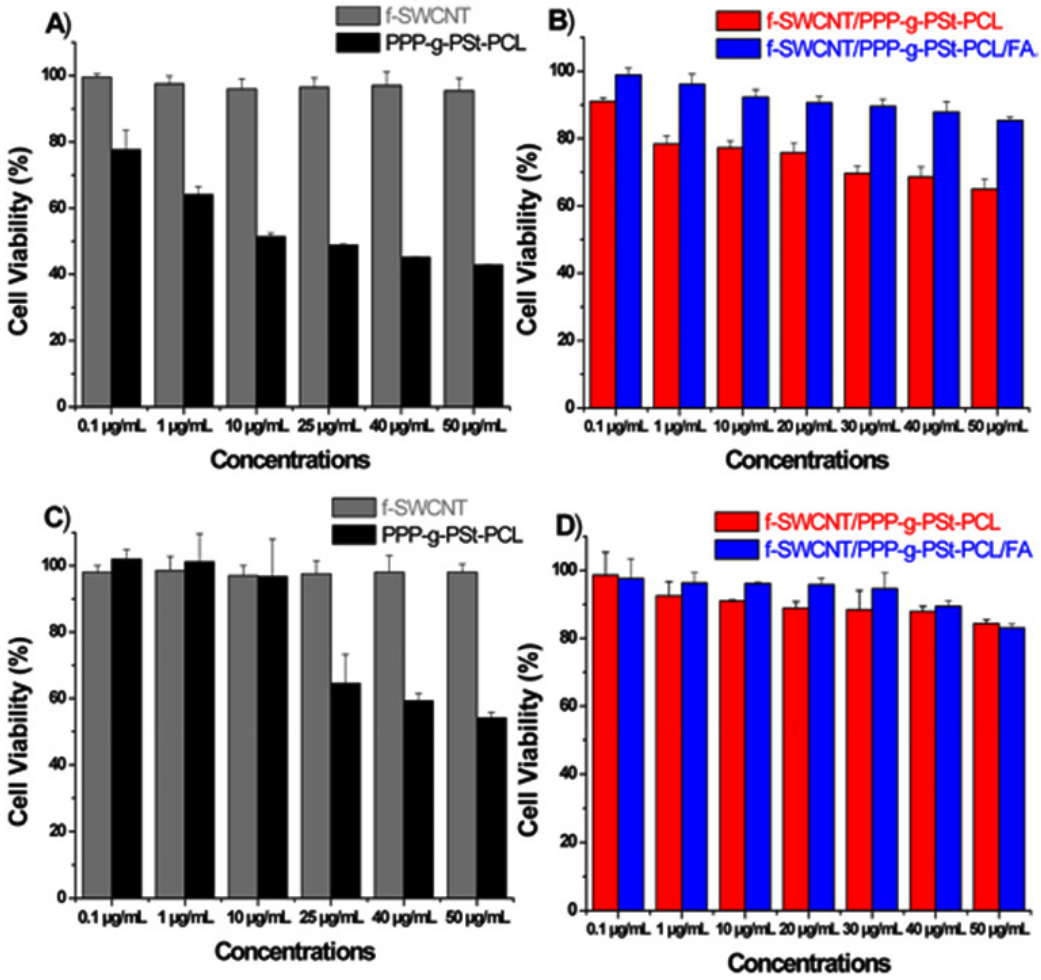

Fig. 4. (a-d): CNTs cytotoxic effects[45]

