Review Article

Nano Based Drug Delivery System: Its Recent Developments and Future Prospects

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ABSTRACT

Nanoparticles play an essential role in biomedical applications, such as drug delivery, bio sensing, and tissue engineering. They guarantee the delivery of drugs to the target tissues. The controlled release mechanisms improve the efficacy and safety of the treatments. Further, Nano-based methods have been developed where cancer therapies are integrated with diagnostic imaging techniques, offering hope for combined or integrated treatments in the future. Over the past decade, tremendous research has revolutionized drug delivery systems by focusing on delivering therapeutic agents and natural active compounds directly to the targeted site for the treatment of various diseases. Although the prevailing drug delivery systems have found immense applications, problems including drug stability, bioavailability, and precise targeting continue to persist. Such limitations open up avenues for more advanced technologies to emerge to discover higher efficacy and safety of the therapy. Nano-based drug delivery systems have emerged as promising options in improving the solubility and controlled-release delivery of drugs and targeted site delivery. By encapsulating therapeutics within Nano carriers, it shields therapeutic agents from degradation while ensuring their delivery to the target site and, thereby minimizing the side effects with maximum effectiveness. Nanotechnology is now in the pipeline day by day in search of the precise aspect of its potential in medicine, promising to make a revolution in chronic and complex diseases into more efficient and personalized therapies. This holds a promising treatment of vast diseases as medicine is destined for further progressions in NDDS. Nanotechnology shall thus be able to revolutionize the delivery method in a way that drugs would be administered in a more effective manner, personalized, and therefore reachable to patients all over the world.

Keywords: Nanotechnology, Nanoparticles, medicine, drug delivery, controlled release.

INTRODUCTION

Humans have been using plants and natural products as medicines for thousands of years. Even today, most of the modern drugs originate from traditional knowledge, and about 25% of essential medicines are still obtained from natural sources. The unique structures of these natural compounds therefore have been a viable template in the discovery of new drugs, and scientists have recently begun synthesizing drugs that mirror the properties of these natural compounds. While natural products have the advantage of possessing diverse chemical structures with low toxicity, their applications remain limited in modern medicine by biocompatibility and toxicity issues that could lead to the failure of clinical trials. All these not withstanding, natural compounds are increasingly being tested for use as potential drugs for major diseases, including cancer, diabetes, cardiovascular conditions, inflammatory diseases, and microbial infections. The rationale behind these compounds is their low toxicity with fewer side effects and at lesser costs, plus great therapeutic potency. The delivery of these compounds is still a problem due to issues such as poor bioavailability, low solubility, and difficulty in targeting tissues.[1]

To overcome these challenges, there is now a diversified development of novel drug delivery systems; nanotechnology forms a major sector in these efforts. Nano drug delivery systems (NDDS) have emerged as revolutionizing means of drug delivery in modern medicine. These drug delivery systems use nanomaterials, defined as materials between 1 and 100 nanometers in size and having special chemical, physical, and biological properties. Nanoparticles are smaller, so they move more smoothly and comfortably along the body than larger materials, hence delivering the nanomaterials to targeted sites with high efficiency. New drug formulations developed by nanotechnology are such as controlled release, targeted delivery, and heightened therapeutic efficacy. Nanoparticles play an essential role in biomedical applications, such as drug delivery, bio sensing, and tissue engineering. They guarantee the delivery of drugs to the target tissues. The controlled release mechanisms improve the efficacy and safety of the treatments. Further, Nano-based methods have been developed where cancer therapies are integrated with diagnostic imaging techniques, offering hope for combined or integrated treatments in the future.[2]

First-generation nanoparticle therapies such as FDA-approved liposomes and micelles are already making an impact in the medical field. Such systems can carry inorganic particles like gold or magnetic ones to enhance drug delivery or imaging functions. Nanostructures provide the protective microenvironment that shields drugs from undergoing degradation in the gastrointestinal tract, thus enhancing the delivery of poorly water-soluble drugs. Success in Nano medicine can be imagined with

improvement in the bioavailability and accurate targeting. The physiological mechanisms in nanoparticle systems that are inherent for oral uptake make better uptake by endocytosis of the nanoparticles. Thus, with nanotechnology, it has emerged as the most instrumental tool to take the advancement forward in therapy to targeted therapies, biosensors, and microfluidics where disease prevention and treatment play an important role.[3]

Although the promising range that NDDS has, concern for the toxicity of these nanoparticles dominates. Current scientists have been able to address such issues through combining nanoparticles with natural products, which reduces its toxicity and increases their biocompatibility. Using the protocol of green chemistry for the design of a drug-loaded nanoparticle minimizes harmful substances during the process, thus reducing the side effects. Size, shape, and surface property modified nanostructures are also being explored to alter their bioactivity and targeting capabilities. Even with these advances, the full potential of NDDS is yet to be tapped. Information about the toxicity of nanoparticles still poses a challenge up to date, and thus, research has to be continued for their safe and effective use in medicinal applications. This review deals with the different Nano-based drug delivery systems, the paramount applications of natural compound-based Nano medicines, and factors including bioavailability, targeted delivery, and controlled drug release. It also focuses on the problems faced in the medical field with nanomaterials and stresses the necessity of more research in this area to ultimately overcome these problems and ensure effective safety of NDDS. Since nanotechnology is evolving incessantly, its applications are promising for the treatment of diseases like breast cancer, ulcerative colitis, liver cancer, and non-infectious uveitis. The next sections of this work will present the progresses and future directions in the area of Nano-based drug delivery systems for therapeutic applications in these areas.[4]

