CNT–BasedNanomaterial'sinPharmaceutical Nanotechnology and Biomedical Engineering

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ABSTRACT:

Nanotechnologyinvolves working with stuff that has at least one dimension between one and one hundred nanometers(nm). Surface area and quantum mechanical processes play a significant role in characterizing the characteristics of matter at this scale, which is often referred to as the nanoscale. All forms of study and technology pertaining to these unique characteristics are included in this definition of nanotechnology. The terms "nanotechnologies" and "nanoscale technologies" are frequentlyused in the plural to describe studies and applications that share the characteristic of scale.Present perspectives on use of operationalizecarbon nanotube (*f*-CNTs) in nano-medicine and bioengineering are diversely projectedon to designing safe,effective,controllable,andtargeted strategies.Theobjective of CTN-based formulations is to deliver medicines to selected tissues, minimize the side effects of medications,increase their bio-availability, or heal tissues that are injured. They are also utilized in the detection.The diagnostic andmonitoring devices Carbon nanotubescan be applied to the composition of repairing components and they used to strengthen the framework of compound implants-numerous distinct physical and chemical, mechanical, electricalandchemicalinnature,andelectromagneticradiationpropertiesofcarbonnanotube orrenderthemuseful inmanykindsofapplications.Thisarticlecovers recentdevelopments in designing Carbon nanotubes materials applicable to pharmaceutical bioscience and bioengineering.

KEYWORDS:

Carbon nanotube,Nanotechnology, Bioengineering, Electromagnetic radiation, Therapy, Bioscience.

INTRODUCTION:

Carbon nanotubes are a type of carbon allotrope with a unique cylindrical microscopic architecture. CNTs may consist of one-to-manylayers in their structures, and their lengths varying from nanoscale to micro scale, with their diameters vary from a handful to tens of millimicrons. Bacon first discovered nanotube s made of carbon in 1960 and called them "graphite whiskers" [1].It was until in 1991, that, the carbon nanotubes by addingof Metalreactant to metal electrodes to the electric particles [2]. Multi-walled carbon nanotubes. Theyare formed up of multiple layers of which are concentricallyrolled up and held together through inter-molecular forces, single-walled carbon nanotubes, which are made up of a single blackhead layer rolled up through a specific different index, are the two common categories for carbon nanotubes. A helpful bottom-up procedure for adjusting the physicaland chemical and electrically properties of carbon nanotubes is chemical modification [3-5]. Because of their aspect ratio and the strong inter-tube inter-molecular forces pressures, pristine, they have an ability to collect into bunches and ropes [6-7].

One major issue with technical uses is their bundling; to avoid this, certain soluble. [e.g.: surfactants,polymers,DNAmolecules]Sincenon-covalentimplementmaygenerate

disassociation carbon nanotubes without compromising their integrity as structures, certain types of non-covalent interaction, such as n-stacking and polymer wrapping, can produce stable and soluble supra molecular assemblies with carbon nanotubes. It works best in applications that call for more perfect carbon nano tubesunique performance [8-9]. Sincea non-covalent implement can generate disassociation with no loss of their structural integrity, DNA molecules can be added to tear up the bundles of carbon nanotube s and generate stable and soluble supra molecular structures with this through specific non-covalent interactions like n-stacking and polymer wrapping.It works better in applications that make use for more flawless carbon nanotube s unique performance. In addition toside-wall implement, carbon nanotube s exhibit tetrahedral operationalbecause the interior of the hollow tubes acts as a perfect microncontainer for hydrophobic and nanosized molecules that can be stabilized duringtransit to a specific location because the molecules are non-covalent adsorbed onto the inner surface of carbon nanotube s or they can be shielded from a potentially destructive environment provide numerous types of significant qualities, particularly high strength, durability, light weight, electrical conductivity, and thermal resistancethat enable them to be used in bio-medicine, bioengineering, and engineering [10-11].

CNTsANDITSBIOMEDICALAPPLICATIONS:

Modify some of the therapy methods. However, due to their strongly bio persistence, aggregation profile, and possiblyremainingmetal-trace impurities from their manufacturing techniques, CNTs are problematic for their possible harmful effects [12]. Different organs or tissues may exhibit unique toxicity profiles for CNTs. For instance, mice showed a dispersal-sensitive CNT buildup in their lungs, while no such sensitive was observed in their liver or spleen [13].