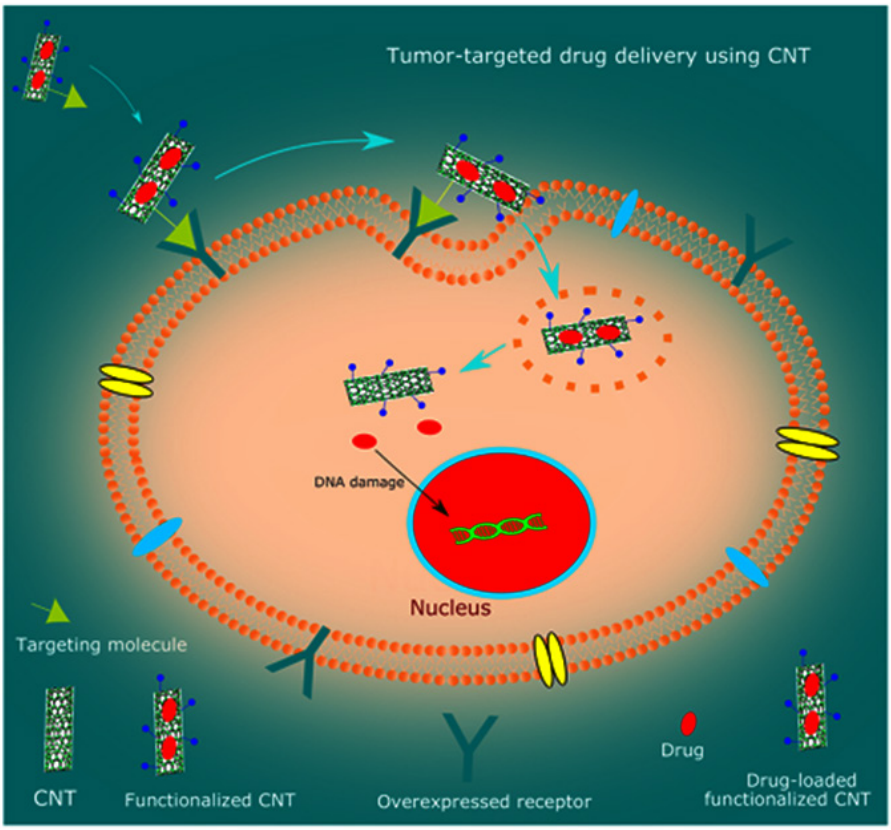

Fig. 5. CNT treated tumor cell CNT[70]

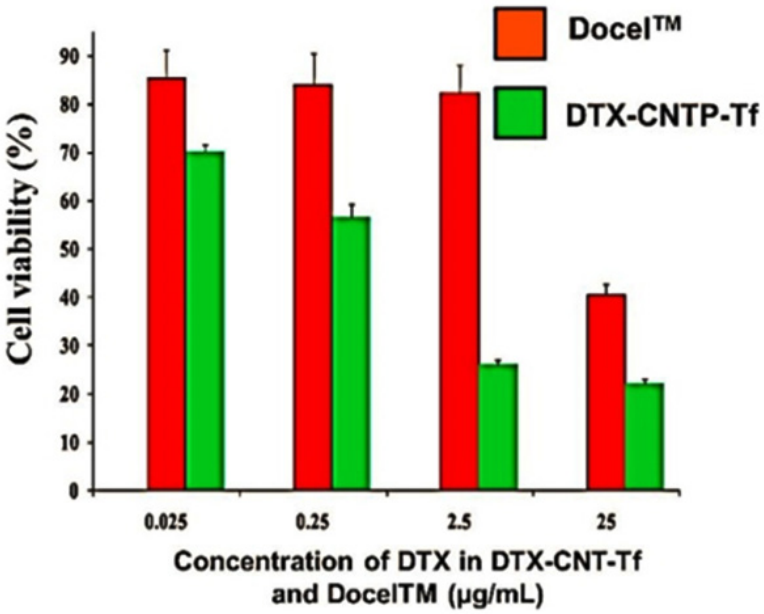

Fig. 6. DTX and DTX-CNTP-Tf study[73]

evaluate sample quality. Oxidized CNTs have a G/D ratio of 0.70.

