Nanoparticles as a Better Alternative Agent for Effective Drug Delivery System

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Abstract

Nanoparticles present a potential yet effective solution against traditional drug delivery systems which benefit from their small size scale and broad surface area and better drug availability properties alongside targeted and prolonged drug delivery capabilities. The widespread use of conventional drug delivery systems comes with various problems because they lead to low drug uptake and fast degradation and result in drug substances spreading across non-specific areas producing systemic reactions including gastrointestinal distress and pain from injections and tissue damage. Restricted drug distribution leads to both diminished medication effectiveness and heightened resistance in pathogens and raises the number of harmful side effects. Nanoparticles resolve these problems through their fresh mechanism of action which enables them to deliver drugs more specifically and efficiently.

Keywords: Nanoparticles, Alternative methods, Traditional drug delivery agents, Mechanisms, Drug delivery

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Introduction

Nanoparticles are small sized particles that ranges from 1-100nm (Qurashi et al., 2024). Nanoparticles have unique biological, chemical, and physical properties due to their small size (Ahmad et al., 2024). These properties make them enable to be used for multiple fields including material science, medicine, electronics, and many more (Saeed et al., 2025). The small size of nanoparticles allows them to interact with the biological systems more effectively as compared to the other agents which are bigger in size (Yusuf et al., 2023). Effectiveness of the drug can be enhanced by the effective drug delivery systems (Chandrakala et al., 2022). Nanoparticles can be used as an effective system for drug delivery because of the larger surface area, potential for modification, enhanced bioavailability, and ability to encapsulate multiple drugs (Mitchell et al., 2021). In the recent years, nanoparticles have acquired a significant attention of the researchers to make better alternative ways for drug delivery system (Liu et al., 2023). The multiple significant properties of nanoparticles make them ideal carrier for the delivery of drugs in humans and animals (Afzal et al., 2022). The traditional methods for the drug delivery are not very effective because of multiple reasons including rapid degradation, non-specific distribution, and poor solubility (Waheed et al., 2022). These drawbacks of traditional delivery of therapeutic agents can cause multiple other side effects (Sultana et al., 2022). Drug resistance is also increasing day by day because of these poor methods (Qureshi et al., 2023). Plant-based compounds are also under study as an alternative strategy to overcome the resistance issue (Abbas et al., 2025). However, nanoparticles have the ability to enhance the stability of drugs, provide targeted delivery of the drugs, and provide sustained and controlled release of the drug (Bai et al., 2022). Different types of the nanoparticles have been extensively studied for their potential use for the treatment and cure of multiple diseases of humans and animals (Domínguez-Oliva et al., 2023). Most commonly used types of nanoparticles are metallic nanoparticles, polymeric nanoparticles, polymers, and dendrimers (Khan et al., 2022). They can be used to treat multiple diseases, including neurological disorders, infection, and cancer (Rahman et al., 2022). This chapter focuses on the importance of the nanoparticles as better alternative agents for drug delivery system in humans and animals and their mechanisms of action.

1. Drug Delivery Systems

The traditional methods for the drug delivery to cure or treat the disease or infection have several drawbacks (Sultana et al., 2022). The most common routes used for drug delivery include oral drug delivery system, intravenous route, intramuscular route, subcutaneous route,

transdermal and tropical route, pulmonary route, and ophthalmic and nasal route (Gupta et al., 2022; Wiwanitkit, 2024). Detail of these routes, agents used for each route and their drawbacks are given as follows:

1.1. Oral Route

Tablets, solutions, and capsules are used for the oral route of drug delivery (Salunke et al., 2022). Drugs given through the oral route are ingested and absorbed in gastrointestinal tract (Vinarov et al., 2021). The major drawback of using oral route is poor or variable absorption depending on the gastric pH, enzyme degradation, and food intake (Azman et al., 2022). Drugs given through the oral route of administration need to pass the 1st-pass metabolism of the liver, which makes poor bioavailability (Saleem et al., 2024). However, if we need quick onset, oral route for drug administration is not recommended because it has very poor and slow onset of the drugs (Baryakova et al., 2023). Because of these numerous drawbacks of using tablets, syrups/solutions, and capsules, we need to focus on the alternative method for drug delivery (Nangare et al., 2021).

1.2. Intravenous Route

Injectables are given through the intravenous route of administration (Bruno et al., 2022). This method has the fastest onset of the drugs as the drug is directly delivered into the bloodstream of the organisms (Sultana et al., 2022). However, this method has its several side effects. In this method of drug administration, the drug is distributed non-specifically, which may lead to systemic toxicity (Chen et al., 2025). The given drug is released quickly from the body and thus needs frequent doses of drug (Baryakova et al., 2023). However, this method requires more experience and professional administration, and patient's convenience is limited in this method (Hansen & Solbakken, 2024).

