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Nanotechnology in Drug Delivery

Gafale Shravani Mhataraba, Diksha Anil Adangale, Ms. Kalyani Bhor
Student of Samarth Institute of Pharmacy, Belhe, Pune, Maharashtra.
Professor, Department of Pharmaceutics, Samarth Institute of Pharmacy, Belhe, Pune, Maharashtra
shravanigafale@gmail.com, dikshaadangale876@gmail.com

Abstract: *Nanotechnology has emerged as a powerful tool in the field of drug delivery, offering novel strategies to overcome the limitations associated with conventional therapeutic systems. Nanoscale drug carriers such as liposomes, polymeric nanoparticles, dendrimers, solid lipid nanoparticles, and metallic nanoparticles enable improved solubility, enhanced bioavailability, prolonged circulation time, and targeted delivery of drugs. These systems allow controlled and stimuli-responsive drug release, thereby reducing systemic toxicity and improving therapeutic efficacy. Nanotechnology-based drug delivery has shown significant potential in the treatment of cancer, infectious diseases, neurological disorders, and cardiovascular conditions. This review discusses the fundamental principles of nanotechnology in drug delivery, various types of nanocarriers, their biomedical applications, as well as current challenges and future prospects in the development of safe and effective nanomedicines.*

Keywords: Nanotechnology; Drug delivery systems; Nanoparticles; Nanocarriers; Targeted drug delivery; Controlled release; Nanomedicine

I. INTRODUCTION

Drug delivery plays a vital role in determining the therapeutic effectiveness and safety of pharmaceutical agents. An ideal drug delivery system should deliver the required amount of drug to the target site at the right time while minimizing adverse effects on healthy tissues. However, conventional drug delivery approaches often face significant limitations, including poor aqueous solubility of drugs, low bioavailability, rapid degradation or clearance, lack of target specificity, dose-related toxicity, and poor patient compliance. These challenges have motivated the development of advanced drug delivery technologies.

Nanotechnology has emerged as a promising and innovative approach to address these limitations. Nanotechnology involves the design, fabrication, and application of materials at the nanometer scale, typically ranging from 1 to 100 nanometers. At this scale, materials exhibit unique physicochemical properties such as increased surface area, enhanced reactivity, and tunable surface characteristics, which can be exploited for biomedical applications. The integration of nanotechnology into medicine has led to the development of nanomedicine, a field that focuses on the use of nanoscale systems for diagnosis, treatment, and prevention of diseases.

In drug delivery, nanotechnology enables the development of nanocarriers capable of encapsulating, protecting, and transporting therapeutic agents to specific sites in the body. These nanocarriers can improve the solubility and stability of poorly water-soluble drugs, protect sensitive drugs from enzymatic or chemical degradation, and provide controlled or sustained drug release. Moreover, nanocarriers can be engineered to achieve targeted delivery through passive targeting mechanisms, such as the enhanced permeability and retention (EPR) effect, or active targeting strategies using ligands that bind selectively to receptors overexpressed on diseased cells.

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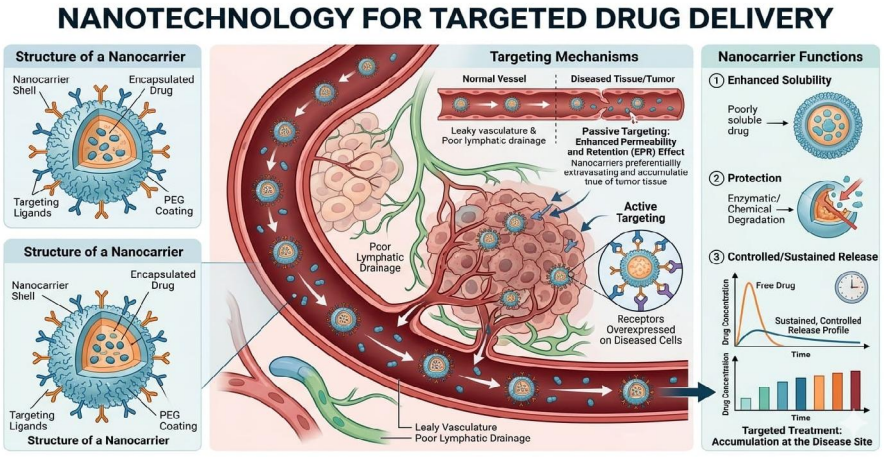

The application of nanotechnology-based drug delivery systems has shown remarkable progress in various therapeutic areas, particularly in cancer therapy, where targeted delivery of chemotherapeutic agents can significantly reduce systemic toxicity and improve treatment outcomes. In addition, nanotechnology has demonstrated potential in the treatment of infectious diseases, neurological disorders, cardiovascular diseases, and in gene and vaccine delivery. The ability of certain nanocarriers to cross biological barriers, such as the blood–brain barrier, further expands their clinical relevance.

