Nanotechnology in drug delivery system: current status and future perspective

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Abstract

Nanotechnology is a technology for nanoparticles made from synthetic or natural polymers. In recent years, nanotechnology has become a popular term for the major efforts of science and technology today. Nanotechnology is unique because it encompasses a wide variety of disciplines, from basic materials sciences to personal care applications.But prior to their application, considerablechallenges related to clinical toxicities should be taken into account.Nanotechnology hasfinally and firmly emerged as the realm of drug delivery. The performance of intelligent drugdelivery systems is continuously improved with the purpose of maximizing therapeutic activityand minimizing undesirable side effects. Recent advances in material design and theemergence of new therapeutics are contributing to the development of more sophisticatedsystems. This review provides an overview on the relation between nanotechnology and drug delivery, various nano based drug delivery systems being commercialized and undergoing, recent advances in various nano based drug delivery systems, principal challenges both from a manufacturing and regulatory perspective and safety issues in nano-based drug delivery systems.

Keywords: Drug delivery systems, Nano carriers, Nano formulation, Nanocrystals, Nanomedicine Nanoparticles, Nanotechnology

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INTRODUCTION

The provision of therapeutic components to the desired location is an important problem in the treatment of many diseases.The main disadvantages of conventional drug delivery systems are limited effectiveness, low biodistribution, adverse side effects and lack of sensitivity. Various strategies have been invented and used to overcome these issues by transporting the drug to site of action. Additionally, drug delivery systems provide protection against drug degradation or rapid approval. It also enhances drug centration in target tissues; therefore, lower doses of drug are required. Such a type of delivery is required when there is the discrepancy between a dose or concentration of a drug and its therapeutic results or toxic effects. However, the most reliable approach is to attach drug molecules to a designed carrier to target a specific site of action or specific cell. Such an approach is known as cell- or tissue-specific targeting. Size reduction of targeted formulation and designing its pathways for suitable drug delivery system is a more fundamental and successful approach that forms the basis of nanotechnology. According to the recent advancements in

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nanotechnology, nanoformulations have acquired great potential as drug carriers [1]. Different types of nanostructures that exhibit unique physiochemical and biological properties are yields from various size reduction methods and technologies. Pharmaceutical technology is an emerging branch of biomedical sciences. Pharmaceutical nanotechnology covers the applications of nanotechnology to pharmacy as nanomaterials and as devices like drug delivery, diagnostic, imaging, and biosensors. Pharmaceutical nanotechnology has provided more fine-tuned diagnosis and focused treatment of disease at a molecular level. Pharmaceutical nanotechnology offers various opportunities to fight against many diseases such as cancer, diabetes mellitus, and neurodegenerative diseases, as well as to detect microorganisms and viruses associated with infections. It is expected that in the next 10 years the market will be flooded with nanotechnology-devised medicines. Applications of nanotechnology to pharmacy that provide intelligent and smart drug delivery systems are expected to emerge as the most important and powerful tool as an alternative to conventional dosage form. Various prominent features and applications of nanosystems are mentioned.Today's nano drug delivery systems are very appealing delivery systems because of their nanosize property. These systems are very similar to biological entities, such as a virus. Typical nano drug delivery systems have at least one dimension that is within the size range of 1-100 nm [2]. The efficiency of drug delivery to various parts of the body is directly affected by its dimensions. Their small physical dimensions enable them to penetrate through biological and physiological barriers that are normally impermeable for larger particulate structures. The therapeutic value of various promising drugs for the treatment of neurological diseases is diminished due to the restriction offered by bloodbrain barrier. Nanotechnology gives a solution for effectively delivering drug entities to the brain and treating brain disorders. To alter and tune pharmacokinetic or pharmacodynamic properties of drug molecules, surfaces of nano drug delivery systems can easily be modified using conventional chemical techniques. For example, polyethylene glycol (PEG) linked to nanocarrier surfaces increases their circulation time within the body, thus reducing nonspecific uptake and harboring by the reticuloendothelial system [3]. The flexible surface chemistry of nano drug delivery systems also allows conjugation of targeting ligands. Biological moieties, such as peptides, nucleic acids, and antibodies, can be attached to their surfaces to target drugs to specific diseased sites [4]. Targeted nano drug delivery system (nano-DDS) can increase the drug payload while significantly reducing various risks of adverse side effects, leading to enhanced therapeutic efficacy and better patient compliance.Furthermore, nanostructures have the ability to alter size, shape, and composition during synthesis to meet the requirements of present drug delivery strategies. Due to their different sizes and shapes, they have the ability to enter different types of cells and tissue. For example, the colloidal nanoparticles (50 nm) can easily pass-through cell membrane, thus increasing cellular uptake. Elongated nanostructures, such as tubes, wires, and rods, have been shown to possess a longer circulation time within the body, resulting in reduced metabolic clearance [5].