In general, adequate chemical implement the CNT surface (f-CNTs) improves the water dispersal and can lower the likelihood of bundle formation toxicity. This technique is responsible for the covalentand non-covalent attachment of polar groups to nanotube s of carbon include, polyethylene glycol (PEG) chitosan (CS) andpeptides. This has allowed for numerous research related to biomedical applications. Theoperationalize of an armchair carbon nanotube (CNT) enhances the CNT–DOX (doxorubicin) binding affinity and stability in a thermodynamic suitable (exothermic) process, according to studies based on density functional theory (DFT) [14]. The energetically unfavorable, the drug has a significantly higher affinity for the COOH implement tube than for the pristine CNT, and the tube can establish inter-molecular H-bonds. Further, it was discovered that carbonation tubes hadbetterbindingstability.Furthermore,vinblastineanddacarbazinehavebeen conjugatedwitha carboxylated CNT and a pristine CNT, respectively. Regardless of whether the tube's surface has been implemented or not, both systems show spontaneous drug encapsulation.
Accordingto molecular dynamics simulations, entrapment of VLB inside the nanotube s may result in a decreased capacity to deliver the drug to the intended site of action in the inter-cellular protein micro-tubule, unless the diameter of the CNTs or their implement is further altered.

In order to achieve optimized drug-release performance and "intelligent" drug delivery, other systems have been developed that include extra surface functionalities to increase the aquaphilic bio-availability, and bio-compatibility of CNTs. For example, Kamazani have created åNew psychoactive substances nano-liquid and a-carboxylated MWNT when combined with bromo-criptine (BRC) to lower medication dosage and ultimately lessen the side effects of BRC [15]. During in vitro anticancer activity assessments, their systemshowed

i) greatereffectivenessrelativetothefreedrug,
ii) inhibitionof the A549QU-DB lungcancercellsandapoptosiswithasmaller doseand necrotic effects.
iii) noadverseaction in thenormal MRC5cell line at ahigh drugdose

Implementing carbon nanotube,with polymers to generate a hybrid system is an intriguing strategy that has been used in recent years. For example, created a nano-composite using the acid-betulinic and oxidized MWNT–COOH that was operationalize non-covalently with a number of hydrophilic synthetic polymers. At dosages of up to 100 μg mL, the nanotechnology had no apparent toxicity effects on the NIH/3T3 cell line, which is a normal embryonic mouse fibro blast cells line. Many researchers are interested in learning about the competitive drug adsorption between peptides and CNTs, therapeutic agent release enablement, bio mimicry, and general enhancement of CNTs' physico-chemical properties as a result of the addition of biopolymers (such as proteins and peptides) conjugated with CNTs for drug delivery.
When PW3 peptide chains were present, paclitaxel (PTX) on the zigzag SWNT showed enhanced PTX binding efficiency; nevertheless, the drug was bound to the functional groups on theside-wall of-CNTs (i.e.,–OH,–COOH), not thepeptides[16].To understand theDOX binding behavior onto the armchair pristine (CNTs) in the presence of the cell-penetrating poly (L-histidine) (PLH), computational simulations were conducted utilizing the meta dynamics method. The obtained results showed that the DOX–CNT–PLH nanohybrids were adsorbed at neutral pH rather than in acidic circumstances on the phosphatidylcholine membrane [17].
Strong CNT–drug interactions were proposed as the cause of the observed outcomes, operating as "smart" drug platforms. Meanwhile, PLH greatly enhanced drug adsorption, favoringdrugreleaseinlowerpHenvironments. Anintriguingmethodfor improving thebio-availability and bio compatibility of CNTs was shown by a bio-inspired implement of the particles that imitated the interactions of the lateral segments in micro tubule protofilaments. In a variety of peptides–CNT scenarios, Barcelos et al. assessed the microtubule segments as non-covalent implement peptides.