1.3. Subcutaneous and Intramuscular Route

In subcutaneous and intramuscular route of drug administration, the drug is given directly under the skin and into the muscle respectively (Dubbelboer & Sjögren, 2022). The given drug is then gradually absorbed in the bloodstream. Like every traditional method of drug delivery, this method also has some drawbacks. When the drug is given through subcutaneous or intramuscular route, there can be pain, irritation, and discomfort at the site of the injection (Davis et al., 2024). Drug efficacy of this method is very variable because of the inconsistent rate of drug absorption in the bloodstream of the organism (Haripriyaa & Suthindhiran, 2023). However, drug suitability is limited for some drugs that require immediate action.

1.4. Transdermal and Tropical Route

Creams, ointments, and patches are used for tropical and transdermal route of drug administration (Witkowska et al., 2024). In this method, the drugs are applied to the skin for systemic and localized absorption (Gowda et al., 2022). The major drawback of this method is limited and poor absorption of the drug through the skin barrier (Alkilani et al., 2022). There is a high risk of skin allergy and severe irritation of skin (Lee & Goh, 2021). However, this method is only suitable for the fat-soluble (lipophilic) drugs which have very small molecular weight (Umbarkar, 2021).

1.5. Pulmonary Route

Nebulizers and inhalers are used through pulmonary route of drug administration (Heida et al., 2023). In this method, drugs are inhaled through oral-nasal route into the lungs (Sadeghi et al., 2024). This method has a high risk of lungs infection/damage or irritation (Li & Schneider-Futschik, 2023). It requires frequent administration because of the very short duration of drug action (Kienitz et al., 2022).

1.6. Ophthalmic and Nasal Route

Eye drops and nasal sprays are administered through ophthalmic and nasal route respectively (Wirta et al., 2022). The drug is given directly into the eyes and nasal cavity for systemic and local effects (Gupta et al., 2025). Some drugs (mostly hydrophilic) have very limited absorption (Lanier et al., 2021). It can also cause severe irritation, allergic reaction to some drugs, and discomfort (Salapatek et al., 2021). However, eye drops and nasal sprays have very short time of retention because of the fast clearance through mucosal secretions and tears (Račić & Krajišnik, 2023).

2. Importance of Advanced Drug Delivery Agents

Because of so many drawbacks of traditional agents of drug delivery, we need to focus on the alternative ways in order to increase the efficiency of the drugs. Advanced drug delivery agents, mainly nanoparticle plays very important role in improving the many properties of drug delivery (De et al., 2022). The details of each property are given as follows:

2.1. Sustained and Controlled Release

Nanoparticles have the ability for very controlled and sustained release of the drug (Bai et al., 2022). This ensures the constant release of the drug over a longer period of time. Low dosage and less frequent administration of the drug is required because of this ability of nanoparticles (Rahman et al., 2022).

2.2. Targeted Drug Delivery

Nanoparticles are engineered to deliver the drug at a specific desired site (Sharma et al., 2022). Nanoparticles can be directly targeted to the cells and tissues, which can reduce the toxicity that is caused by other drug delivery agents (Unnikrishnan et al., 2023). Targeted drug delivery reduces the off-target effects that enhance the effectiveness of the drug (Riaz et al., 2025).

2.3. Enhanced Bioavailability

Nanoparticles enhance the bioavailability of drugs by improving the stability and solubility of the drugs (Kumari et al., 2023). This ensures the maximum absorption of the drug in the bloodstream of the organism. The drug is released in the sustained manner which aids in a maximum improvement in the health recovery of humans or animals (Yang et al., 2023).

2.4. Reduction in Side Effects

Most common side effects using traditional drug delivery agents include vomiting, diarrhoea, overdosing, pain, discomfort, abscess formation, skin irritation, nervousness, headache, nausea and many more (Phadke & Amin, 2021). These side effects can be reduced by using nanoparticles.

3. Mechanisms of Drug Delivery through Nanoparticles

There are multiple mechanism of actions of the nanoparticles (Abdulmalek et al., 2021). The most significant mechanism of the action of nanoparticles is disruption of the cell membrane. Nanoparticles have the ability to attach at the surface of the bacteria's cell wall or cell membrane. They affix to the bacterial cell wall/membrane and cause severe damage to it (You et al., 2025). Death of the bacteria happens because of the leakage of the important cellular components and material (Elbasuney et al., 2023). However, nanoparticles can also cause instability in the cellular membrane of the bacteria, that leads to disruption in the cellular function and alteration in the cell permeability. Some nanoparticles have the ability to disrupt the function and integrity of the cell by releasing metal ions on the surface of the cell membrane. Another important mechanism of the action of nanoparticles is the production of reaction oxygen species, which leads to the production of oxidative stress. Reactive oxygen species are highly reactive molecules that can damage the cell and its component including proteins, DNA, and lipids (Juan et al., 2021). This will ultimately cause the death of the cells. However, some other mechanisms of the action of nanoparticles include enzyme degradation, protein denaturation, DNA damage, and inhibition of different cell functioning (Figure 1).

