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Review Article

Nanoparticles in Targeted Drug Delivery System

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A B S T R A C T

Nanotechnology has emerged as a transformative approach in modern pharmaceutical sciences, particularly in improving drug delivery system[1,3]. Nanoparticles, due to their unique physicochemical properties, enable targeted delivery of therapeutic agents to specific sites within the body. This thesis explores the principles, types, mechanisms, advantages, limitations, and applications of nanoparticles in targeted drug delivery. Special emphasis is placed on their role in enhancing bioavailability, reducing toxicity, and improving therapeutic efficacy [7,16]. The study also highlights recent advancements and future perspectives in nanomedicine.

Keywords: Nanotechnology, Targeted Drug Delivery System, Nanoparticles

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INTRODUCTION

Nanotechnology has made such great strides over the past several decades that its use has completely changed the way we design and deliver therapeutic agents. Traditional drug delivery methods have had many significant limitations, including poor bioavailability, lack of selectivity for the target tissue, quick degradation, and systemic side effects [2,6].

These limitations have led researchers to develop more efficient, accurate drug delivery systems, which is why nanotechnology-based drug delivery systems based on nanoparticles are positioned as a potential solution [3,14].

Nanoparticles are particles that range in size from 1 to 100 nanometers (nm) and have unique physical and chemical properties, including high surface area to volume ratio, adjustable surface chemistry, and the ability to cross biological barriers.

With these properties, nanoparticles are highly amenable to delivering various therapeutic components, including small molecules, proteins, and nucleic acids. The engineering of nanoparticle-based drug delivery systems has been accomplished through the application of pharmacology principles. The principles of materials science have also provided groundbreaking advances in the ability to solve solubility issues associated with drug delivery, provide enhanced stability for therapeutic agents and provide controlled or sustained delivery of therapeutic agents.

Nanoparticles used for drug delivery offer a number of advantages. One of the more significant advantages associated with the use of nanoparticles for drug delivery is that it allows for the targeted delivery of therapy to patients. Drug-loaded nanoparticles may achieve targeted delivery through both passive (e.g., the enhanced permeability and retention [EPR] effect) and active targeting mechanisms (i.e., ligand-receptor interactions) resulting in the selective accumulation of drug-laden nanoparticles in diseased tissues with little or no exposure of drug-loaded nanoparticles to healthy tissues.

This targeted delivery approach is especially advantageous to the treatment of complicated disease states, such as Cancer, due to the fact that conventional modality Drug Treatment is

generally associated with significant side effects and is ineffective compared to other treatment options.

Nanoparticles do not only enhance the overall efficacy of therapy; they provide an opportunity to develop therapeutic strategies that are based on individual patient characteristics. For example, through the conjugation of a variety of different ligands, antibodies, or polymers on the surface of the nanoparticle, the development of a highly individualized drug delivery system can be accomplished. Additionally, the use of nanoparticles to integrate diagnostic and therapeutic applications into a single delivery platform (ex.-theranostics) represents a major advancement towards the goal of achieving healthcare that is more precise and effective than traditional methods would provide.

Although there have been some advances in nanotechnology, there are still many obstacles that must be overcome before their clinical application can be widely accepted. The main problems are related to the toxicity level, the compatibility with human beings, the ability to produce large quantities, and the regulatory approval process. There is also much work done to develop a better understanding of how nanoparticles will behave in a biological environment.

This article includes an extensive review of the various types of nanotechnology-based drug delivery systems. Also included are detailed descriptions of how each system works, their benefits and disadvantages, and what has been completed since last spring. It is the purpose of this review to provide current insights into emerging trends and future opportunities that can lead to improved and safer approaches to therapeutic methods.

The effectiveness of a therapeutic agent is no longer solely based upon the agent's intrinsic properties but also how effectively that agent is delivered to the site of action. Although traditional delivery methods for pharmaceuticals have been commonly employed, there are many hurdles associated with traditional routes of administration such as poor solubility; limited bioavailability; non-targeted specific effect. Therefore, researchers have been motivated to develop novel strategies to provide cures or improved health outcomes for patients with less damage to surrounding healthy tissues.