Despite the promising advantages, the clinical translation of nanotechnology-based drug delivery systems faces several challenges, including concerns related to toxicity, biocompatibility, large-scale manufacturing, reproducibility, and regulatory approval. Understanding these challenges alongside the benefits is essential for the successful development of safe and effective nanomedicines.

This review aims to provide a comprehensive overview of nanotechnology in drug delivery, focusing on its fundamental principles, different types of nanocarriers, mechanisms of drug targeting and release, major biomedical applications, and current challenges, as well as future perspectives in this rapidly evolving field.

Principles of Nanotechnology in Drug Delivery

Nanotechnology-based drug delivery systems rely on unique physicochemical properties of nonmaterial's, such as high surface area-to-volume ratio, tunable size, shape, and surface chemistry. These properties allow:

- Improved solubility of poorly water-soluble drugs
- Protection of drugs from enzymatic degradation
- Enhanced cellular uptake
- Controlled and sustained drug release
- Targeted delivery to specific tissues or cells

Targeting can be achieved through passive mechanisms, such as enhanced permeability and retention (EPR) effect, or active mechanisms using legends that bind to specific receptors on target cells.

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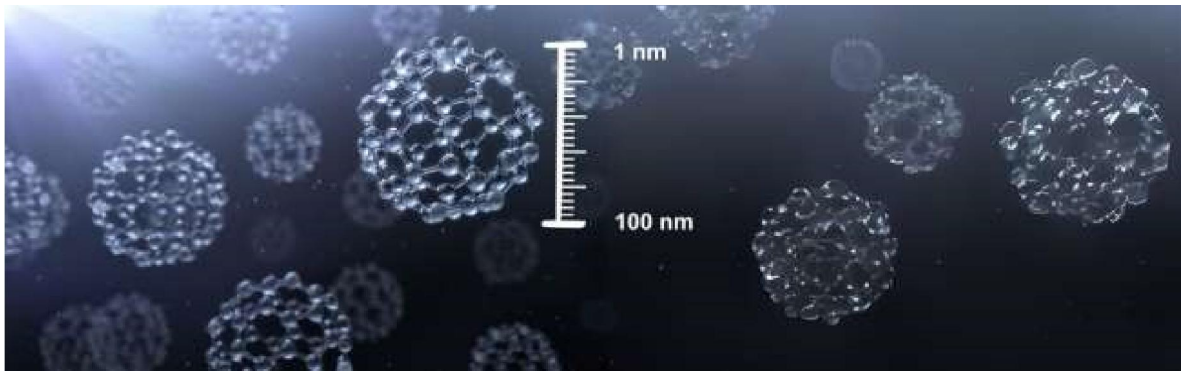
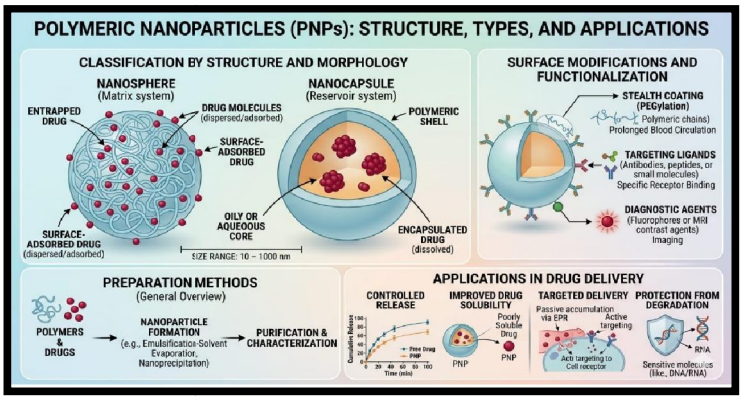


