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Nano Based Drug Delivery Systems: Present and Future Prospects

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ABSTRACT

Nanotechnology and development of nanoparticle-based drug formulations is a growing and promising field, which has been extensively studied to overcome limitations of current therapies in several diseases and to develop novel treatment and diagnosing modalities. Thus, nanoparticles were used to increase drug bioavailability, drug accumulation at a specific site and to decrease drug side effects, leading to improved therapeutic effectiveness and increased patient adherence to treatment. Through manipulation of size, surface characteristics, proper drug load and release with targeted drug delivery, the nanoparticles could be developed into smart systems encasing therapeutic and imaging agents. The current review presents recent advances in the field of nanomedicines and nano based drug delivery systems through comprehensive scrutiny of the discovery and application of nanomaterials in improving both the efficacy of novel and old drugs and selective diagnosis through disease marker molecules. The opportunities and challenges of nanomedicines in drug delivery from synthetic/natural sources to their clinical applications are also discussed. A variety of nano based drug delivery systems are available in field of nanotechnology. The applications of nanotechnology in drug delivery will be a potential priority research area for the pharmaceutical and biotechnology industries in the future due to its unique potential to overcome the limitations and drawbacks of conventional drugs. It might be possible to develop new strategies providing target-specific drug therapy through newly developed nano based drug delivery systems in various disease treatments.

INTRODUCTION

Since ancient times, natural products have been used in the field of medicine. However, many of them are not clearing the clinical trial phases. The reasons comprise the use of large size materials in drug delivery which poses major challenges, including *in vivo* instability, poor solubility and bioavailability, poor absorption, lack of target-specific delivery and probable toxic effects of drugs. Therefore, using new drug delivery systems with specific targeting drugs could be an option that might solve these critical issues. In recent decades, nanotechnology has found an unprecedented attention and shown to bridge the barrier of biological and physical sciences. It has a significant role in advanced drug formulations, targeting arena and their controlled drug release and delivery with immense success. Nanoparticles are solid, colloidal particles with size range from 10 nm to <1000 nm; however, for nanomedical application, the preferential size is less than 200 nm. Nanoscale sized

particles exhibit unique structural, chemical, mechanical, magnetic, electrical and biological properties. Nanomedicines have become well appreciated in recent times due to the fact that nanostructures could be utilized as delivery agents by encapsulating drugs and deliver them to target tissues more precisely with a controlled release; resulting in disease prevention and remediation [1]. The review focused on the necessity, desirable characteristics for successful nanoparticle based drug delivery systems, their types as well as the various applications in which these nanoparticle systems have shown promise. In addition, we have discussed the future prospects of emerging nano based systems in field of nanomedicine.

Requirement

Use of nanoparticles for therapeutic and diagnostic use, as well as advancement of drug delivery, is important and much needed. As traditional drugs available now for oral or injectable administration are not always manufactured as the optimal formulation for each product. Products require a more innovative type of carrier system to enhance their efficacy and protect them from unwanted degradation. The efficiency of most drug delivery systems is directly related to particle size. Due to their small size and large surface area, nanoparticles show increase solubility and thus enhanced bioavailability, additional ability to cross the blood brain barrier (BBB), enter the pulmonary system and be absorbed through the tight junctions of endothelial cells of the skin. Their fundamental functions are to increase the drug concentration in targeted tissues and to reduce systemic side effects by modulating the pharmacokinetics and biodistribution of the drug payload. Nanoparticles made from natural and synthetic polymers have received more attention because they could be customized for targeted delivery of drugs, improve bioavailability and provide a controlled release of medication from a single dose; through adaptation the system can prevent endogenous enzymes from degrading the drug. Secondly, development of new drug delivery systems is providing another advantage for pharmaceutical sales to branch out. Innovative drug delivery is driving the pharmaceutical companies to develop new formulations of existing drugs. While these new formulations will be beneficial to the patients, it will also create a powerful market force, driving the development of even more effective delivery methods [2,3].