RECENT ADVANCES IN NANO DRUG DELIVERY

Liposomes

Since their initial introduction in the 1970s, liposome-based DDSs have successfully demonstrated the delivery of anticancer drugs, enzymes, and proteins with numerous injectable formulations that are now used in clinical medicine. So far, the many achievements obtained using liposomes have

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far surpassed those of all other nano-DDSs under investigation. Comprised of naturally occurring biocompatible phospholipids and cholesterols, their successful biointegration includes their non-toxic nature and the body's innate ability to metabolize them [6].Liposomal anticancer drugs were the first nanobased formulations approved for cancer therapy by the US Food and Drug Administration (FDA). The ones widely used and traded in clinical oncology treatments in the United States are Doxil (doxorubicin), DaunoXome (daunorubicin), and Depocyt (cytarabine) [7,8]. What turns liposomes into an ideal drug carrier is the tendency of hydrophilic drugs to get entrapped in the core, whereas the hydrophobic types get bound to the lipid bi- layers. Thus, the hydrophilic drugs get encapsulated by the aqueous core, and in the same manner, lipid bilayers entrap the hydrophobic ones, resulting in the separation of drug molecules from the surrounding environment and best ensuring the full protection of the cargo. Depending on the production methods, liposomes vary in size, lamellarity, and surface charge. In general terms, the unilamellar liposomes (50-200 nm) are suitable hydrophilic drug carriers, while multilamellar types (1-5 mm) are ideal for loading hydrophobic drugs [9]. Although the beneficial properties of these structures, such as biocompatibility, the presence of biologically inert profiles and the absence of toxic reactions in patients, stand out, the "complement activation-related pseudoallergy', which is a drug-induced active immune toxicity produced in hypersensitivity reactions, is the main drawback when liposomal drugs are injected intravenously [10]. Liposome circulation removal is the result of binding of opsonins (such as immunoglobulins, fibronectin, and C-reactive proteins) to the surface of liposomes. Consequently, liposomes are recognized by the mononuclear phagocyte system by recognizing these serum proteins rather than vesicles. On the other hand, the invading extrinsic particles get repelled by the membrane attack complex, which acts to identify liposomes and gives rise to membrane lysis via pore formation; furthermore, it boosts uptake by neutrophils, monocytes, and macrophages. In fact, the chemical equilibrium between the blood opsonic and restrictive proteins modulates the rate of liposome clearance [3]. Previously, only a single drug could load into the drug-bearing lipo- somes; however, currently two or more drugs (gemcitabine and tamoxifen) can attach to the newer generation of liposomes in cancer cells. The so-called liposomal multidrug carrier can be laden with hydrophilic / hydrophobic substances with / without any interaction between components [11]. Since conventional liposomes exhibit low systemic circulation time, synthesis of stealth liposomes has been attemptedby coating the liposome surface with polymers, such as PEG, poly(vinyl pyrrolidone) (PVP),poly(acryl amide) (PAA), poly[N-(2-hydroxypropyl)methacrylamide] and amphiphilic poly(N-vinylpyrrolidones), biodegradable polymer lipid conjugate, polyvinyl alcohol, amphipathic polymers poly(2-methyl-2- oxazoline) and poly(2-ethyl-2-oxazoline) [12]. The combination of various commercial lipid molecules can alter the physiochemical characteristics of liposomes so that they can hold their size, surface charge, and uncomplicated utilization within limits, which obviates the need for further chemical synthesis steps and complex alterations that are normally prerequisites for other carriers like polymer conjugates [13]. The restricted loading capacity of slightly soluble drugs can be attributed to the highly limited available space in the membrane and the destabilization of the outer space as a result of drugs' function; consequently, water-soluble drugs gain prominence even though their loading capacity is restricted [8].