According to[43] Raman research, CNTs were produced using the intensities of different D-band groups. Amorphous carbon was indicated by the generated CNTs' G-bands, which were observed at peaks of 1562 cm^{-1} and 1586 cm^{-1}, and D-bands, which were observed at a peak of 1343 cm{ [1]. The pure CNT G-band appeared at 1586 cm^{-1}, whereas the second order Raman bands were observed at maxima of 941 cm-1 and 1075 cm{ [1]. The formation of CNTs was also seen in the SEM. Pure CNTs' G-band was found at maxima of 1585 cm^{-1} and 1563 cm^{-1}, respectively. D-band gives the material is pure and free of amorphous carbon because of its much lower intensity and clear shape.

SEM analysis

The results of analysis of the CNT nanoparticles using a scanning electron microscope[32] (JEOL JSM 6700F) are shown in **Figs. 2(a-d).** These CNTs are non-functionalized at 1000 nm and 1000000 nm magnifications. With CNT diameters ranging from 31 to 36 nm, the vertical alignments were clearly visible. Some impurities, such as excess catalyst particles and amorphous carbon, are visible at low magnification.

TEM analysis

The transmissions electronic microscope (TEM) image[37]. CNTs have a diameter between 20 and 50 nm. According to the bamboo's shape, CNTs contains tube shape structure. It clearly showed the hollow cylindrical shape in the centre. An solitary carbon nanotube has a diameter of roughly 20 to 50 nm. The TEM image from[36] it shows the highest quality with a diameter of 40–60 nm. CNTs had very few metal catalyst particles bonded to them.

The TEM images of selected CNTs under optimal conditions are shown in Figs. 3(a-b)[32]. The TEM (JEOL JEM 2010) images with different resolutions were displayed. Graphitic sheets have distinct edges that are positioned at an approximate angle of 2° with respect to the tube axis and separated by 10 nm. The TEM image shows that CNTs produced at 850 °C have about 19 graphitic walls.

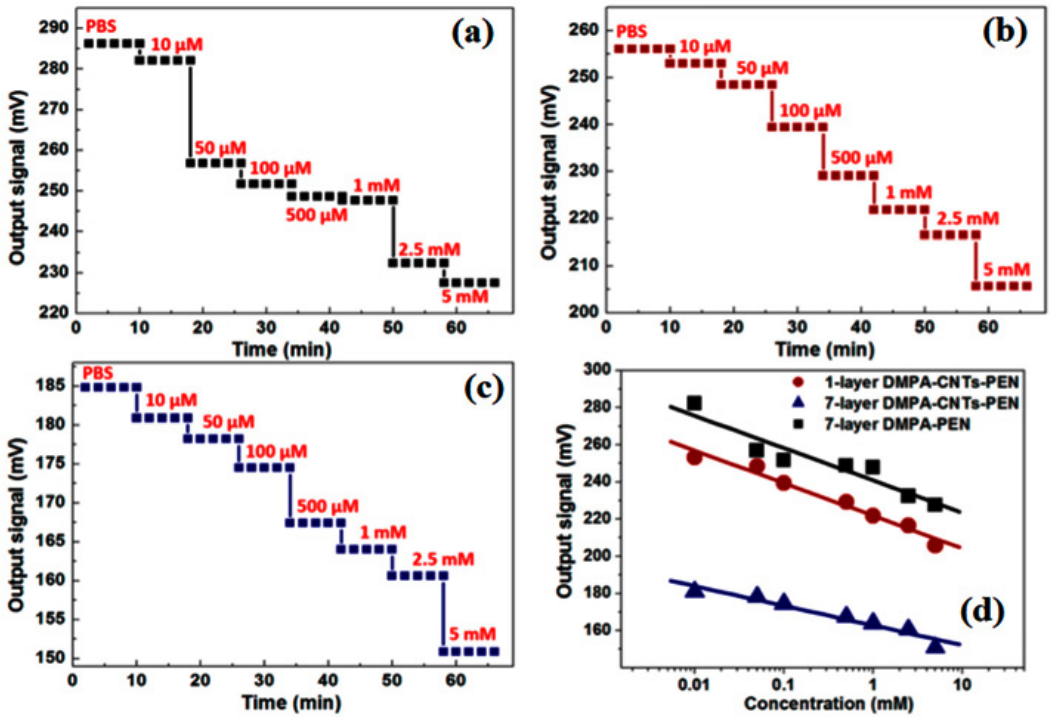

Fig. 7. (a-d): ConCap response curves[93]