Characteristics of Nanoparticles

Particle size: The distribution, toxicity and targeting ability of nanoparticles in the body depends on shape and size. As particles size gets smaller, surface area to volume ratio gets larger. This would imply that more of the drug is closer to the surface of the particle compared to a larger molecule. Being at or near the surface would lead to faster drug release. It has been shown that particles 200 nm or larger tend to activate the lymphatic system and removed from circulation quicker. Thus, from the literature so far, it is clear that the optimum size for a nanoparticle is approximately 100 nm. At this size, the particle could pass through the blood brain barrier (BBB), deliver sufficient amount of drug due to high surface area to volume ratio and avoiding immediate clearance by the lymphatic system [4].

Surface properties: For an optimum nanoparticle drug delivery system, the incorporation of appropriate targeting ligands, surface curvature and reactivity is important to prevent aggregation, improve stability, receptor binding and post pharmacological effects of the drug. As hydrophobic nanoparticles cleared easily, it seems logical to assume that making their surface hydrophilic would increase their time in circulation. By creating polymer complexes, clearance issues have been addressed, but aggregation is still a concern with small particles due to large surface area. Several strategies have been employed to prevent aggregation through particles coating with capping agents and altering the zeta potential (surface charges). The size of the particle must be large enough to avoid leakage into blood capillaries, but not too large to become susceptible to macrophage clearance. By manipulating the surface, the extent of aggregation and clearance could be controlled [5].

Drug loading and release: The release of drug from the nanoparticle based formulation depends on many factors, namely, pH, temperature, drug solubility, desorption of the surface-bound or adsorbed drug, drug diffusion through the nanoparticle matrix, nanoparticle matrix swelling and erosion, and the combination of erosion and diffusion processes. Depending on the type of nanoparticle being used, the release of drug will differ. The prepared polymeric nanoparticles are of two types, *i.e.,* nanocapsules or nanospheres based on their composition. Nanospheres are homogeneous system in which the

Nano Based Drug Delivery Systems: Present and Future Prospects. Nanomedicine And Nanotechnology Journal. 2019; 2(1):121.

polymer chains arrange in a similar fashion to surfactants in micelle formation. In nanospheres, the drug is physically and uniformly dispersed and released by erosion of the matrix. There is a rapid burst of drug release related to weakly bound drug to the large surface area of the nanoparticle followed by a sustained release. While, nanocapsules are heterogeneous system, in which the drug is inside a reservoir composed of the polymer (like vesicle). In nanocapsules, the release controlled by drug diffusion through the polymeric layer and thus, diffusion of drug through that polymer is definitely a determining factor of its deliverability. If there are ionic interactions between the drug and polymer, they will form complexes which inhibit the release of drug from the capsule. This could be avoided by adding other auxiliary agents such as polyethylene oxide-propylene oxide (PEO-PPO). This will decrease the interactions between the drug and capsule matrix allowing for greater release of drug to target tissues [6].

Targeted drug delivery: Ideally, a nanoparticle drug delivery system should reach, recognize, bind and deliver its amount to specific tissues and minimize drug induced toxicity to healthy tissues. Thus, coating specific targeting ligand(s) on the surface of nanoparticles is the most common strategy. These targeting ligands could be small molecules, peptides, antibodies, designed proteins and nucleic acid. Small organic molecules are the most commonly employed targeting agents due to relative ease of preparation, stability, and control of conjugation chemistry with. These targeting ligands may not have desired specificity and affinity [7]. Nanoparticles can enter the human body, via direct injection, inhalation and oral intake. Once, they enter systemic circulation, particle-protein interaction taking place before distribution into various organs. Absorption from the blood capillaries allows the lymphatic system to further distribute and eliminate the particles. The fluid recovery, involves the filtering of fluids by the lymphatic system from blood capillaries, enable encompassing immunity. As the system recovers excess fluid, it also picks up foreign cells and chemicals from the tissues. As the fluids filtered back into the blood, the lymph nodes detect any foreign matter passing through. If something is recognized as foreign, macrophages will engulf and clear it from the body [8].