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Nonetheless, their extra drawbacks are worth considering. The problems range from poor stability and industrial reproducibility, sterilization complications, the tendency of phospholipids to oxidate,to poor control of conventional formulations on drug release, thus resulting in profiles of release in rapid bursts. However, it is hoped that some strategies, namely thermosensitive, pH-sensitive, and ultrasound- triggered drug release, help to eliminate or mitigate these shortcomings [14]. The stimulus-responsive liposome can be provoked by an external signal. Any particular chemical, physical, or biochemical stimulus can trigger modifications in the structural composition or conformation of liposomes, so the liposomes so releasing of active agents to specific biological environment would occur [15]. The pH-sensitive liposomes are geared to either pH-sensitive elements like unsaturated lipid molecules such as phosphatidylethanolamine (PE), amphiphilic molecules (cholesteryl hemisuccinate or oleic acid) or polymers having ionizable groups such as amines or carboxylic acids [11]. Recent developed techniques for thermosensitive vesicles (TSL) are as follows: (1) utilization of phospholipidswith a phase transition temperature between 41 and 42 C which can tolerate thegel-to-liquid crystalline transitions; and (2) use of leucine zipper sequence peptide with disuniting capacity of disuniting above its melting temperature (w40 C) in a disorganized conformation [16]. The infusion of some lipid compounds, for instance, lysolipid or oligoglycerol-PG into the structure of TSLs, has improved the membrane permeability of TSLs [17]. Liposomes are the promising active targeting carriers that attach monoclonal antibodies or anti-body fragments to the outer layer of liposomes (immune liposomes), thus enhancing the antitumor activity of the anticancer agent, either by being free or enclosed in simple liposomes. In addition, they diminish the systematic toxicity of the free drug. What makes immune nanocarriers more favorable is the rather higher capacity to be loaded by cytotoxic drugs as opposed to the drug conjugates with a lower tendency to be bound with molar equivalents of drugsto avert erroneous coupling with antigens. On top of that, the strong targeting inclination of immunoliposomes can be owed to the fact that they canintegrate with several antibodies and targeting moieties. However, they barely creep into solid tumors due to their rather large size and restricted circulating period in blood, which can be somewhat resolved by PEG coating. This is considered to be their main drawback [16]. Having studied the myriad merits of the clinical validation of liposomes, grave demerits concerning stability and a limited control of drug release cannot be disregarded. However, these limitations have been overcome by the advent of polymeric nanocarriers since they demonstrate higher stability, a significantly prolonged circulation time, considerable loading capability, and the capacity to show more controlled and targeted drug-release profiles during both prolonged periods and at different predetermined rates [18].

Lipid-Based Micelles

Small amphiphilic molecules are used as surfactants for lipid micelles and, depending on their chemical makeup, several micelle geometries can be generated, such as spherical, ellipsoidal, or rod-shaped [18].Hydrophobic drugs, such as taxanes, can be trapped in the lipophilic core of the micelles. A variety of commercial dosage forms, including paclitaxel and docetaxel, can be included in micelles. The main restrictive drawbacks of micellar nanocarriers include the fairly low hydrophobic volume of the interior space, which restricts the drug-loading capacity, and also dilution in an aqueous or biological environment, which causes them to disintegrate [19]. Several alternative methods are introduced to

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address these obstacles. The problem withTaxol and Taxotere is overcome by the inclusion of ethanol in two dosage forms to ease the process of drug dissolution and to enhance stability. In addition to the toxicities induced by organic solvents, in the case of Taxotere, micellar solutions need to be diluted in an infusion medium, and subsequent to being supersaturated, must be utilized in 4 h before docetaxel crystallization. To merge the merits of both polymeric micelles and lipid micelles, a new sterically stabilized micellar system, constituting of PEG-grafted distearoylphosphatidyl ethanolamine, is introduced to deliver water-insoluble drugs such as paclitaxel [20].