Fig : Principle of Nanoparticle

III. TYPES OF NANOCARRIERS

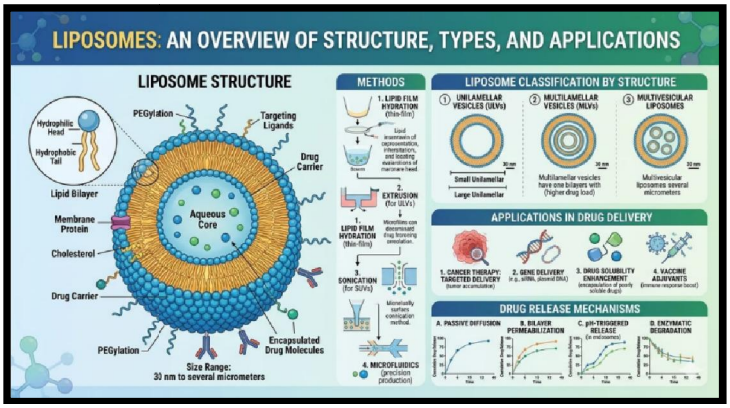
3.1 Polymeric Nanoparticles

Polymeric nanoparticles are made from biodegradable polymers such as PLGA, chitosan, and alginate. They can encapsulate drugs within their matrix or adsorb them onto the surface, providing controlled release and improved stability.



3.2 Liposomes

Liposomes are spherical vesicles composed of phospholipid bilayers. They can carry both hydrophilic and hydrophobic drugs and are widely used due to their biocompatibility and ability to reduce drug toxicity.



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3.3 Solid Lipid Nanoparticles (SLNs)

SLNs consist of solid lipids stabilized by surfactants. They combine the advantages of liposomes and polymeric nanoparticles, offering good stability and controlled drug release.

3.4 Dendrimers

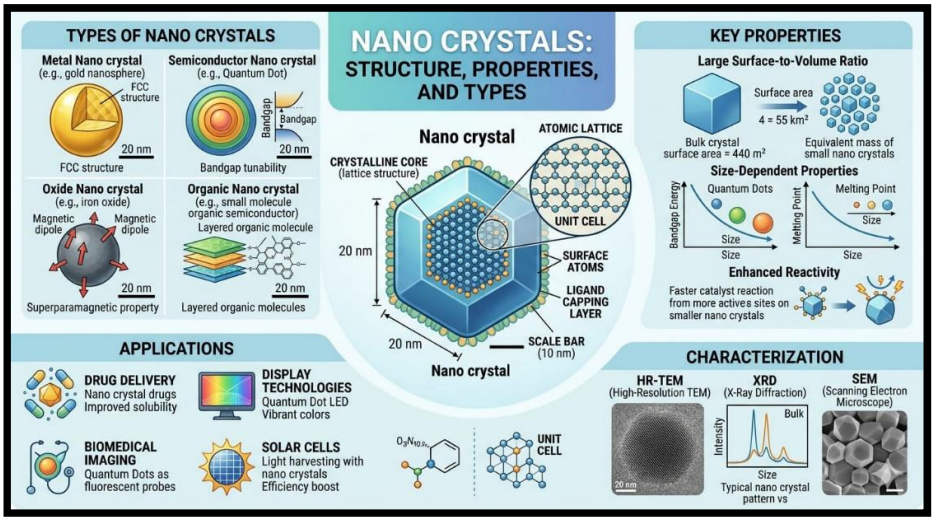
Dendrimers are highly branched, tree-like macromolecules with a well-defined structure. Their multiple functional groups allow high drug loading and precise surface modification for targeted delivery.

3.5 Metallic Nanoparticles

Metallic nanoparticles, such as gold and silver nanoparticles, possess unique optical and magnetic properties. They are particularly useful in cancer therapy, imaging, and theranostics.

3.6 Nanocrystals

Nanocrystals are pure drug particles reduced to the nanoscale, enhancing dissolution rate and bioavailability without the need for carrier materials.



IV. MECHANISMS OF DRUG TARGETING AND RELEASE

4.1 Passive Targeting

Passive targeting relies on the natural biodistribution of nanocarriers and the unique pathophysiological characteristics of diseased tissues. One of the most widely studied mechanisms is the enhanced permeability and retention (EPR) effect, commonly observed in tumor tissues and inflamed areas. Tumors possess leaky vasculature with large endothelial gaps, allowing nanoparticles to extravasate and accumulate in the tumor interstitium.

4.2 Active Targeting

Active targeting involves the functionalization of nanocarriers with specific ligands that can recognize and bind to receptors overexpressed on the surface of target cells. These ligands may include antibodies, peptides, aptamers, folic acid, carbohydrates, or transferrin. Upon ligand–receptor interaction, the nanocarrier is internalized into the target cell through receptor-mediated endocytosis. Active targeting enhances cellular uptake, improves intracellular drug concentration, and reduces off-target effects, making it particularly effective in cancer therapy and gene delivery.