Nano Based Drug Delivery Systems (NDDSs)

Hydrogel: Hydrogel nanoparticles are based on hydrophobic polysaccharides for encapsulation and delivery of drug, therapeutic protein, or vaccine antigen. A novel system using cholesterol pullulan (extracellular polysaccharide excreted by the fungus *Aureobasidium pullulans)* shows great promise. In this regard, four cholesterol molecules gather to form a self-aggregating hydrophobic core with pullulan outside. The resulting cholesterol nanoparticles stabilize entrapped proteins by forming this hybrid complex. These particles stimulate the immune system and are readily taken up by dendritic cells. Alternatively, larger hydrogels can encapsulate and release monoclonal antibodies [9].

Emulsion: Emulsions are isotropic, thermodynamically stable systems composed of oil, water and surfactant. They contain two phases consisting of two immiscible liquids that are mixed together and stabilized with the aid of a surfactant with or without a co-surfactant. They may have droplets in the range suspensions of 5-100 nm. Microemulsions have been proposed as drug delivery systems to enhance the absorption of drug across biological membranes. Some of the advantages of micro-emulsions include increased solubility and stability of drugs and ease and economy of scale-up. Few disadvantages also associated including premature leakage/release of incorporated drug, phase inversion, lack of pharmaceutically acceptable toxicity profile in many effective surfactants and often require development of complex systems that might be time consuming [10].

Micelle: Polymeric micelles are <100 nm in size and normally have a narrow distribution to avoid fast renal excretion, thus permitting their accumulation in tumor tissues. In addition, their polymeric shell restrains nonspecific interactions with biological components. These nanostructures have a strong prospective for hydrophobic drug delivery since their interior core structure permits the assimilation of these kind of drugs resulting in enhancement of stability and bioavailability [11].

Liposome: Liposomes are small spherical vesicles with one or more aqueous compartments completely enclosed by molecules that have hydrophilic and hydrophobic functionality. They could be single or in multiple bilayers. Those containing one bilayer membrane are termed small unilamellar vesicles or large unilamellar vesicles based on their sizes. If more than one

Nano Based Drug Delivery Systems: Present and Future Prospects. Nanomedicine And Nanotechnology Journal. 2019; 2(1):121.

bilayer is present then they are called multilamellar vesicles. Liposomes are commonly used as model cells or carriers for various bioactive agents including drugs, vaccines, cosmetics and nutraceuticals. Drugs associated with liposomes have markedly altered pharmacokinetic properties compared to free drugs in solution. Liposomes are also effective in reducing systemic toxicity and preventing early degradation of the encapsulated drug after administration [12].

Dendrimer: Dendrimers are highly branched macromolecules with many functional groups available for the attachment of drug, targeting and imaging agents and their absorption, distribution, metabolism and elimination (ADME) profile is dependent upon various structural feature [13]. Dendrimers are highly bifurcated, monodisperse, well-defined and three-dimensional structures. They are globular-shaped and their surface is functionalized easily in a controlled way, which makes these structures excellent candidates as drug delivery agents [14].

Inorganic nanoparticle: Inorganic nanoparticles include silver, gold, iron oxide and silica nanoparticles. Studies focused on them are not as many as there are on other nanoparticle types discussed in this section although they show some potential applications. However, only few of the nanoparticles have been accepted for its clinical use, whereas the majority of them are still in the clinical trial stage. Metal nanoparticles, silver and gold, have particular properties like surface plasmon resonance (SPR), that liposomes, dendrimers, micelles do not possess. They showed several advantages such as good biocompatibility and versatility when it comes to surface functionalization [11].

Nanocrystal: Nanocrystals are pure solid drug particles within 1000 nm range. These are 100% drug without any carrier molecule attached to it and are usually stabilized by using a polymeric stabilizers or surfactants. A nanocrystal suspension in a marginal liquid medium is normally alleviated by addition of a surfactant agent known as nano-suspension. In this case, the dispersing medium is any aqueous or non-aqueous media. Nanocrystals possess specific characters that permit them to overcome difficulties like increase saturation solubility, increased dissolution velocity and increased glueyness to surface/cell membranes [15].