A bioinspired functionalization of the particles that mimicked the interactions of the lateral segments in microtubule protofilaments demonstrated an interesting approach to enhancing the bio availability and bio compatibility of CNTs. Barcelos et al. evaluated the microtubule segmentsasnon-covalentfunctionalizingpeptidesinarangeofpeptides–CNTscenarios .Effectiveanti-cancermedicationDOXisextensivelystudiedinitsfreeform,andits

efficacy is contrasted with that of DOX supplied via CNT-based carriers. In contrast to the drug remainingattachedtothetubeatneutralpH,mechanisticstudiesof DOXreleasefrom a-MWNT treated in nitric acid demonstrated an effective release of about 90% of the drug at pH 5.4 after 20 minutes [18].Acid-treated MWNTs that have been non-covalently functionalized with guanidinylated dendritic molecular transporters to create guanidinylated hyperbranched polyethyleneimine (GPEI) comprise the DOX delivery system described by Lyra et al. The DOX–MWNT–GPEI complex's preferred interactions between guanidinium moieties and water molecules enhanced the nanosystem's aqueous solubility and high selectivity for prostate cancer cells (DU145 and PC3 lineages). Additionally, a greater capacity for CNT cell penetration was noted [19].

The impacts of varying pH settings have been highlighted by in silico studies of releasing DOX load. In the Khoshoei et al. model, trimethyl chitosan (TMC) polymer is used to synthesize either DOX or PTX on a n-carboxyl-SWNT. At low pH tissues, the DOX release was aided by the positive charge of the TMC. In both neutral and acidic solutions, it encouraged the creation of more H bonds between DOX and CNTs, enabling effective DOX adsorption onto the-SWNTs.At blood pH, the PTX exhibited the maximum aqueous compatibility when compared to DOX on-CNT, suggesting that pH-responsive polymers are appropriate for DOX transport. Arabian, also investigated the release profile and adsorptionof DOX in both neutral and acidic pH. The findings demonstrated that the release was influenced byboth DOX protonation and pH. An armchair SWNT with non-covalent tags for either folic acid,tryptophan, or both makes up the system. They conducted another intriguing study on the drug-release capabilities of CNTs DNA material and a pH-sensitive DOX locking mechanism of a cytosine-rich DNA segment covalent bonded to a CNT complex are both present in the produced nanosystem. Because, DOX prefers strong knot-like contacts between the fragments with random coil secondary structure, it inhibited spontaneous release to the medium in the drug encapsulation experiment at neutral ph. Additionally, as the DNA molecule folded into i-motifs, the DOX molecules were liberated from the CNTs at an acidic pH. As a result, interactions between DOX and other system components were significantly diminished[20]. Doping can enhance the CNT-based carriers'-controlled drug-release mechanism. Abbaspour et al. used a number of iron nano-wires and nano-clusters to computationally investigate the anticancer cisplatin-releasing mechanism of an N-doped CNT. Theteam identified apromising possibilityforCNT-drug encapsulation. It's interesting that they came to the conclusion that CNT doping can affect the pace at which the drug is released [21]. Similarly, doping molecularly imprinted polymer (MIP) composites with polyhedral oligomeric silsesquioxanes andresultedin a remarkable regulatedrelease of gallic acid (GAL). Promising outcomes in anti-cancer immuno-therapies have also been shown in other research on the use of N-doped CNT nano-particles in drug delivery [22].

IMMUNOSTIMULANTSANDANTIBIOTICSANDANTIVIRAL:

Carbonnanotubehaveasignificantrateofcellularabsorptionbecauseoftheirtinydiameter

and high aspect ratio. Because of these special qualities, CNTs are now being used to treat viral infections like COVID-19, bacterial resistance, and immune system enhancements. To investigate the activation of peritoneal macrophages in mice, a MWNT–CS combination containingtheimmunostimulant,HericiumErinaceusPolysaccharide(HEP)wascreated.The findings of the experiment demonstrated that the synthetic compound may successfully enhance the humoral immuneresponse [24] [Kofoed created PEGyledHiPco-SWNT complexes], where HiPco stands for a high-pressure carbon monoxide method. To improve medication efficacy, the complexes were non-covalently bonded to either the anti-inflammatorymedication methotrexate(MTX),smallinterferingRNAthattargetstheNotch1 gene, or both. By inhibiting target-specificity to immune cells, mostly B cells, thenanosystem decreased theassociatedtoxicityof MTX,indicatingthepromiseoftheproposed complexes in drug administration, particularly helpful for immune cells involved in rheumatoid arthritis [25].