Lipid Nanoparticles

In general, solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs), two categories of lipid nanoparticles with solid matrix, may be distinguished [20]. Since these two groups outperform liposomes or polymeric nanoparticles, it is possible to manufacture products at an industrial scale without using organic solvents. Furthermore, SLNs and NLCs are substantially more tolerable in vitro than polymeric nanoparticles[20]. Previously, the term lipid had a wider range, including triglycerides (eg, tristearin), partial glycerides (e.g., Imwitor), fatty acids (e.g., stearic acid), steroids (e.g., cholesterol), and waxes (e.g., cetyl palmitate) [21]. A distinct benefit of SLN lies in the fact that lipid matrix is composed of physiological lipids that lessen the risk of acute and chronic toxicity. The administration route mostly determines the choice of kind of emulsifier, which is very restrictive in the case of parenteral administrations [22]. In terms of parenteral application, SLNdemonstrates dominant attributes such as superior physical stability, protection of incorporated labile drugs against degradation, controlled drug release (fast or sustained) based on the incorporation pattern, excellent endurance, and precise site-specific targeting [23]. In contrast, lessfavorable properties such as inadequate loading capacity during ejection after polymorphic transition during storage and a rather high water content of the dispersion have been reported [24]. More complex lipids with different chain lengths, such as mono, di, and triglycerides, are required for higher drug loading. Drug ejection may be caused by the change from lipid particles to highly organized lipid particles. The drug is ejected from the lipid matrix and cannot be protected from degradation or released in a controlled manner during the polymorphic transition that occurs during the storage phase [21]. The development of a nanoparticulate lipid carrier that has a certain nanostructure with the ability to enhance the payload and blocking drug expulsion is the main objective behind the use of NLCs [24]. Generally, NLCs are classified into three main categories: (1) solid lipids mixed with a small quantity of liquid lipids (imperfect type NLC), (2) solid lipid matrix containing oily nanocompartments (multiple type NLC), and (3) the particles are solid but mixing special lipids pre- vents crystallization upon cooling (amorphous type NLC) [24]. Since efficacious drug loading and prolonging drug half-life are desirable elements for parenteral administration routes, NLCs have been shown to be favorable carriers [25].

Polymeric nano drug delivery systems

Polymeric nanoparticles for DDSs have garnered the interests of researchers for many decades. From the discovery of “Starburst” dendrimeric polymers in the 1980s to more recent advances in self-assembled polymeric micelles, various strategies have been developed to encapsulate drug molecules [27]. One of the most studied polymeric nano-DDSs is the use of biodegradable systems for controlled drug release platforms [28]. A typical biodegradable nano-DDS consists of colloidal polymeric nanoparticles with drug molecules

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that are encapsulated, mixed, absorbed, or attached onto the polymer matrix [29]. Various methods associated with drug loading, as well as polymer chemical properties, directly regulate the mechanics of drug release. A main advantage of using these polymeric nano-DDSs is their biocompatibility and sustained drug-release capabilities at target-specific sites.