Carbon Based Nanoparticles

Carbon based nanoparticles include two main types: carbon nanotubes (CNTs) and fullerenes. CNTs are an allotropic form of carbon with cylindrical framework and deepening on number of sheets in concentric cylinders, they can be classified as single-walled carbon nanotubes (SWCNTs) and multiwalled carbon nanotubes (MWCNTs). CNTs are unique in a way as they are thermally conductive along the length and non-conductive across the tube. The other physical properties of CNTs, such as mechanical strength, electrical conductivity, and optical properties, were used in biomedical applications. Carbon nanotubes can also be chemically modified to specific moieties (e.g., functional groups, molecules, and polymers) to impart properties suited for biological applications. Nitrogen-doped carbon nanotubes for instance have been developed for drug delivery applications. However, the issue of cytotoxicity of CNTs is an area that has already attracted much research interest and has not resulted in a definitive answer yet [16].

Fullerenes are the allotropes of carbon having a structure of hollow cage of sixty or more carbon atoms. The structure of C-60 is called Buckminsterfullerene, and looks like a hollow football. The carbon units in these structures have a pentagonal and hexagonal arrangement. These have commercial applications due to their electrical conductivity, structure, high strength, and electron affinity. In the field of nanotechnology, heat resistance and superconductivity are some of the more heavily studied properties. Fullerenes were under study for various medicinal use, in binding specific antibiotics to the structure to target resistant bacteria and even target certain cancer cells such as melanoma and as light-activated antimicrobial agents [17]. Fullerenes were made to be absorbed by HeLa cells by using the functional groups L-phenylalanine, folic acid, and L-arginine among others [18]. Few publications have also been available on fullerene toxicity that indicated that these carbon nanoparticles were not only dose and time-dependent, but also depends on a number of other factors [19].

Polymeric Nanoparticles

Polymeric nanoparticles are organic based nanoparticles. Depending upon the method of preparation, these have shaped like nanocapsular or nanospheres structures. A

Nano Based Drug Delivery Systems: Present and Future Prospects. Nanomedicine And Nanotechnology Journal. 2019; 2(1):121.

nanosphere particle has a matrix-like structure whereas the nanocapsular particle has core-shell morphology. In the former, the active compounds and the polymer are uniformly dispersed whereas in the latter the active compounds are confined and surrounded by a polymer shell. Some of the merits of polymeric nanoparticles are controlled release, protection of drug molecules, ability to combine therapy and imaging, specific targeting and many more. They have applications in drug delivery and diagnostics. The drug deliveries with polymeric nanoparticles are highly biodegradable and biocompatible. In cancer, targeted polymeric NPs can be used to deliver chemotherapies to tumor cells with greater efficacy and reduced cytotoxicity on peripheral healthy tissues [20].

Lipid Based Nanoparticles

Lipid nanoparticles are generally spherical in shape with a diameter ranging from 10 to 100 nm. It consists of a solid core made of lipid and a matrix containing soluble lipophilic molecules. The external core of these nanoparticles is stabilized by surfactants and emulsifiers. These nanoparticles have application in the biomedical field as a drug carrier, delivery and RNA release in cancer therapy. Thus, the field of nanotechnology is far from being saturated and it is, as the statistic says, sitting on the staircase of an exponential growth pattern. It is basically at the same stage as the information technology was in the 1960s and biotechnology in the year of 1980s. Thus, it can easily be predicted that this field would witness a same exponential growth as the other two technological fields witnessed earlier [21]

Quantum Dot

Quantum dots (QDs) are known as semiconductor nanocrystals with diameter range from 2 to 10 nm and their optical properties, such as absorbance and photoluminescence are size-dependent. The QDs has gained great attention in the field of nanomedicine, since, unlike conventional organic dyes, the QDs presents emission in the near-infrared region (< 650 nm), a very desirable characteristic in the field of biomedical images, due to the low absorption by the tissues and reduction in the light scattering. In addition, QDs with different sizes and/or compositions can be excited by the same light source resulting in separate emission colors over a wide spectral range [22]. Their absorption spectrum ranges from UV to a wavelength within visible spectrum and provide high quantum yield, tunable emission spectrum and photostability. Size of the nanodot determines where in the spectra that individual particle falls. Larger particles have longer wavelengths with narrow emission [23].