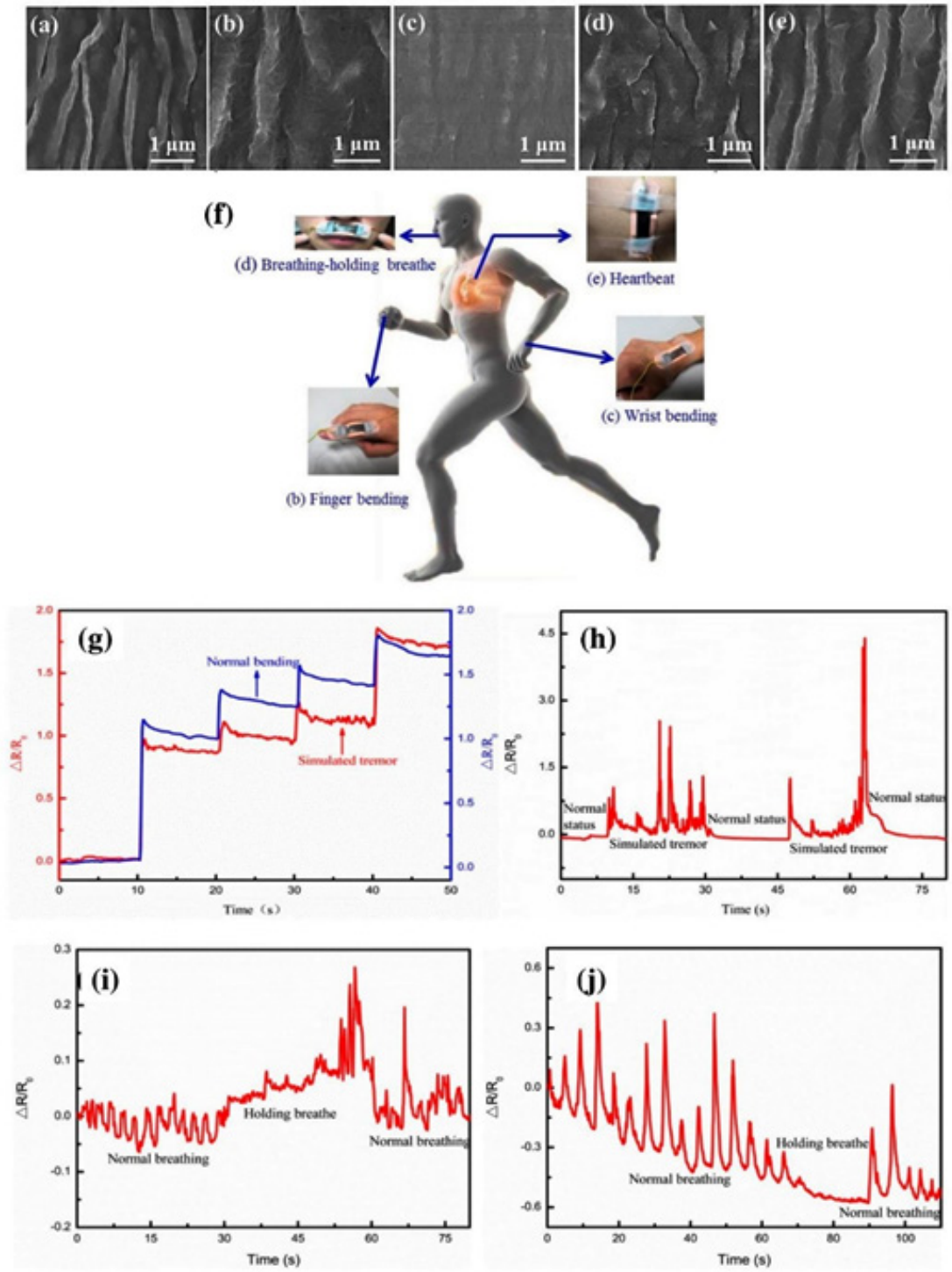

Fig. 8. (a-j): Ag-CNT-PDMS-based wearable sensors[95]