Targeting drugs to specific parts of the body is a method of using nanoparticles to create drug carriers that can recognize and bind to certain types of cells, tissues, or receptors in the body. Targeting can happen passively through mechanisms, such as the enhanced permeation effect associated with tumor tissues; or actively through the functionalization of nanoparticles with specific ligands, antibodies, or peptides thus allowing them to bind to disease-specific markers.[24,38]. Thus, drugs accumulate predominantly at the desired site of action versus being distributed systemically throughout the body. For instance, when treating patients with cancer, nanoparticles could be designed to bind to tumor cells that overexpress certain receptors on their surface; thus ensuring that the drug is delivered specifically to the area of disease.

This level of precision provides a unique opportunity to avoid exposing normal tissues or organs to poorly targeted delivery systems while simultaneously improving the efficacy of therapeutic modalities.

Advantages of nanoparticles in TDDS -

The foremost benefit derived from using nanoparticles in targeted delivery of medicines is that they can specifically target the diseased area of the body for drug delivery through modification of the surface of the matrix with targeting attachment points for a particular type of cell. The use of HER2-targeted nanoparticles, for example, allows for delivery of drugs to only HER2-positive breast cancer cells, thereby improving drug efficacy while minimizing toxicity to surrounding healthy tissue [17, 27].

Nanoparticles allow for the targeted delivery of a therapeutic agent due to their ability to concentrate the drug in/near the area of interest; thus, the overall exposure of the body to the drug is reduced, resulting in fewer adverse effects (compared to traditional treatments).

For example, by using liposomal forms of chemotherapeutic agents (e.g., doxorubicin), the potential for cardiotoxicity is considerably diminished while retaining anti-cancer efficacy. The result is that patients should experience fewer adverse effects and improved quality of life during the course of their treatment.

Nanoparticles can also be designed to deliver drugs in a more controllable and sustained manner; thus, allowing for greater maintenance of therapeutic concentration as well as reducing the frequency with which a dose must be given.

This is especially important for chronic diseases (e.g., hypertension, diabetes) where a long-term effect from a drug may not only improve compliance but also increase the overall quality of life of a patient due to their fulfilling their treatment regimen.

Poor water solubility and low bioavailability are common obstacles that reduce the effectiveness of many drugs. Nanoformulations provide a means to increase the solubility &absorption of poorly soluble drugs through encapsulating drug molecules in the structure of the nanoparticle. One type of nanoformulation that has been shown to improve the solubility, absorption and therapeutic effect of curcumin is through the use of nanoparticles [11,36].

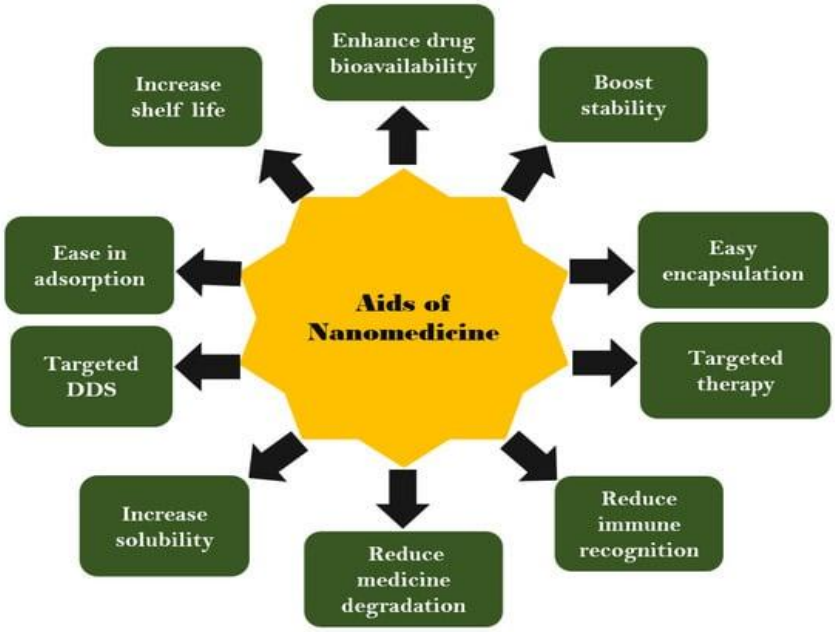

Figure: 1 AIDS OF Nanoparticles

(Afzal, O.; Altamimi, A.S.A.; Nadeem, M.S.; Alzarea, S.I.; Almalki, W.H.; Tariq, A.; Mubeen, B.; Murtaza, B.N.; Iftikhar, S.; Riaz, N.; et al. Nanoparticles in Drug Delivery: From History to Therapeutic Applications. Nanomaterials 2022, 12, 4494. https://doi.org/10.3390/nano12244494)