Biopolymeric Nanoparticle

Starch is a common polysaccharide, occurs majorly in plants where they act as storage materials. Chemically, it is composed of recurring units of glycopyranose in an alpha D-(1, 4) linkage and on hydrolysis yields the monosaccharide, glucose. The use of starch in pharmaceutics is extensive. It is used as co-polymer and incipient in controlled drug delivery as drug carriers in tissue engineering scaffolds as hydrogels and as solubility enhancers [24].

Cellulose and its derivatives are extensively utilized in drug delivery systems basically for modification of the solubility and gelation of the drugs that resulted in the control of the release profile. The presence of the hydrogen bonds between the cellulose nanocrystals and the drug, resulted in sustained release of the same, and subsequently the nanoparticles made with oxidized cellulose nanocrystals presented lower release when compared to the nanoparticles produced with native cellulose nanocrystals [25]. Chitosan polymer is obtained from the partial N-deacetylation of chitin found in the shells of crustacean. It is composed of glucosamine and N-acetyl glucosamine linked by β 1-4 glucosidic bonds and is one of the most widely studied natural polymers for nano-drug delivery. The deacetylation of chitin is both concentration and temperature dependent with optimal yields achieved at temperatures between 600 °C - 800 °C using 50% w/w alkali. Chitosan exhibits muco-adhesive properties and can be used to act in the tight epithelial junctions. Thus, chitosan-based nanomaterials are widely used for continued drug release systems for various types of epithelia, including buccal, intestinal, nasal, eye and pulmonary [26]. Gelatin is obtained from the breakdown and hydrolysis of collagen of connective tissues, bones and skin of animals. It is a known matrixing drug delivery agent. Gelatin was shown to be versatile due to its intrinsic features that enable the design of different carrier systems, such as microparticles and nanoparticles, fibers and even hydrogels. Gelatin microparticles can serve as vehicles for cell amplification and for delivery of large bioactive molecules, whereas gelatin nanoparticles are better suited for intravenous

delivery or for drug delivery to the brain. Gelatin fibers contain a high surface area-to-volume ratio, whereas gelatin hydrogels can trap molecules between the polymer's crosslink gaps, allowing these molecules to diffuse into the blood stream. Another interesting area is the combination of tissue bioadhesive-based gelatin with controlled drug release for pain management and wound healing [27]. Alginate is a biomaterial that has found numerous applications in biomedical science and engineering due to its favorable properties, including biocompatibility and ease of gelation. This biopolymer presents final carboxyl groups, being classified as anionic mucoadhesive polymer and presents greater mucoadhesive strength when compared with cationic and neutral polymers. Alginate have been particularly attractive in wound healing, drug delivery, and tissue engineering applications to date, as these gels retain structural similarity to the extracellular matrices in tissues and can be manipulated to play several critical roles [28]. Xanthan gum (XG) is a high molecular weight heteropolysaccharide produced by *Xanthomonas campestris*. It is a polyanionic polysaccharide and has good bioadhesive properties. Because it is considered non-toxic and non-irritating, xanthan gum is widely used as a pharmaceutical excipient. Xanthan gum has the potential in retarding drug release to its gelling nature and ability of entrapping the drug within the gel [29].