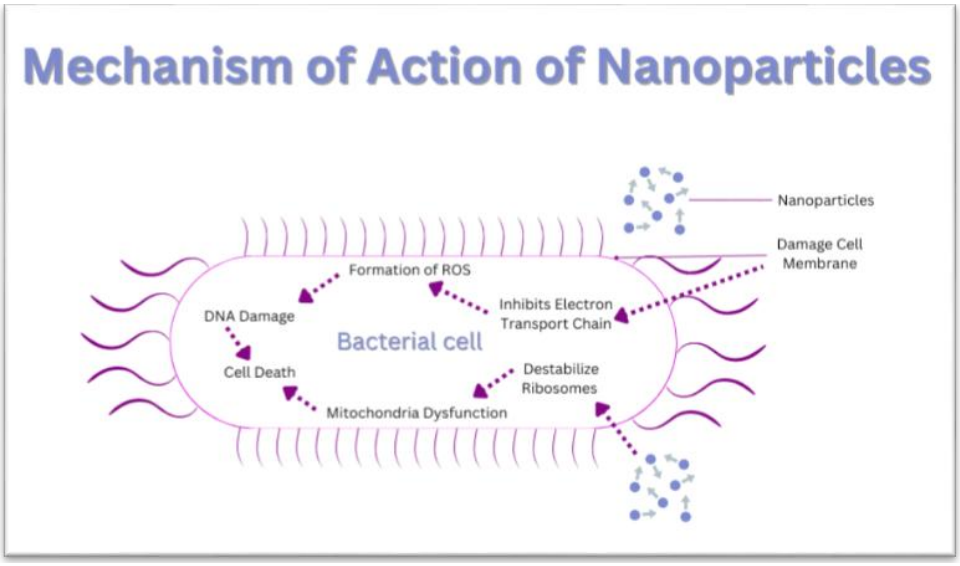

Fig. 1: Mechanism of Action of Nanoparticles

4. Limitations

Nanoparticles have more benefits as compared to any other traditional drug delivery agent (Chandrakala et al., 2022). However, there are some limitations to using nanoparticles as drug delivery agents. Some nanoparticles have toxic effects on the human and animal body, that is why they cannot be used for a longer period of time (Ajdary et al., 2021). Some types of the nanoparticles cause hypersensitivity effects and activate the immune system of the organism. The nanoparticles are hard to manufacture because of their very small size. However, we have limited knowledge about the safety index, toxicity of the nanoparticles, and long-term using effects. Targeted drug delivery and bio-distribution of the drugs with the help of nanoparticles is also another challenging task (Skotland et al., 2022). We need more study and research on these limitations of the nanoparticles so that they can be used as better alternative agents for drug delivery and improve health and life of organisms.

Conclusion

Nanoparticles present a potential yet effective solution against traditional drug delivery systems which benefit from their small size scale and broad surface area and better drug availability properties alongside targeted and prolonged drug delivery capabilities. The widespread use of conventional drug delivery systems comes with various problems because they lead to low drug uptake and fast degradation and result in drug substances spreading across non-specific areas, producing systemic reactions including gastrointestinal distress and pain from injections and tissue damage. Restricted drug distribution leads to both diminished medication effectiveness and heightened resistance in pathogens and raises the number of harmful side effects. Nanoparticles resolve these problems through their fresh mechanism of action which enables them to deliver drugs more specifically and efficiently. Nanocomplexes enable successive and controlled drug delivery, which enables patients to take medications less frequently with lower general drug amounts circulating inside their bodies. Such a feature leads both patients and healthcare providers toward better treatment results. The designed nature of nanoparticles enables precise targeting of specific cells and tissues, which

minimizes adverse effects along with toxicities. The increased bioavailability enables the drug to reach its target location in optimal concentrations, which results in more efficient treatment while reducing recovery times.

The bacterial cell membrane disruption effect together with ROS production and metal ion release by nanoparticles renders them high performing in combating infections including drug-resistant bacteria strains. The range of advantages of nanoparticles does not eliminate their existence of specific drawbacks. Multiple issues persist related to natural nanoparticle toxicity and both sensitivity reactions and immune system reactions as well as problems with large-scale production. Studies regarding long-term effects and bio-distribution of nanoparticles need further investigation because full understanding of these aspects remains incomplete.

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