Dendrimers

A distinct family of well-defined nanostructured macromolecules known as dendrimers has a highly branching three-dimensional structure, high surface functionality, and controllable form and size. The chemistry behind dendrimers was initially described in 1978, with the discovery of the first dendrimer reported by Donald A. Tomalia during the early 1980s. The diameters have three distinctive architectural elements: (1) an initiator core, (2) an interior layer (generations), composed of repeating units, radially attached to the initiator core, and (3) an exterior (terminal functionality), attached to the outermost interior generation. Dendrimers are often created by a series of interacting reactions where each new contact results in a dendrimer of greater generation. Dendrimers can be synthesised using a variety of synthesis techniques, including (1) the divergent method, (2) the convergent method, (3) the accelerated approach, (4) the double-exponential approach, (5) lego chemistry, or (6) click chemistry. Numerous sources, including poly (amido amine) dendrimers, poly (propylene) imine (PPI) dendrimers, peptide dendrimers, glycol dendrimers, hybrid dendrimers, PEGylated dendrimers, etc., offer a wide variety of compositionally distinct dendrimers. Dendrimers have a number of distinctive characteristics that raise their potential as new scaffolds for drug delivery, including a monodispersive nature, precise nanoscale sizes, controllable molecular weight, a large number of readily available functional groups on the surface, and an extraordinary ability to encapsulate guest molecules within the internal hydrophobic environment. Dendrimers have a significant impact on drug solubility as well as drug targeting (active and/or passive targeting).Different types of dendrimers are shown in figure 1 [30,31].

Kaminskas et al. [32] developed doxorubicin-conjugated dendrimers using 56 kDa PEGylated polylysine through acid labile linker for assisting controlled and sustained release of drug for pulmonary cancer. The anticancer efficacy assessed in MAT 13762 IIIB rat model of lung cancer shows 95% decrease in burden of lungcancer after intratracheal instillation of doxorubicin-loaded dendrimers, as well as 30%e50% decrease in tumor burden through intravenous delivery of pure doxorubicin solution.

Zhang et al. [36] synthesized the paclitaxel-loaded dendrimer (PAMAM-PTX) using the N-hydroxy succinimide method, and this was further modified to form the peptide-dendrimer-paclitaxel complex (GE-PAMAM-PTX). The prepared GE- PAMAM-PTX was evaluated using a cytotoxicity and cellular uptake study in 293T and L132 nonsmall cell lung cancer (NSCLC) cell lines. The results concluded that GE-PAMAM-PTX complex show higher cytotoxicity as well as higher cellular uptake when compared to pure PTX because GE-PAMAM-PTX helps in targeting to tumor and sustained release of paclitaxel for longer period.

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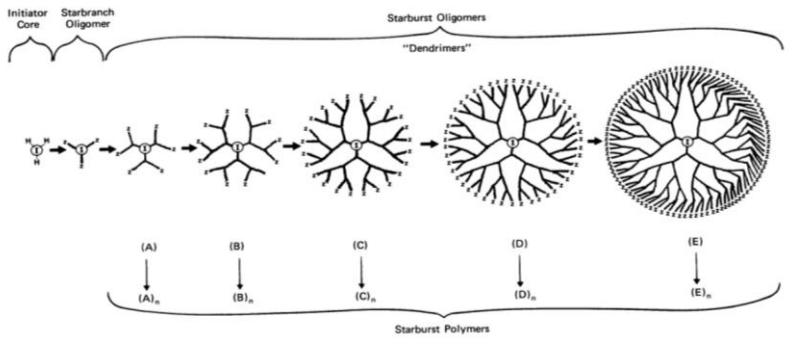

Fig.1 Different types of dendrimers

Polymeric Micelles

Polymeric micelles are self-assembled nanoscopic core shell structures formed by amphiphilic copolymer inside water, which are able to hold hydrophobic drugs in the core of micelles and hydrophilic bioactive molecules such as DNA or siRNA in the outer shell of polymeric micelles [37,38]. The size of polymeric micelles isusually <100 nm and used for the systemic delivery of hydrophobic drugs. The hydrophilic surface of polymeric micelles shields them from nonspecific uptake by reticuloendothelial system. Polymeric micelles are known for their superior control release property and tissue-penetration capability; additionally, they have been shown to be an excellent novel drug delivery system because of their high stability under physiological conditions, high and versatile loading capacity, high accumulation of drug at target site, and the possibility of the functionalization of end group for conjugation of targeting ligands.