APPLICATIONS

Cancer Therapy

Micelles and liposomes offer an option for delivery of chemotherapeutic agents in treatment of cancer like diseases. Additionally, micelles are also a great way to make insoluble drugs soluble due to their hydrophobic core and hydrophilic shell. If the micelle's surface is further PEGylated, it increases the ability of the nanocarriers to get through fenestrated vasculature of tumors and inflamed tissue through passive transport, thus resulting in higher drug concentration in tumors. As of now, several polymeric micelles containing anticancer drugs, NK012, NK105, NK911, NC-6004, and SP1049C are under clinical trials and one such system, Genexol-PM (paclitaxel) is approved for breast cancer patients [3]. A polyfunctional dendrimer system has been reported for successful localization (folic acid), imaging (fluorescein) and delivery of the anticancer drug methotrexate *in vitro*. Nanoparticle therapeutics based on dendrimers can improve the therapeutic index of cytotoxic drugs by employing biocompatible components and the surface derivatization with PEGylation, acetylation, glycosylation and various amino acids. Since Carbon nanotubes have very hydrophobic hollow interior, water insoluble drugs can easily be loaded them. The large surface area allows for outer surface functionalization and can be done specifically for a particular cancer receptor as well as contrast agents. Moreover, buckminsterfullerene C_{60} (spherical molecule) and its derivatives are also evaluated for the treatment of cancer [3].

Diagnosis

Advantages associated with tagging of the quantum dots. First, they are excitable using white light. Secondly, they can be linked to biomolecules that can spend considerable amount of time in the living system to probe various bio-mechanisms. This technology allows monitoring of many biological events simultaneously by tagging various biological molecules with nanodots of a specific color [23]. Recently, theranostic nanoparticles can be used for treatment as well as diagnoses have gained much attention [30]. This strategy has been realized in many classes of nanoparticles including, drug conjugates, dendrimers, surfactant aggregates (micelles and vesicles), core-shell particles, and carbon nanotubes. By combing both drug and imaging agent in one smart formulation, it is possible to monitor the pathway and localization of these nanoparticle at the target site as well drug action to assess therapeutic response [31].

HIV and AIDS Treatment

Research has shown a way to make the treatment even more effective by creating polymeric nanoparticles that deliver antiretroviral (ARV) drugs intra-cellular as well as to the brain. This technology can also be used in adjunct with vaccinations to prevent HIV infections. In order to prevent the development of resistance and aggressively counter the HIV progression, a combination of multiple drugs are used, this known as highly active antiretroviral therapy (HAART). Nanotechnology has played a pivotal role in delivering the antiretroviral drugs and improving compliance. Antiretroviral drugs must be able to cross the mucosal epithelial barrier when taken orally or other non-parental routes. Nanoparticles are known to be able to cross blood brain barrier (BBB) by endocytosis/ phagocytosis

Nano Based Drug Delivery Systems: Present and Future Prospects. Nanomedicine And Nanotechnology Journal. 2019; 2(1):121.

and many reports exist showing successful delivery of anti-HIV medications [32].

Nutraceutical Delivery

Nutraceuticals are food derived, standardized components with noticeable health benefits. They are commonly consumed as complement to various allopathic treatments as well as to provide extra health benefits and decrease risks of several chronic illnesses. Similar to any other drug, the bioavailability and efficacy of orally consumed nutraceuticals is affected by food matrices interactions, aqueous solubility, degradation/ metabolism and epithelial permeability. Most nutraceuticals are lipophilic molecules, such as fat soluble vitamins (A, D, E and K), polyunsaturated lipids and other phytochemicals. Nanotechnology again offers comprehensive assistance and most of the investigations have been aimed at improving the dissolution mechanisms of nutraceuticals via nanoparticle formulations [33,34].