The outcomes of the experiment demonstrated that the artificial complex may successfully enhance the humoral immune response. Kofoed Andersen et al. created PEGyledHiPco-SWNT complexes, where HiPco stands for a high-pressure carbon monoxide method. To improve pharmacological efficacy, the complexes were non-covalently bonded to the anti-inflammatory medication methotrexate (MTX), small interfering RNA (siRNA) that targets theNotch1 gene, orboth. Byinhibitingtarget-specificityto immunecells,namelyBcells,the NanoSystems decreased the associated toxicity of MTX, suggesting the promise of the developed complexes in drug administration, particularlyuseful for immune cells involved in rheumatoid arthritis.

To increase the effectiveness of the medication, the complexes were non-covalently bondedto either the anti-inflammatory medication methotrexate (MTX), small interfering RNA (siRNA) that targets the Notch1 gene, or both. By inhibiting target-specificity to immune cells, mostly B cells, the nano system decreased the associated toxicity of MTX, indicating the promise of the proposed complexes in drug administration, particularly helpful for immune cells involved in rheumatoid arthritis. For the treatment of tuberculosis (TB) infections, Zomorodbaksh et al. [26]. To increase the effectiveness of the medication, the complexes were non-covalently bonded to either the anti-inflammatory medication methotrexate (MTX), small interfering RNA (siRNA) that targets the Notch1 gene, or both. By inhibiting target-specificity to immune cells, mostly B cells, the nano system decreasedthe associated toxicity of MTX, indicating the promise of the proposed complexes in drug administration, particularly helpful for immune cells involved in rheumatoid arthritis [25].

Susceptibilitytoexternalstimuli:

Active research has also been done on controlled drug transportation methods that utilize different stimuli-responsive characteristics. Madani et al. [27] used the special near-infrared (NIR) optical and electronic capabilities of carbon nanotubes (CNTs) to develop an implantable, optically regulated drug-release platform based on DNA-wrapped (9,4) CNTs with liposomes implanted within a 3D alginate hydrogel. The authors claim that by utilizing an NIR laser to cause a particular optical resonance on a stimuli-responsive moiety, which resultsinphysicalorchemicalchangesinthecarrier,acontrolleddrugreleaseprofilecanbe

produced. As nanocarriers, liposomes have several benefits, including great biocompatibility and compatibility with both hydrophilic and hydrophobic medications.

The entrapment efficiency and long-term delivery of ibuprofen from the alginate–CS–MWNTs nanohybrid were examined in a different CNT-based experiment. In addition to demonstrating pH and temperature sensitivity, the data demonstrated an effective encapsulation rate of up to 88% and 68% sustained drug release within the first 6 hours [28].

A typical stimulus makes use of MWNTs' sensitivity to a sufficient magnetic field. For instance, it was discovered that the anti-cancer 5-fluorouracil (5-FU) may bind to either the pristine or the chloromethylated semiconductive SWNT in a physical and exothermic manner without compromisingthe structural integrityof the medication. Because SWNTs function as a bipolar semiconductor, theywere especiallysuited to securelydeliver 5-FU to its target site with the help of a magnetic field [29]. In comparison to the free EPI, the nano system can demonstrate a sustained-release profile, extended drug lifetime, improved antitumor, and meaningful cytotoxicity when iron oxide (Fe3O4) and the anti-cancer medication epirubicin are loaded onto MWNTs. Additionally, the outcomes of both in vitro and in vivo studies indicate that the method works well for bladder cancer treatment when administered by intravesical instillation. For DOX transport, an injectable silk-incorporated-folic acid (FA)–CNT hydrogel has been suggested in order to improve the drug's bioavailabilityand lessen its negative effects on non-targeted cells. Localized intra-tumoral administration and sustained drug accumulation at the intended spot were features of the system's design. Within 14 days, the tumor's acidic pH and NIR light stimulation led to the production of SWNT-FA-DOX, which was then endocytosed by folic acid receptor-positive (FR + ve) cancer cells to trigger apoptosis. The heating step weakened the electrostatic and hydrogen bonding connections between the SWNT–FA and DOX, promoting the release of the medication [30].