Sun et al. [39] designed acid-sensitive Dlinkm bridged copolymer and the Micel- leplex system (PEG-Dlinkm-R9-PCL) by using molar ratio of PCL, R9, and PEG (1:0.97:1.05) incorporating siRNA. The micelleplex system with and without Dlinkm-bridged copolymer were prepared through the solvent exchange method, denoted as Dm-NP and NP, respectively. This Dm-NP that incorporates siRNA better protectsserum siRNA, increases its circulation time, and increases uptake of siCDK4 into A549 tumor xenografts (tumor pH w6.5) in nude mice after intravenous injection detected by fluorescence imaging. Dm-NPsiCDK4 lowered the growth of A549 cells to 22.7%2.1% with 200 nM siCDK4 concentration atpH 6.5. Furthermore, Dm-NP shows an improved gene silencing efficiency after systemic delivery and an in vivo tumor inhibition activity with fewer side effects.

Polymeric Nanoparticles

Polymeric nanoparticles consist of a biodegradable polymer that is biocompatible and non-toxic. Features such as biocompatibility are required for potential applications in tissue engineering, drug and gene delivery, and new vaccine strategies. Recent research explored some advanced modifications of natural polymers, which consisted of synthetic polyesters like poly(D, L -lactide) or polycyanoacrylate and related polymers like poly(lactide-co-glycolide) PLA or poly(lactic acid). Among natural polymers, chitosan is the most widely used polymer. In addition to chitosan, many others such as gelatin and sodium alginate overcome some toxi- cological problems that the synthetic polymers have. Synthetic polymers used for nanoparticle preparation may be in the form of preformed polymers, e.g., polyesters like polycaprolactone (PCL), PLA, or monomers that can be polymerized in situ, e.g., polyalkyl cyanoacrylate. There are many advantages to using polymeric nano- particles in drug delivery, such as biocompatibly and biodegradability, increasing the stability of any volatile pharmaceutical agents, being less toxic, targeted drug delivery, non-immunogenicity, and non-toxicity.

Silica-Based Nano Drug Delivery Systems

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Among various silicon-based materials, porous silicon and silica, or silicon dioxide are the most commonly used materials that are architecture in form of calcified nanopores, platinum materials containing nanopores, porous nanoparticles, and nanoneedles. The size (diameter) and density can be accurately controlled to achieve a constant drug delivery rate through the pores. There are various forms (porous hollow silica nanoparticles) that are fabricated in a suspension containing sacrificial nanoscale templates. This is followed by the addition of silica precursors, such as sodium silicate, into the suspension, which is then dried and calcinated. The template material is then dissolved further leaving behind the porous silica shell. These nanoparticles are mixed with the drug molecule and, subsequently, the mixtureis dried to coalesce the drug molecules to the surface of the silica nanoparticles. Examples of therapies being investigated for use with silicon-based delivery systems include porous silicon embedded with platinum as an antitumor agent [47], calcified porous silicon designed as an artificial growth factor [48], silicon nanopores for antibody delivery [49], and porous silica nanoparticles containing antibiotics [50], enzymes [51], and DNA [52].

Mesoporous Silica Nanoparticles

Since the use of mesoporous silica nanoparticles (MSNs) for drug delivery was launched in 2001, MSNs have received a lot of technical interest for their future implementation in the nanomedicine and biotechnology areas. MSNs have been increasingly applicable in drug delivery of anticancer drugs due to their effective ability for loading of drugs, their control drug release, and versatile abilities. MSNs are basically taken up by lung tumor cells through endocytosis process [53].Zhang and his coworkers made a similar attempt as Chen et al. [57] by replacing dextrin with dextran as surface modifying agent for mesoporous silica nanoparticles. At pH 7.4, dextran dialdehydes block the pores to prevent premature release of the anticancer drug doxorubicin hydrochloride. However, in the weakly acidicintracellular environment (pH w5.5), the hydrazone can rupture and the drug can be released from the carriers. *In vivo* results demonstrate that modified mesoporous silica nanoparticles with an excellent pH sensitivity can enter HeLa cells to release doxorubicin hydrochloride intracellularly due to the weakly acidic pH intracellular and kill the cells [58].