Protection of Drug Molecules

Drug molecules that are sensitive to biological environments will often lose their activity by being degraded due to biological processes. Sensitive drugs such as proteins, peptides, and nucleic acids are susceptible to degradation in the biological environment. By encapsulating these forms of drug molecules within nanoparticles, drug molecules that are sensitive to biological environments can be protected from enzymatic degradation and the undesirable effects of various physiological conditions . For example, insulin is currently being delivered using nanoparticles to preserve its structural integrity and prevent degradation in the gastrointestinal tract, which could allow the possibility for the development of oral insulin therapy to occur.

By crossing biological barriers, nanoparticles play an essential role in the treatment of neurological disorders, including Alzheimer's disease and brain tumors. The ability of certain nanoparticles to cross the blood-brain barrier (BBB) enables targeted delivery of drugs directly to the brain, thus producing superior therapeutic results when compared with traditional drug therapies for the central nervous system.

Because of their ability to target specific cells or tissues with high precision and to provide controlled drug release over time, lower doses of drugs are often adequate to produce the desired therapeutic results. Therefore, the administration of lower doses of medication reduces the risk of toxicity and the need to administer drugs frequently. As a result, patients will experience fewer side effects, a decreased treatment burden, and improved compliance with their therapy.

Disadvantages of Using Nanoparticles for Targeting Drug Delivery Systems

1. Potential Toxicities and Safety Issues:

A potential disadvantage of nanoparticles is their risk for toxicity[28,29].Because of their small size, nanoparticles can find their way into biological membranes and accumulate in critical organs such as the liver, kidneys, lungs, and the brain. These accumulations can result in cellular damage due to oxidative stress, inflammation and long-term damage to tissues. An example of this is metallic nanoparticles (such as silver or gold), which can have cytotoxicity due to their accumulation in the body at high concentrations when used in drug delivery. Therefore, if a patient undergoes treatment with nanoparticles and experiences no ill effects from their treatment, there is still a concern regarding whether these nanoparticles will have a long-term effect on their health.

2. Complexity Of Design and Manufacturing:

The formulation of drug nanoparticle delivery systems is very complex and requires sophisticated equipment, highly trained personnel, and careful control of variables size of nanoparticles, surface charge, and efficiencies of drug loading to obtain an effective drug delivery system. Small change in the preparations can create large differences in performance and safety of the nanoparticles. For instance, during the formulation of

polymeric nanoparticles for use in targeted cancer therapy, ligand bonding needs to be exact in order to obtain optimal targeting of the nanoparticles, thereby increasing the complexity of the nanoparticle formulations. Therefore, these complexities result in difficulty manufacturing large quantities of the nanoparticles, hence limiting widespread access to these systems [31,39].

Compared to conventional products, nanoparticle-based treatments are much more expensive due to the complex technology and materials these products utilize. The high costs associated with these types of products may cause a large portion of the population (particularly individuals in developing countries) to not have access to catheter-based treatments. Liposomal formulations utilized for cancer treatment are extremely more expensive than conventional formulations, resulting in unequal access to advanced treatments for only certain patients.

Another problem that nanoparticles must deal with is stability during storage and transportation. Many nanoparticles have the potential to aggregate or degrade, losing their functional characteristics relative to their therapeutic efficacy, throughout the period of storage prior to use. Key environmental conditions (e.g., temperature, pH, light) caneffect the stability of nanoparticles. For example, inappropriately storing lipid-based nanoparticles may cause them to undergo oxidation or structural changes, reducing their shelf life and creating obstacles to maintaining product quality.

Limited Targeting Efficiency in Practice

Even though nanoparticles are engineered for specific drug delivery to target organs or tissues, they typically do not achieve complete target specificity in human. Several factors have contributed to this lack of target specificity, including biological barriers (e.g., barriers imposed by the blood-brain barrier), recognition by the immune system, and non-specific distribution of nanoparticles within the body, thereby significantly decreasing targeting efficiency. For example, nanoparticles designed to be delivered to tumors may be ingested by the reticuloendothelial system (RES), which is composed of macrophages located in the liver and spleen, further decaying the amount of drug being delivered to the tumor site. This will reduce the overall efficacy of the therapeutic drug being delivered.