Combinationandmonotherapyforcancer:

A number of studies have been performed to use tumor-targeting CNT-based systems for fightingcancer,particularlyphotothermaltherapy,immunotherapy,chemotherapy,radiation therapy, high temperatures, and combination therapies.

Phytothermaltherapy:

Due to their high NIR absorption, photothermal activity, and photothermal conversion capacity, carbon nanotubes (CNTs) have shown promise in photothermal therapy (PTT) in recent years. The technique can enhance patients' quality of life because it has a brief treatment duration and may lead to a speedy recovery. In order to "burn" the tumor cells [31,32], the PPT healing principle involves inserting photothermal materials into the cancer cells and converting light energy from a specific external light source into thermal energy.created a photothermal fiber system with a lanthanide titanate (LTO) matrix doped with Yb3+ and Nd3+ . They employed CNTs for tumor ablation heating under PTT and temperature monitoring using upconversion luminescence Nd3+ ions. When subjected to temperature-sensitive 980 nm laser stimulation, the nanocomposite was able to precisely and successfullytargetcancercellsinmice.Nagaietal.integratedananti-TRP-1antibodyinto

SWNT. It was made of PEG methacrylate (PEGMA) monomers and furan-protected maleimide methacrylate, and it was embedded in a maleimide gel [33].

Chemotherapyofcancer:

Even though it is typically recommended for treating advanced cancer stages, it can still have serious side effects. A CNT-based complex has been researched with the One of the oldest and widespread methods for treating cancer is chemotherapy. goal of being more accurate, non-invasive,andsuccessfulthantraditionalchemotherapytreatments.Inordertoremovethe hyaluronic acid (HA) matrix barrier in a tumor, Fan et al. investigated hyaluronidase in tumor-bearingmicewithpancreatic cancer.TheremovaloftheHAbarrierandtheapplication of DOX-loaded nanoprobes improved the efficacy of medication absorption into the tumor [34].

Immunotherapy:

By using appropriate immunotherapeutic antibody treatment (such as durvalumab and nivolumab), the activated immune cells eradicate a number of cancer cells. Using the durvalumab–CNT–polyethyleneimine (PEI)–aptamer–siRNA chimeric nano-complex, Qiang et al. created a novel immunotherapy strategy. In vitro and in vivo tests revealed no impacts on healthy liver and lung cells, indicating that the technique boosted anti-cancer immunity against hepatocellular carcinoma (HCC).Durvalumab was released in a regulated and sustained manner for 48 hours, causing HepG2 cell death and T cell proliferation [35]. To strengthen the apoptotic and immunotherapeutic effects, a recombinant human surfactant protein D was also added together with the nanocarrier, CNT–rfhSP-D. The K562 leukemic cells were the target of the method. By focusing on intracellular signaling cascades, it caused eosinophilic cells to undergo apoptosis and showed promise as a treatment for leukemic cells [36].

CombinationalTherapies:

Since monotherapies are typically insufficient to eradicate cancer tissues, which commonly result in cancer reappearance, combinational tumor therapies are intended to increase the curative efficacy of therapies.

Chemo-PTT, or chemotherapy plus PTT, has been explored for potential synergistic effects. Das et al. demonstrated a CNT nanocarrier embedded in β-cyclodextrin, a polymer that is sensitive to temperature and pH [37]. Curcumin and DOX hydro chloride's anti-angiogenic effects demonstrated a synergistic antitumor action and angiogenesis suppression that impacted vascular endothelial growth factor (VEGF) and fibroblast growth factor 2 (FGF2). The chorioallantoic membrane assay (CAM), an in vivo test, validated several anti-cancer processes. Overthecourseof30hours,aconsistentreleaseprofileofthetwocompoundswas noted, with DOX achieving a 90% release rate undertumor microenvironmental conditions, whereas curcumin release rate was 85% under high temperature at neutral pH. The designed material exhibited a cell mortalityrate of 70% on HeLa and MCF-7 cells that surpassed up to 80% with photothermal inducement in vitro [38].

Biomedicalengineeringandregenerativemedicine:

In attempt to restoration, preserve, improve, or replace different biological tissues such asskin boneligament regenerative medicine has been widely and diversely applied to tissue scaffolds, cells, and others[39].