Future Prospects

The science of nanomedicine is currently among the most fascinating areas of research to diagnose diseases and even combining diagnosis with therapy has also become realism. In near future, firstly, the fate of nano based drug delivery systems (NDDSs) such as their integrity, surface characteristics, pharmacokinetics, biodistribution and immunological effects need detailed tracing and analysis. Advanced technologies and methods are essential for this challenging exploration. Secondly, there should be a normative evaluation framework to assess the efficiency of NDDSs and rational animal models should be established. The right target, tissue exposure, safety, patient and commercial potential of NDDSs might be of beneficial guidance. The skills of chemists, mathematicians, biologists and medical scientists to design clinically valuable NDDSs are equally important. Understanding the heterogeneity and biological nature of the tumor will really help us create NDDSs which may meet the expected treatment efficiency. In addition, to structurally simple and reproducibly synthesized NDDSs should pay more attention because these have the greatest potential to reach the patient. Even though regulatory mechanisms for nanomedicines along with safety/toxicity assessments will be the subject of further development in the future, nanomedicine has already revolutionized the way discovers and administer drugs in biological systems [2].

CONCLUSION

Nanotechnology is an innovative, multidisciplinary approach that has potential applications in medicinal and health research. Drug-loaded nanoparticles have emerged as one of the most important applications in medicine. It is evident that application of nontechnology in drug delivery and medicine has paved new pathways and opened many doors for providing customizable and safer treatment options. Nanotechnology definitely promises to serve as drug delivery carrier of choice for the more challenging conventional drugs used for the treatment and management of chronic diseases such as cancer, asthma, hypertension, HIV and diabetes. Advantages of nanoparticles for drug delivery applications include drug targeting, controlled drug release, protection of therapeutic payload and improved bioavailability. Ultimately, through the manipulation of molecular size and surface properties, researchers are able to deliver drugs for longer period of time with less frequent dosing and with greater precision and penetration in difficult to access tissues. In all, despite great challenges, a well-designed nanosystem can make an important contribution to the development of promising products for the improvement of human health.

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REFERENCES

1. Martinho N, Damgé C, Reis CP. (2011). Recent advances in drug delivery systems. J Biomater Nanobiotechnol. 2: 510-526.
2. Wang YF, Liu L, Xue X, Liang XJ. (2017). Nanoparticle-based drug delivery systems: What can they really do in vivo?. 6: 681.
3. Rizvi SAA, Saleh AM. (2018). Applications of nanoparticle systems in drug delivery technology. Saudi Pharm J. 26: 64-70.
4. McMillan J, Batrakova E, Gendelman HE. (2011). Cell delivery of therapeutic nanoparticles. Prog Mol Biol Transl Sci. 104: 563-601.