Immune System Activation and Clearance

Upon entering the body, some nanoparticles will trigger an immune response as if they are here to attack. During this attack, the immune system will most often kill the active nanoparticle's capability to perform healing before ever being able to reach its site of action. Another common occurrence is that nanoparticles can sometimes trigger additional immune responses such as inflammatory or anaphylactic response reactions due to the polyethyleneglycol shell enrollment with some polymeric nanoparticles as well as activating complement pathways causing an unwanted immune response to the patient. Such situations can lead to increased side effects and/or diminished pharmacological efficacy of the therapeutic nanoparticles.

Challenges: Ethical and Regulatory

Nanoparticles used in drug delivery face a number of regulations that are strictly enforced because there is uncertainty about their efficacy, safety and long-term effects. Regulatory agencies require a great deal of research and testing before products can be approved for human consumption, which also results in delays in product approval. In addition to regulatory uncertainty regarding nanoparticle toxicity, ethical issues associated with their environmental impact must also be addressed. For example, while the long-term fate of nanoparticles within the body and the environment is not known, this uncertainty creates an ethical issue for researchers and regulatory agencies.

Although nanoparticles have many benefits, they also have a number of drawbacks in their use as a vehicle for targeted drug delivery, including possible toxicity, high cost, formulation complexity, and a lack of effective targeting. It is important that we address these challenges so that nanotechnology can be used safely and effectively in medicine. Continued research and technological advancements should alleviate these barriers to making therapies using nanoparticles more available, reliable, and patient-friendly in the future.

Possible Future Directions of Nanoparticle-Based Targeted Drug Delivery System-

Nanoparticle-based drug delivery systems have the potential to work in concert with the concept of personalized medicine. In the future, we're likely to see the development of treatment regimens that are tailored to a patient's individual genetic makeup, disease state, and response to medications. Nanoparticles could be designed and manufactured such that they deliver their therapeutic agent(s) based on the presence of known biological markers in a patient's body. For example, in the treatment of cancer patients, nanoparticles can be designed to deliver drugs specifically targeted to mutations present in an individual’s tumour, thereby providing highly targeted therapeutics. Personalized medicine will provide patients with a greater sense of comfort and confidence regarding their treatment because it eliminates the reliance on trial and error to determine the correct medical treatment, and patients are more confident that they are receiving a more efficacious and safe treatment.

Nanotechnology nanoparticlesresponsive systems are projected to be intelligent in their ability to react to both

internal/external stimuli, such as pH temperature, enzymes and/or light. The release of any drugs carried by these nanoparticles will occur at the location of therapy and/or under specified conditions (examples include acid sensitive Nanoparticles, which undergo conformational changes when exposed to low pH, will only release their anticancer drug to the tumor microenvironment while remaining inactive in normal tissues) limiting exposure, thereby ensuring that the only impact on a person is at the location and/or for the period of time necessary for them to receive the medical intervention they need[11,33].

Anticipated to play a major role in new and advanced therapeutic delivery methods, nanoparticles will be used for gene and RNA based therapies/vaccines. The protective properties of nanoparticles will allow for the transport of genetic material (siRNA, mRNA, DNA) into cells without degradation. One example of this is the use of Lipid Nanoparticles to deliver mRNA vaccines producing new methods to treat infectious disease and genetically based disorders. It is anticipated that Nanoparticle Mediated Gene Delivery will become a viable method for treating inherited and some types of cancer at the molecular level providing hope for long-term or permanent resolution of listed conditions.

Nanotheranostics

Nanotheranostics is an advanced approach that integrates diagnostic and therapeutic mechanisms in one nanoformulation. These multifunctional nanoparticles can detect the presence of disease, provide molecularly targeted treatment, and monitor therapeutic response all at once. For example, imaging agents of gold nanoparticles can carry anticancer drugs in tumor detection and targeted therapy. Such a syncretic tactic is designed to monitor treatment efficacies in real-time and initiate changes in therapy regimens without delay. In clinical practice, nanotheranostics can help diminish repetition of diagnostic procedures and overall accuracy of treatment. Humanistically, this alleviates the distress or anxiety patients might face due to repeated diagnostic procedures and ensures more optimized and accurate treatment plans[12,40].

m RNA Delivery Systems

Nanoparticle-based mRNA delivery systems have etched significant importance owing to their role in modern therapeutics. The mRNA molecules are usually packed and guarded against by lipid nanoparticles to ensure that they remain stable and are delivered efficiently into the host cells. Once in the cells, the mRNA is translated into therapeutic proteins. A critical example is the lipid nanoparticle-based mRNA vaccines, the immune responses for which are elicited in a short time upon administration. Beyond vaccines, mRNA delivery is being explored for cancer immunotherapy, treatment of genetic disorders, and protein replacement therapies. From a humanized perception, this design can provide a minimally invasive and highly versatile treatment solution with fewer chances of repeated doses.Contribute to more compassionate and holistic the approach to treatment[13,35].