Applicationsfordressingsandhealingmaterials:

Using a cellulose acetate-collagen nanocomposite, David et al. created a wound-healing dressing with improved antibacterial and biocompatible properties. It included TiO2 NPs and MWNTs, which inhibited the growth of both gram-positive and gram-negative pathogens [40]. Khalid et al. investigated the regenerative bandaging and antimicrobial activities ofNPs. They examined the effects of the biocomposite that contained-MWNTs integrated intoa three-dimensional microporous bacterial cellulose matrix.

TheydiscoveredthatCNTshadobservablesuppressingeffectsagainstKlebsiellasp.,E.coli, P. aeruginosa, and S. aureus, outperforming the conventional bactericidal. when synthesised using an ex-situ immersion approach. The new composite functioned as an effective anti-infection healing biomaterial that might hasten the healing of diabetic wounds while maintaining moisture retention [41].A quick and efficient joint-welded (JWCNT)/hydroxy butyl chitosan (HBC) sponge was presented by Zhang et al. as a workable biomedical substitute. Because of its porous structure, the haemostatic dressing had the ability to absorb blood and showed significant antibacterial activity, blood compatibility, high elasticity, and blood maintenance [42].

Materialsthatregenerate:

Unprecedentedtissueengineeringconceptshavebeensparkedbybioprintables.

Regenerated silk (RS) from Bombyx Mori cocoons has been incorporated into-carboxyl-CNTs to create a bio-adhesive bioink that can be used for 3D printing by seeding andgrowing human skin fibroblasts for implantable devices. The suggested-CNTs–RScomposite demonstrated exceptional biocompatibility and adhesive qualities on wetbiological substrates, and it was electrically controlled [43]. The literature has also reported on other structural investigations; for instance, Oliveira et al. detailed the viable cells following the therapy with B-carboxyl–MWNT, using stem cells from a model of human exfoliateddeciduousteeth.Thecomplexwasfoundtobeusefulforregenerativedentistryand did not change superoxidedismutase activity, produce oxidative stress, genotoxicity, or other adverse consequences [44].

Scaffoldsforconstructionandregeneration:

It is anticipated that tissue replacement will eventually fuse with the native organ tissue that was transplanted in order to improve cellular viabilityand maintain or improve the functions of tissue. Mehrotra et al. created a cardiac scaffold using CNTs and a conductive bioink basedonnon-mulberrysilk. Itmadeitpossibletopreciselyshapeananisotropicvascularised structure that resembles the tissue found in the heart. Cardiomyocytes may be impacted by the enhanced conductivity and mechanotransduction capabilities of CNTs, indicating their potential to promote the formation of heart tissue [45].

Biosensorfordiseasedetection:

For patients receiving efficient treatment and recover, advanced diagnostic tools are helpful. An immunosensor was created as a sensitive, cost-effective, and accurate method of Alzheimer's disease diagnosis. The technique relied on the identification of phosphorylated tau 181 protein; a biomarker unique to AD. The sensor consisted of a platinum nanoparticle carbon screen-printed electrode (C-SPE) coated with an electron-transfer antibody that binds ϒ-aminated MWNTs[46].

Biosensorforviraldiagnostics:

For early COVID-19 monitorability, the most recent and distinctive CNT-based techniques for rapidly assessing SARS-CoV-2 (COVID-19) infection have been investigated. SWNTs were non-covalently bound to the human host angiotensin-converting enzyme 2 (ACE2) in a hybrid biosensor described by Pinals et al., which demonstrated spike-protein reading in 90 minutes[47]. According to reports, another COVID diagnostic instrument demonstrated the benefits of being easy to use, cost-effective, electrochemically quantifiable, and NIR sensitive, and it was responsive in two to three minutes. A field-effect transistor (FET) of surfacespikeproteinS1 wasusedtoconstructtheCNTprintingonaSi/SiO2surfacewiththe anti-SARS-CoV-2, demonstrating a minimum retained sensing of 91.18% [48].

Particular biosensors:

Bakh et al. presented a stable manufactured NIR-fluorescent composite nanosensor. Two vitamins, riboflavin and ascorbic acid can be selectively sensed by the sensor, which is made up of DNA-wrapped SWNTs embedded in PEG diacrylate hydrogel. The outcomes are advantageous for the best possible use of vitamin detection [49].