DISCUSSION

CNT for biomedical applications

Biomedical imaging

For accurate imaging of organs, tissues, and cells, this looks like a fantastic idea. The CNTs can be used to alter imaging functions, claim[44]. The MRI are the specialized techniques can apply. Moreover, an extra external magnetic field can be used to excite carbon nanotubes. The addition of more recent parts changes the whole characterizations of the CNT. Adding gold nanoparticles and quantum dots are two methods that can be used to increase image capacity. The levels of toxicity of the other elements must be periodically checked. This method of treating tumors appears to be promising. The creation of a fluorescent bioimaging probe enabled the bioimaging of HeLa cells that are unique to the folate receptor. According to[45], CNTs cytotoxic effects over A549 and HeLa cells are dose-dependent (Fig. 4a-d).

For fluorescent bioimaging probes, CNTs' NIR fluorescence is an excellent option. The CNTs are give them the ability to be imaged. Because of their special capacity to absorb more NIR light, CNTs[46]. Additionally, FL emerges crucial instrument in biological and scientific domains. The CNTs can be dissolved with the aid of PEGylated amphiphilic polymer. FL may use for kills the tumor cells[47].

The CNT electrodes made using the CNT method delivered MRI tests with reduced distortion pictures in comparison to other reference electrodes. Furthermore, the favorable electrochemical characteristics of this CNT electrode create new opportunities for deep brain stimulation and another cutting-edge MRI applications[48]. The Ag nanoparticles are superior to CNTs in applications including biomedical therapies. Ag nanoparticle integration allows for the incorporation of drugs such as doxorubicin into carbon nanotubes (CNTs).

Biomolecular detection

Lab-on-a-chip (LOC), which is constructed using protein-functionalized CNTs, is used to detect low-density lipoprotein (LDL). Carbon nanotubes, or CNTs, offer a variety of physical-mechanical properties that make them potentially useful in biomedicine for implanted devices and biomarkers. Carbon nanotubes (CNTs) have excellent mechanical and electrical properties that make them suitable for creating ultrasensitive light-sensitive coatings (LOCs) that employed for biomolecular inspection[49].

The observation for production of CNT/NiO solution persistence depends on the biomarker for cholesterol detection[50]. Higher surface expansion, better electromechanical properties, and a greater ability to degrade proteins, enzymes, RNA, antibodies, and other substances are all brought about by the presence of nickel oxide. The enhanced electrostatic potential produced by the nickel oxide is primarily responsible for antibody transmission interactions by CNTs, gives electrical pavement. The CNTs special qualities make them selective as well, requiring less energy and fewer samples.

Drug and gene delivery

CNTs are appropriate for biomedical applications due to their unique properties. CNTs are suitable for a variety of biological applications due to their hydrophobic nature[51]. According to[52] CNTs have multiple functional moieties. They connect with cell surface receptors and induce them to internalize. Targeted cell loading is made possible via receptor-mediated mechanisms. (a) Therapeutic applications, (b) Gene and drug delivery. CNTs have been utilized in the development of several medication for diseases. Because of their unique properties, such as their huge surface area, robust mechanical strength, and etc.[53].