CONCLUSION

To conclude, the most recent developments of nanoparticle-based targeted drug delivery systems represent a solid step forward in the conceptualization of modern medical technologies, as well as in the practical application for the treatment and care of patients. These innovations, including smart nanoparticles, artificial intelligence (AI) integration, nanotheranostics, and mRNA delivery, have reshaped the precision, effectiveness, and versatility of therapeutic measures. Such technologies shift the traditional drug delivery into a controlled and targeted course of action that ensures drugs act only in the required tissues while avoiding other healthy tissues. Smart nanoparticles, with their ability to respond to specific biological stimuli, have introduced a level of control that was previously unattainable, making treatments more effective and less detrimental[1,20].

Integration with artificial intelligence has further sped up the development of these systems by optimizing design and predicting results and eliminating a lot of the time and uncertainty associated with formulating drugs. Nanotheranostics has bridged the gap between diagnosis and treatment, allowing for real-time monitoring and making adjustments to the treatment regimen, which is critical in complex diseases like cancer. Likewise, mRNA delivery systems have paved new ways to treat infectious diseases, genetic disorders, and cancers by the body producing its therapeutic agents. Considering a humanistic point of view, these advancements do not only include scientific progress but also benefit the quality of life patients receive. Through the mode of action of reducing side effects, minimizing invasive procedures, and improving treatment outcomes, patients experience less physical discomfort and emotional stress. The ability to receive a more precise and tailored therapy also boost the patient's confidence and trust towards medical treatments.

Also, there is promise that as these technologies keep changing and becoming more reachable, they can help in shrinking the healthcare gaps and offer advanced medical care to more people. However, despite the promising future of nanoparticle-based drug delivery, it is crucial to deal with the already existing hitches, including safety concerns, increasing cost, and large-scale production. Continuous research, ethical considerations, and regulatory advancements will play crucial role in ensuring that these innovations are safely and effectively translated to clinical practice.Overall, integrating advanced technologies with nanoparticle drug delivery systems is a step towards more compassionate, precise, and patient-centered healthcare. The above innovations have resulted in not only better treatment of diseases but in the general perception of patients of the therapy, making it less painful and more hopeful.