On the basis of a CNT-paper composite capacitance transcutaneous biosensor of vitamins, a comprehensive non-electrical-contact blood haemostasis analysis biosensor was created. It applied NIR fluorescence to the treatment of patients with haemorrhages, aggressive therapies, or antithrombotic medications [50].

Heat-detectingbiosensors:

It has been reported that a CNT composite temperature-monitoring sensor can measure the temperature of the skin. At high temperatures, the heat gap between the CNTs and the matrix restricts the tubes, changing their electrical characteristics. In addition to being a flexible, wearable, and biocompatible temperature sensor appropriate for lab-on-a-chip devices or artificial-sensory skin, the suggested biosensor demonstrated adequate, stable, and reproducible features under a variety of thermal loads [51].

Bioimaging:

Atargeted,non-invasiveimagingtechniquecreatedbyGifanietal.canidentifyinflammatory atherosclerotic plaques in diseased arteries prior to their rupture, which could result in a heart attack, stroke, or death.

The atherogenic mouse model, which replicates human-inflamed plaque, allowed the team to preciselyscanvulnerableplaquesexvivo.Inordertotargetthemanyarterial-wallimmune

cells, the team employed injectable ultra selective SWNTs as contrast agents. Foamy macrophages and inflammatory Ly-6Chi monocytes may be linked to plaque inflammation. Immune cells particularly absorbed the NPs, which caused SWNTs to aggregate inside the atherosclerotic plaques—but not in healthy arteries. The technique may help in the early detection of atherosclerosis damage by translatable photoacoustic imaging [52].

CNTtoxicity:

In the realm of biomedicine, CNTs have a number of benefits. They are appropriate for drug delivery systems because of their high aspect ratio and wide surface area, which can increase therapeutic efficacy overall and improve drug penetration into cells [53]. They can be employed as contrast agents in imaging procedures because to their special electrical and optical characteristics, which improve the visibility of biological structures [54].Additionally, CNTs exhibit potential in tissue engineering applications by offering a framework that promotes cell growth and regeneration. Moreover, CNTs can be functionalisedwithavarietyofbiomoleculestoimprovetheirbioactivityandenableselective targeting. All things considered, CNTs' special qualities make them usefulinstruments in biomedicine, with the potential to improve tissue engineering, imaging, drug delivery, and other areas.

Thebiocompatibilityandbiodegradability:

The carbon nanotubes are another crucial factor that prevents them from being used in therapeutic settings. The ability of a material to survive with living tissues or creatures without generating negative consequences is known as biocompatibility. Since many experts believe that carbon nanotubes (CNTs) have carcinogenic qualities akin to asbestos, their biocompatibility is an important topic of research and discussion. Although the properties of asbestos and carbon nanotubes (CNTs) differ in terms of surface charge, hydrophilicity/hydrophobicity, active metal properties, tensile strength, and bio-durability, there is worry that CNTs mayhave carcinogenic qualities similar to asbestos because of their fibrous morphology [55].

CONCLUSION:

Applications of CNT-based nanomaterials in medicine and pharmacology have been exciting and expanding quickly. Thus, there is a large body of literature on this subject, and its scopeis continuouslygrowing quickly. Therefore, this overview onlyoffers a small samplingof the most important developments in this field. Numerous more research that are nonetheless significant are left out of this evaluation. For instance, there have been reports of innovative skincare-emulsion cosmetics that include graphene oxide (GO), MWNT, and lignin nanoadditives with enhanced UV balancing and sun protection aspects to maintain healthy skin

It is also expected that the usage of CNTs in Alzheimer's disease treatments would have a bright future because they effectively suppress amyloidbeta (Aβ) aggregation whenmisfolding. In order to improve immune responses against Koi Herpesvirus Disease in vaccinatedkoifish,CNTshavebeeninvestigatedasvaccinecarriers,suchasinthe

immersion vaccine application. CNT-based nanocomposites have been researched for enhancing structural reinforcing and human implant performance because of their strong mechanical properties.

It has been demonstrated that-'SWNTs' biocompatibility in an ultra-high molecular weight polyethylene (UHMWPE) matrix is beneficial for knee, skull, or hip replacement requirements.

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