However, CNTs increase the solubility of organic and aqueous environments by allowing medication omits to be delayed for a sufficient amount of time through amide and ester bonding[54]. Because MWCNTs interact with brain tissue cells, they can be useful in the development of efficient gene and drug delivery systems[55]. There is a greater chance that SWCNT will include drugs. Through endocytosis or passive diffusion, functionalized CNTs with drug encapsulation enter cells and internalize into the organelles and nucleus. Enzymatic breakdown and exocytosis methods by CNTs are destroyed from cells[56]. Curcumin, a naturally occurring anticancer drug, may be easily loaded into the novel cocoon-like nanoparticles constructed of MWCNTs and polyethylene glycol, which exhibit significant potential as nano-biomaterials[57].

Carbon nanotube based anticancer

drug delivery methods are popular and involve functionalization to enable selective targeting[58,59,60,61] . It is possible to lessen the toxicity and negative effects of CNTs since they are sensitive to the tumor microenvironment. According to[62], the use of a CNT-based technology is anticipated to reduces the drug intensity of Tumor cells. Furthermore, according[63], CNTs acts antigen immunization. Certain medications, such acetylcholine, are easy to transfer to the brain with SWCNT, which is not possible with traditional techniques[64].

According to a recent study, cisplatin, an anticancer drug, exhibits antileishmanial properties. The study highlighted the exceptional potential of CNTs as drug nanocarriers by demonstrating the cisplatin-bonded MWCNTs' decreased cytotoxicity and enhanced antileishmanial activity at very low concentrations[65]. Recently, CNT bucky sheets have demonstrated potential in the transdermal delivery of pharmaceuticals. The in vitro tests shown that CNT bucky sheets might control drug release[66]. Numerous chemical compounds are created between nucleic acids and carbon nanotubes as a result of their electrostatic interactions. Transporting nucleic acids into cells is one of the primary functions of CNTs[67]. The primary objective is for the plasmid DNA to ally with cells and enter the cell nucleus. such other non-viral transporters such liposomes for plasmid DNA applications[68,69].

Cancer therapy

Photothermal therapy based on carbon nanotubes can heal tumors. The nanosize facilitates enhanced drug loading capacity and easy tumor internalization. CNTs also protect drugs from enzymatic degradation. CNT-based tumor targeted delivery is shown in **Fig. 5**[70]. MWCNTs are more cytotoxic than the free docetaxel seen in **Fig. 6** when loaded with anticancer docetaxel (DTX) and combined with the targeted chemical transferrin (Tf)[71]. Some chemotherapeutic medications reduce DNA activity, impede DNA replication, and slow the growth of cancer cells[72]. When an anti-neoplastic drug is added to the MWCNT, larger diameter CNTs are more effective than smaller diameter CNTs[73]. The functionalization of the carbon nanotubes significantly increases the loading efficiency of the tube. After carboxylation, CNTs exhibit enhanced hydrogen bond conjugation. The stability and capture capacity of these carboxylated MWCNTs are improved[74].

MWCNTs coated with PEG and hyaluronic acid have been shown to release gemcitabine (GEM) over an extended period of time, indicating that GEM is a powerful tool for targeting colon cancer[75,76].

The usage of hybrid nanocomposites based on carbon nanotubes has shown beneficial in the treatment of cancer. Because of its improved biocompatibility, smaller arrangement, and stronger surface reactivity, CNT is a more effective drug delivery method. Oxidized MWCNTs interact with iron and folic acid nanoparticles to form a double-targeted drug delivery system that targets cancer with external field[77]. In future, pancreatic cancer may be treated with MWNTs that have a remarkable photothermal conversion efficiency and are less cytotoxic and biostable[78].

Biosensors

Biosensor containing solution by using the properties of the molecules reacting with a certain chemical. Because of their strong physicochemical potential, CNMs are an ideal material for applications involving pathogen detection and sensing[79,80]. Compared to commercially available sensors, CNT-based biosensors offer several advantages, such as enhanced luminescence, quick reaction times, and great stability[81].

The 1-D features of CNTs allow for the sensible detection of analyte since even minor atom swaps in the chemical environment have a significant impact on electrical or optical characteristics[82]. This feature is crucial for keeping an eye on the optical sensor in a range of scenarios[83]. Because of their superior surface area, volume ratio, high conductivity, and electro-catalysis, electrochemical biosensors are the most commonly employed type[84]. An electron transfer occurred in these biosensors[85,86,87]. CNTs may improve immobilization of bio-receptors[88].