REFERENCE

1. Allen TM, Cullis PR. Drug delivery systems: Entering the mainstream. *Science*. 2004;303(5665):1818–1822.

2. Peer D, Karp JM, Hong S, Farokhzad OC, Margalit R, Langer R. Nanocarriers as an emerging platform for cancer therapy. *Nat Nanotechnol*. 2007;2(12):751–760.
3. Farokhzad OC, Langer R. Impact of nanotechnology on drug delivery. *ACS Nano*. 2009;3(1):16–20.
4. Torchilin VP. Multifunctional and stimuli-sensitive pharmaceutical nanocarriers. *Eur J Pharm Biopharm*. 2009;71(3):431–444.
5. Duncan R. The dawning era of polymer therapeutics. *Nat Rev Drug Discov*. 2003;2(5):347–360.
6. Zhang L, Gu FX, Chan JM, Wang AZ, Langer RS, Farokhzad OC. Nanoparticles in medicine. *Clin Pharmacol Ther*. 2008;83(5):761–769.
7. Patra JK, Das G, Fraceto LF, et al. Nano-based drug delivery systems. *J Nanobiotechnol*. 2018;16:71.
8. Shi J, Kantoff PW, Wooster R, Farokhzad OC. Cancer nanomedicine. *Nat Rev Cancer*. 2017;17(1):20–37.
9. Bobo D, Robinson KJ, Islam J, Thurecht KJ, Corrie SR. Nanoparticle-based medicines. *Pharm Res*. 2016;33(10):2373–2387.
10. Alexis F, Pridgen E, Molnar LK, Farokhzad OC. Nanoparticle biodistribution. *Mol Pharm*. 2008;5(4):505–515.
11. Mura S, Nicolas J, Couvreur P. Stimuli-responsive nanocarriers. *Nat Mater*. 2013;12(11):991–1003.
12. Lammers T, Kiessling F, Hennink WE, Storm G. Nanotheranostics. *Mol Pharm*. 2010;7(6):1899–1912.
13. Kulkarni JA, Witzigmann D, Chen S, Cullis PR. Lipid nanoparticle technology. *Acc Chem Res*. 2019;52(9):2435–2444.
14. Panyam J, Labhasetwar V. Biodegradable nanoparticles. *Adv Drug Deliv Rev*. 2003;55(3):329–347.
15. Couvreur P. Nanoparticles in drug delivery. *Adv Drug Deliv Rev*. 2013;65(1):21–23.
16. Parveen S, Misra R, Sahoo SK. Nanoparticles in therapeutics. *Nanomedicine*. 2012;8(2):147–166.
17. Wang AZ, Langer R, Farokhzad OC. Nanoparticle drug delivery. *Annu Rev Med*. 2012;63:185–198.
18. Davis ME, Chen Z, Shin DM. Nanoparticle therapeutics. *Nat Rev Drug Discov*. 2008;7(9):771–782.
19. Sercombe L, Veerati T, Moheimani F, et al. Liposome drug delivery. *Front Pharmacol*. 2015;6:286.
20. Mitchell MJ, Billingsley MM, Haley RM, et al. Precision nanoparticles. *Nat Rev Drug Discov*. 2021;20(2):101–124.
21. Torchilin VP. Recent advances with liposomes. *Nat Rev Drug Discov*. 2005;4(2):145–160.
22. Jain KK. Nanomedicine: Application of nanobiotechnology. *Pharm Res*. 2008;25(3):533–549.
23. Brannon-Peppas L, Blanchette JO. Nanoparticle targeting strategies. *Adv Drug Deliv Rev*. 2004;56(11):1649–1659.
24. Maeda H, Bharate GY, Daruwalla J. EPR effect in tumors. *Eur J Pharm Biopharm*. 2009;71(3):409–419.
25. Koo OM, Rubinstein I, Onyuksel H. Role of nanotechnology. *Nanomedicine*. 2005;1(3):193–212.
26. Ferrari M. Cancer nanotechnology. *Nat Rev Cancer*. 2005;5(3):161–171.
27. Cho K, Wang X, Nie S, Chen ZG, Shin DM. Therapeutic nanoparticles. *Clin Cancer Res*. 2008;14(5):1310–1316.
28. Singh R, Lillard JW. Nanoparticle toxicity. *Exp Mol Pathol*. 2009;86(3):215–223.
29. Albanese A, Tang PS, Chan WC. Nanoparticle cellular interactions. *Annu Rev Biomed Eng*. 2012;14:1–16.
30. Blanco E, Shen H, Ferrari M. Principles of nanoparticle design. *Nat Biotechnol*. 2015;33(9):941–951.
31. Petros RA, DeSimone JM. Strategies in nanomedicine. *Nat Rev Drug Discov*. 2010;9(8):615–627.
32. Zhao L, Seth A, Wibowo N, et al. Nanoparticle vaccines. *Nanomedicine*. 2014;9(5):673–689.
33. Shi Y, van der Meel R, Theek B, et al. Nanotechnology in cancer. *Adv Drug Deliv Rev*. 2020;160:78–104.
34. He Q, Shi J. MSN-based drug delivery. *J Mater Chem*. 2011;21:5845–5855.
35. Wang Y, Zhang L, Guo S. Nanoparticles in gene therapy. *Biotechnol Adv*. 2016;34(5):707–720.
36. Cheng CJ, Tietjen GT, Saucier-Sawyer JK, Saltzman WM. Nanoparticle drug delivery. *Nat Rev Drug Discov*. 2015;14(4):239–247.
37. Zhang YN, Poon W, Tavares AJ, et al. Nanoparticle–protein interactions. *J Control Release*. 2016;240:332–348.
38. Kamaly N, Yameen B, Wu J, Farokhzad OC. Targeted nanoparticles. *Chem Rev*. 2016;116(4):2602–2663.
39. Bae YH, Park K. Targeted drug delivery challenges. *J Control Release*. 2011;153(3):198–205.
40. Etheridge ML, Campbell SA, Erdman AG, et al. Nanomedicine future. *Nanomedicine*. 2013;9(1):1–14.