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4.3 Cellular Uptake Mechanisms

After reaching the target tissue, nanocarriers interact with the cell membrane and are taken up by cells through various endocytic pathways. These include clathrin-mediated endocytosis, caveolaemediated endocytosis, macropinocytosis, and phagocytosis. The specific pathway depends on nanoparticle size, shape, surface chemistry, and cell type.

4.4 Controlled and Sustained Drug Release

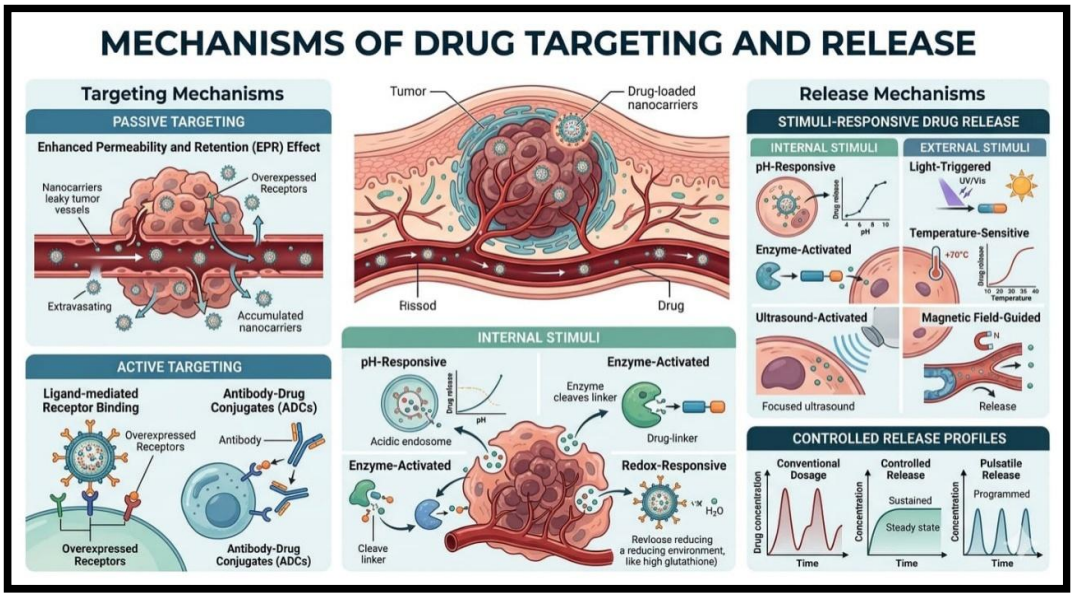
Nanocarriers are designed to release drugs in a controlled and sustained manner to maintain therapeutic drug levels over extended periods. Controlled release can occur through diffusion of the drug from the nanocarrier matrix, degradation of biodegradable polymers, or erosion of lipid-based systems. This mechanism reduces dosing frequency, improves patient compliance, and minimizes fluctuations in drug concentration that may lead to toxicity.

4.5 Stimuli-Responsive Drug Release

Stimuli-responsive or smart drug delivery systems release drugs in response to specific internal or external triggers. Internal stimuli include pH changes, redox potential, enzymatic activity, and temperature variations commonly found in diseased tissues. For example, pH-sensitive nanoparticles release drugs in acidic tumor microenvironments or intracellular compartments.

4.6 Drug Transport Across Biological Barriers

One of the major advantages of nanotechnology-based drug delivery systems is their ability to cross biological barriers, such as the blood–brain barrier, intestinal epithelium, and cellular membranes. Surface modification with surfactants, ligands, or cell-penetrating peptides enhances nanoparticle transport across these barriers. This mechanism is particularly important for the treatment of neurological disorders and oral delivery of macromolecules.



V. APPLICATIONS OF NANOTECHNOLOGY IN DRUG DELIVERY

5.1 Cancer Therapy

Nanotechnology has significantly improved cancer treatment by enabling targeted delivery of chemotherapeutic agents, reducing systemic toxicity, and overcoming multidrug resistance.

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5.2 Infectious Diseases

Nanocarriers enhance the delivery of antibiotics and antiviral drugs, improving their efficacy against resistant pathogens.