To monitor the species and contaminants in the medium, a variety of sensor types are being researched. Chemical and aromatic chemicals, as well as halogenated pesticides, are among the materials that biosensors are used to detect. The solid-state electrochemical sensors are more advantageous in terms of sensitivity, and low energy usage. Concept of biosensor is to analyse relative function beneficial and detrimental microorganisms in soil by utilizing respiration-related variations in oxygen consumption. The surface plasmon

resonance (SPR) technique was studied to develop a biosensor with metallic nanoparticles[89]. Rapid research is being done on nano-biosensors in the agricultural and food processing sectors. CNT may detect the variety of chemicals, such as proteins and dangerous compounds[90,91,92].

Reaction time was significantly decreased by MWCNT-coated electrodes used as a sensor[93]. It has been demonstrated that the Au-MWCNTs nanocomposite has better detection limits and can identify concentrations as low as 0.1 nM[94]. While CNTs can be used to immobilize enzymes, enzymes are suitable substrates for the creation of biosensors. Scholl and associates developed the thin coating of carbon nanotubes (CNTs) to enhance the enzymatic activity of penicillinase. CNTs gives catalytic prospective of penicillinase and increased the enzymatic activity of the enzyme. The ConCap response of penicillin-G detection using a fabricated substrate is shown in **Fig. 7.**

Created a flexible sensor based on Ag/CNT/PDMS to track breathing and heartbeat during active labor **(Fig. 8)**[94]. They discovered that the wrinkled patch is highly conductive and relative due to the CNTs. In preventative medicine, this could be useful for tracking fever or hyperthermia due to illnesses. CNT-made sensors exhibit a distinct output response across the range of measured concentration levels when contrasted with the control. These changes may have a direct effect on the generated sensor's sensitivity, coefficient of determination (R^2), and overall performance[95].

Conclusion

Carbon nanotubes are helpful in meeting the fundamental physics requirements at the non-metric scale and usher in a new era of practical applications. Through their timeless uses in electronics, chemistry, and nearly exclusively in the biomedical sphere, they provide the next generation with amazing, unusual applications. The nanomaterials that are produced by carbon nanotubes have incredibly important uses in a number of therapeutic and biomedical domains. Furthermore, the constraints and limitations that existed in silicon microelectronics have been resolved thanks in large part to nanotechnology. Because of its special mechanical, electrical, and structural characteristics, CNTs can be extremely important from every viewpoint of research. CNT-based established tumor-targeted delivery offers a way around unsolved problems in cancer treatment. CNT buckypaper has the potential to be used for transdermal medication administration. The use of functionalized MWCNTs in medication delivery has expanded due to new evidence of BBB crossing.

To create a CNTs for effective brain therapy, more research is needed. The development of stem cell and different cell system has benefited greatly from the use of CNTs. Although functionalizing CNTs can improve their bioavailability and reduce their cytotoxic effects, a thorough toxicological investigation of this nanomaterial is still required. Furthermore, it necessitates a more thorough comprehension of the physiological mechanisms driving the administration of CNT. Only when the safety issues around the toxicity of carbon nanotubes are resolved will all of these biomedical approaches under their perspective become a reality. There is still another opportunity for super-specific and superior CNT-based systems to eventually replace all of the traditional diagnostic and biomolecular detection methods. Lastly, although not yet being designated for a biomedical use, a number of recently reported sophisticated CNT systems have enormous potential for use in biomedicine.

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This research does not involve any clinical trials

Authors' Contribution

Lingala Syam Sundar: Conceptualization, Methodology, Writing – Original Draft; Faramarz Djavanroodi: Data Collection, Analysis, Writing – Review & Editing; Thota Apparao: Visualization, Supervision, Project Administration.

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