Carbon-Based Nano Drug Delivery Systems

Fullerenes, graphene, and carbon nanotubes are the three main categories of carbon-based structures. The most often employed nanostructure among those mentioned above for drug delivery systems is carbon nanotubes. Carbon nanotubes are made up of hexagonal carbon atom rings that range in size from 1 to 100 nm and resemble rolled tubular shells of graphene sheets. These sheets are one atom thick. Recently, single-walled carbon nanotubes (SWCNTs) and multiwalled carbon nanotubes have attracted a lot of attention as carbon-based structures (MWCNTs). Diagnostics, vaccine delivery, gene delivery, peptide, nucleic acid, and targeted medicine delivery are all uses of carbon nanotubes. It has been demonstrated that surface functionalization of carbon nanotubes may effectively transfer a variety of medicinal chemicals into cells using in vivo systems.Recently, Razzazan et al. [61] functionalized SWCNTs byPEGylation and then conjugated with gemcitabine, an anticancer agent widely used inlung and pancreatic cancers. This functionalization leads to high drug loading, less cytotoxicity, and high therapeutic efficacy. Furthermore, Habibizadeh et al.[62] made an attempt to functionalize MWCNTs through PEGylation. Ibuprofen had been used as model drug, physically and covalently conjugated with PEGylated carbon nanotubes. The results revealed that PEGylated nanotubes did not

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show significant detrimental effects on the viability of L929 cells. The percentage of chemical and physically ibuprofen loading was reported to be 52.5% and 38%, respectively. Chemically loaded MWCNTs showed much sustained release behavior compared to the physically loaded one, especially at pH 5.3.In another study, MWCNTs were covalently conjugated with transferrin by carbodiimide chemistry and loaded with docetaxel as a model drug for effective treatment of lung cancer in comparison with the commercial docetaxel injection (Docel). IC50 values demonstrated that transferrin-conjugated MWCNT could be 136-fold more efficient than Docel after 24 h of treatment with the A549 cells. The results of transferrin-conjugated MWCNT have shown better safetyefficacy than Docel [63].In 2016, Taghavi and his coworkers made an attempt to functionalize SWCNTs with polyethylenimine and its derivatives tagged with 5TR1 aptamer for targeted delivery of Bcl-xL shRNA into breast cancer cells. The results demonstrated the potential and specificity of functionalized Apt-carbon nanotube conjugates for increasing the induction of apoptosis in tumor cells by suppression of Bcl-xL transcript. Furthermore, they functionalized SWCNTs with the polyethylenimine tagged with AS1411 aptamer for thecombination of gene and drug delivery into human gastric cancer cells [64]. In general, the results revealed that the combination of the shRNA-mediated genesilencing strategy with chemotherapeutic agents constitutes a valuable and safe approach to antitumor activity.Wang et al. [65] developed a multimodal gold-coated MWCT material that complements tumor targeting, doxorubicin delivery, and photothermal therapy for localized cancer treatment. The material has a high loading/unloading capacity for the cytotoxic agent doxorubicin. The releaseof doxorubicin, combined with the photothermal properties of the material that induces localized hyperthermia, leads to efficient cancer cell death.

CONCLUSION

Nanotechnology will become a crucial component in human therapies and medication delivery. Drug delivery systems are still in the early stages of research, but they have a bright future. Physicists, chemists, biochemists, and other scientists have potential to use nanotechnology, which is still in its infancy, to create systems that may one day be as sophisticated and precise as biological structures created by nature. A new discipline called nanotechnology has the potential to alter the way we administer drugs to cure diseases. However, there are still a lot of obstacles to overcome before this science can provide therapeutically useful treatments. One of the key obstacles to converting these technologies into treatments is the invention and testing of innovative techniques for managing how nanomaterials interact with the body. The issue of delivering nanomaterials to specified bodily locations while avoiding capture by organs like the liver and spleen must be overcome. There has been plenty of room at the bottom to improve and alter current technologies by manipulating material characteristics at the nanoscale, as Feynman had anticipated. Thus, the promise of nanotechnology-based medicine could materialise with enough time and study.

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