5.3 Neurological Disorders

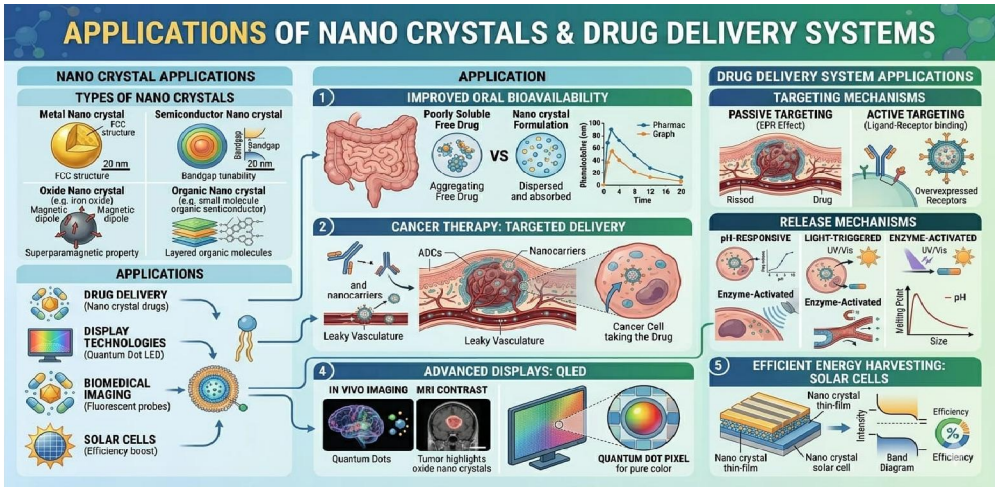
Nanotechnology facilitates drug transport across the blood–brain barrier, offering new treatment strategies for diseases such as Alzheimer's and Parkinson's.

5.4 Cardiovascular Diseases

Nanoparticles are used to deliver drugs that prevent restenosis, thrombosis, and inflammation in cardiovascular conditions.

5.5 Gene and Vaccine Delivery

Nanocarriers play a vital role in delivering DNA, RNA, and vaccines, improving stability and immune response.



VI. ADVANTAGES OF NANOTECHNOLOGY-BASED DRUG DELIVERY

- Enhanced bioavailability
- Target-specific delivery
- Reduced side effects
- Controlled and sustained release
- Improved patient compliance

VII. LIMITATIONS AND CHALLENGES

Despite its potential, nanotechnology in drug delivery faces several challenges:

- Toxicity and biocompatibility concerns
- Complex manufacturing processes
- High production costs
- Regulatory and ethical issues
- Limited long-term safety data

Addressing these challenges is essential for successful clinical translation.

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VIII. DISCUSSION

Nanotechnology-based drug delivery systems significantly improve drug solubility, bioavailability, and therapeutic efficacy compared to conventional formulations. Targeted delivery through passive and active mechanisms enhances drug accumulation at disease sites while reducing systemic toxicity. Stimuli-responsive nanocarriers further enable controlled and site-specific drug release. However, challenges such as potential toxicity, manufacturing complexity, and regulatory issues limit widespread clinical application. Addressing these challenges is essential for the successful translation of nanotechnology-based drug delivery systems into clinical practice.

IX. CONCLUSION

Nanotechnology has transformed drug delivery by enabling targeted, controlled, and efficient delivery of therapeutic agents. Nanocarrier systems improve drug bioavailability, enhance therapeutic efficacy, and reduce systemic side effects. Despite existing challenges related to safety, scalability, and regulatory approval, continued research and technological advancements are expected to promote the successful clinical application of nanotechnology-based drug delivery systems in future healthcare.

X. RESULTS

Studies reviewed indicate that nanotechnology-based drug delivery systems significantly enhance drug solubility, stability, and bioavailability compared to conventional drug formulations.

Nanocarriers demonstrate improved pharmacokinetic profiles, prolonged circulation time, and higher drug accumulation at target sites. Targeted and stimuli-responsive nanodelivery systems show increased therapeutic efficacy with reduced systemic toxicity across various biomedical applications.

Future Scope:

- Development of safer and biocompatible nanocarriers with minimal toxicity
- Advancement of smart and stimuli-responsive drug delivery systems
- Expansion of personalized and precision nanomedicine approaches
- Improved targeted delivery for cancer, neurological, and genetic diseases
- Enhanced ability to cross biological barriers such as the blood–brain barrier
- Integration of nanotechnology with gene therapy and vaccine delivery
- Optimization of large-scale manufacturing and cost-effective production methods
- Establishment of standardized regulatory guidelines and long-term safety studies

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REFERENCES

[1]. Torchilin VP. Nanotechnology for drug delivery and cancer therapy. *Nat Rev Drug Discov*. 2005;4(2):145–160.