5. Sykes EA, Dai Q, Sarsons CD, Chen J, Rocheleau JV, et al. (2016). Tailoring nanoparticle designs to target cancer based on tumor pathophysiology. Proc Natl Acad Sci USA. 113: E1142-E1151.
6. Son G, Lee B, Cho C. (2017). Mechanisms of drug release from advanced drug formulations such as polymeric-based drug-delivery systems and lipid nanoparticles. J Pharmaceut Invest. 47: 287-296.
7. Friedman AD, Claypool SE, Liu R. (2013). The smart targeting of nanoparticles. Curr Pharm Des. 19: 6315-6329.
8. Mu Q, Jiang G, Chen L, Zhou H, Fourches D, et al. (2014). Chemical basis of interactions between engineered nanoparticles and biological systems. Chem Rev. 114: 7740-7781.
9. Singh R, Lillard JW. (2009). Nanoparticle-based targeted drug delivery. Exp Mol Pathol. 86: 215-223.
10. Majuru S, Oyewumi MO. (2009). Nanotechnology in drug development and life cycle management. de Villiers MM, Aramwit P, Kwon GS, editors. In: Nanotechnology in Drug Delivery. Springer-Verlag, New York. 597-619.
11. Patra JK, Das G, Fraceto LF, Campos EVR, Rodriguez-Torres MP, et al. (2018). Nano based drug delivery systems: Recent developments and future prospects. J Nanobiotechnology. 16: 71.
12. Mozafari MR. (2005). Liposomes: An overview of manufacturing techniques. Cell Mol Biol Lett. 10: 711-719.
13. Somani S, Dufes C. (2014). Applications of dendrimers for brain delivery and cancer therapy. Nanomedicine. 2014; 9: 2403-2414.
14. Kesharwani P, Jain NK. (2014). Dendrimer as nanocarrier for drug delivery. Prog Polym Sci. 39: 268-307.
15. Junyaprasert VB, Morakul B. (2015). Nanocrystals for enhancement of oral bioavailability of poorly water-soluble drugs. Asian J Pharm Sci. 10: 13-23.
16. Rastogi V, Yadav P, Bhattacharya SS, Mishra AK, Verma N, et al. (2014). Carbon nanotubes: An emerging drug carrier for targeting cancer cells. J Drug Deliv. 2014: 670815.
17. Tegos GP, Demidova TN, Arcila-Lopez D, Lee H, Wharton T, et al. (2005). Cationic fullerenes are effective and selective antimicrobial photosensitizers. Chem Biol. 12: 1127-1135.
18. Mroz P, Pawlak A, Satti M, Lee H, Wharton T, et al. (2007). Functionalized fullerenes mediate photodynamic killing of cancer cells: type I versus typee II photochemical mechanism. Free Radic Biol Med. 43: 711-719.
19. Lalwani G, Sitharaman B. (2013). Multifunctional fullerene and metallofullerene based nanobiomaterials. Nano LIFE. 3: 1342003.
20. Chan JM, Valencia PM, Zhang L, Langer R, Farokhzad OC. (2010). Polymeric nanoparticles for drug delivery. Methods Mol Biol. 624: 163-175.
21. Raut ID, Doijad RC, Mohite SK. (2018). Solid lipid nanoparticles: A promising drug delivery system. IJPSR. 9: 862-871.
22. Volkov Y. (2015). Quantum dots in nanomedicine: Recent trends, advances and unresolved issues. Biochem Biophys Res Commun. 468: 419-427.
23. Li J, Zhu JJ. (2013). Quantum dots for fluorescent biosensing and bio-imaging applications. The Analyst. 138: 2506-2515.
24. Wu C, Zhongyan W, Zhi Z, Jang T, Zhang J, et al. (2011). Development of biodegradable porous starch foam for improving oral delivery of poorly water soluble drugs. Int J Pharm. 403: 162-169.
25. Bhatia S. (2016). Nanoparticles types, classification, characterization, fabrication methods and drug delivery applications. Bhatia S, editor. In: Natural Polymer Drug Delivery Systems. Springer, Cham. 33-93.
26. Park JH, Saravanakuma G, Kwangmeyung K, Kwon I. (2010). Targeted delivery of low molecular drugs using chitosan and its derivatives. Adv Drug Deliv Rev. 62: 28-41.
27. Foox M, Zilberman M. (2015). Drug delivery from gelatin-based systems. Expert Opin Drug Del. 12: 1547-1563.
28. Lee KY, Mooney DJ. (2012). Alginate: Properties and biomedical applications. Prog Polym Sci. 37: 106-126.
29. Benny IS, Gunasekar V, Ponnusami V. (2014). Review on application of xanthan gum in drug delivery. Int J PharmTech Res. 6: 1322-1326.

30. Janib SM, Moses AS, Mackay JA. (2010). Imaging and drug delivery using theranostic nanoparticles. Adv Drug Deliv Rev. 62: 1052-1063.
31. Datta R, Jaitawat S. (2006). Nanotechnology - The new frontier of medicine. Med J Armed Forces India. 62: 263-268.
32. Jayant R, Nair M. (2016). Nanotechnology for the treatment of NeuroAIDS. J Nanomed Res. 2016; 3: 00047.
33. Acosta E. (2009). Bioavailability of nanoparticles in nutrient and nutraceutical delivery. Curr Opin Colloid Interface Sci. 14: 3-15.
34. McClements DJ, Li F, Xiao H. (2015). The nutraceutical bioavailability classification scheme: Classifying nutraceuticals according to factors limiting their oral bioavailability. Ann Rev Food Sci Technol. 6: 299-327.