[2]. Langer R. Drug delivery and targeting. *Nature*. 1998;392(6679):5–10.

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

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[4]. Jain KK. Nanotechnology in clinical drug delivery. *Methods Mol Biol*. 2008;437:1–50.
[5]. Koo OM, Rubinstein I, Onyuksel H. Role of nanotechnology in targeted drug delivery and imaging. *Int J Nanomedicine*. 2005;1(3):193–212.
[6]. Gupta AK, Gupta M. Synthesis and surface engineering of iron oxide nanoparticles for biomedical applications. *Biomaterials*. 2005;26(18):3995–4021.
[7]. Wang AZ, Langer R, Farokhzad OC. Nanoparticle delivery of cancer drugs. *Annu Rev Med*. 2012;63:185–198.
[8]. Duncan R. The dawning era of polymer therapeutics. *Nat Rev Drug Discov*. 2003;2(5):347– 360.
[9]. Peer D, et al. Nanocarriers as an emerging platform for cancer therapy. *Nat Nanotechnol*. 2007;2(12):751–760.
[10]. Farokhzad OC, Langer R. Impact of nanotechnology on drug delivery. *ACS Nano*. 2009;3(1):16–20.
[11]. Sahoo SK, Labhasetwar V. Nanotech approaches to drug delivery and imaging. *Drug Discov Today*. 2003;8(24):1112–1120.
[12]. Moghimi SM, Hunter AC, Murray JC. Long-circulating and target-specific nanoparticles. Pharmacol *Rev*. 2001;53(2):283–318.
[13]. Zhang L, Gu FX, Chan JM, et al. Nanoparticles in medicine. *Clin Pharmacol Ther*. 2008;83(5):761–769.
[14]. Kreuter J. Nanoparticles and the blood–brain barrier. *Pharm Sci Technol Today*. 2001;4(5):175–180.
[15]. Alexis F, et al. Factors affecting nanoparticle clearance and biodistribution. *Mol Pharm*. 2008;5(4):505–515.
[16]. He C, Hu Y, Yin L, Tang C, Yin C. Effects of particle size and surface charge on cellular uptake. *Biomaterials*. 2010;31(13):3657–3666.
[17]. Panyam J, Labhasetwar V. Biodegradable nanoparticles for drug delivery. *Adv Drug Deliv Rev*. 2003;55(3):329–347.
[18]. Park K. Controlled drug delivery systems: Past forward and future back. *J Control Release*. 2014;190:3–8.
[19]. Roco MC. Nanotechnology: Convergence with modern biology and medicine. *Curr Opin Biotechnol*. 2003;14(3):337–346.
[20]. De Jong WH, Borm PJ. Drug delivery and nanoparticles: Applications and hazards. *Int J Nanomedicine*. 2008;3(2):133–149.
[21]. Sharma P, Garg S. Pure drug nanoparticles for solubility enhancement. *Int J Pharm*. 2010;393(1–2):19–28.
[22]. Sanna V, Sechi M. Nanoparticle therapeutics for prostate cancer. *Nanomedicine*. 2012;8(6):887–906.
[23]. Tiwari G, et al. Drug delivery systems: An updated review. *Int J Pharm Investig*. 2012;2(1):2–11.
[24]. Kumari A, Yadav SK, Yadav SC. Biodegradable polymeric nanoparticles. *Colloids Surf B Biointerfaces*. 2010;75(1):1–18.
[25]. Bangham AD. Liposomes: The Babraham connection. *Chem Phys Lipids*. 1993;64(1–3):275– 285.
[26]. Shi J, Kantoff PW, Wooster R, Farokhzad OC. Cancer nanomedicine. *Nat Rev Cancer*. 2017;17(1):20–37.
[27]. Patel HM. Serum opsonins and liposomes. *Crit Rev Ther Drug Carrier Syst*. 1992;9(1):39– 90.
[28]. Nair LS, Laurencin CT. Biodegradable polymers for drug delivery. *Prog Polym Sci*. 2007;32(8–9):762–798.
[29]. Kulkarni SA, Feng SS. Effects of particle size and surface modification. *Pharm Res*. 2013;30(10):2512–2522.
[30]. Li SD, Huang L. Pharmacokinetics and biodistribution of nanoparticles. *Mol Pharm*. 2008;5(4):496–504