CLASSIFICATION OF NANO DRUG DELIVERY SYSTEMS (NDDS) :

Nano drug delivery systems (NDDS) can be classified based on materials, structural characteristics, and their mode of action. Below is a breakdown of the main types:[8]

1. Lipid-Based Nano Drug Delivery Systems

Lipid-based systems use lipids as carriers due to their biocompatibility and capability in encapsulating both hydrophilic and hydrophobic drugs.

1.1 Liposomes:

Description: Spherical vesicles with a phospholipid bilayer and aqueous core.

Advantages: Biocompatibility, low toxicity, controlled release.

Applications: Cancer therapy, for example, Doxil; antifungal drugs, for example, Amboise.

1.2 Solid Lipid Nanoparticles (SLNs):

Description: Solid lipid core, stabilized by surfactants nanoparticles.

Advantages: Controlled release, better stability, protecting the sensitive drugs.

Applications: Skin care formulations, cardiovascular drugs.

1.3 Nanostructured Lipid Carriers (NLCs) :

Description: Advanced lipid carriers prepared by mixing solid and liquid lipids.

Advantages: Higher drug loading capacity, less crystallinity.

Applications: Cancer therapy, brain drug delivery.

2. Polymeric Nano Drug Delivery Systems

These systems are based on biodegradable polymers for controlled and sustained drug delivery.

2.1 Polymeric Nanoparticles :

Description: Solid colloidal particles composed of polymers, such as PLGA, PLA, or chitosan.

Advantages: Sustained release and resistance to enzymatic degradation

Applications: Antibiotics, anticancer drugs, vaccines.

2.2 Polymeric Micelles :

Description: Self-assembled structures composed of a hydrophobic core and a hydrophilic shell.

Advantages: Suitable for poorly soluble drugs; higher stability

Applications: Chemotherapy, such as paclitaxel delivery.

2.3 Dendrimers :

Description: Highly branched polymers containing multivalent functional groups.

Advantages: Precise targeting and higher drug-loading capabilities.

Applications: Gene delivery, anticancer therapy.

3. Metal-Based Nano Drug Delivery Systems

These systems take advantage of metal's optical, thermal, and magnetic properties.

3.1 Gold Nanoparticles (AuNPs):

Description: Nanoscale gold particles with well-controllable surface chemistry.

Benefits: Non-toxic, ideal for photothermal treatment and imaging.

Applications: Tumor destruction, targeted delivery of drugs.

3.2 Iron Oxide Nanoparticles:

Description: Magnetic iron oxide nanoparticles

Advantages: Magnetic field-driven drug targeting, imaging contrast agents

Applications: For hyperthermia treatment and MRI

4. Carbon-Based Nano Drug Delivery Systems

Carbon nanostructures have high surface area, electrical conductivity, and functionalization potential.

4.1 Carbon Nanotubes (CNTs) :

Description: Cylindrical carbon molecules forming a hollow shell structure.

Advantages: Potential for high drug-loading capacity, ability to penetrate cells.

Applications: Gene therapy, anticancer drugs.

4.2 Graphene Oxide (GO) :

Description: Two-dimensional carbon sheets with oxygen functional groups.

Advantages: Highly efficient Nano-carrier with high drug-loading capacity, good biocompatibility.

Applications: Drug delivery, bioimaging, anticancer therapy.

5. Protein- and Peptide-Based Nano Drug Delivery Systems

These systems use biological molecules to increase biocompatibility and targeting specificity.

5.1 Albumin Nanoparticles :

Description: Nanoparticles of the albumin protein.

Advantages: Non-immunogenic, increases solubility of a drug.

Applications: Cancer treatment (e.g., Abraxane).

5.2 Peptide-Based Systems :

Description: Short peptides targeted to specific cell receptors.

Advantages: Specificity, decreased side effects.

Applications: Targeted treatments in cancer, antibacterial drugs.

6. Inorganic Nano Drug Delivery Systems

Inorganic materials are stable and can be multifunctional.

6.1 Silica Nanoparticles :

Description: Porous or non-porous structures of silica.

Advantages: High stability, controlled release.

Applications: Imaging, anticancer drugs.

6.2 Calcium Phosphate Nanoparticles :

Description: Biodegradable nanoparticles based on calcium phosphate.

Advantages: Non-toxic, suitable for gene delivery.

Applications: Vaccine adjuvants, bone regeneration.

7. Hybrid Nano Drug Delivery Systems

These combine two or more nanomaterials to integrate their advantages.

7.1 Polymer-Lipid Hybrids :

Description: Combination of lipid-based and polymeric systems.

Advantages: Enhanced stability, multifunctionality.

Applications: Cancer therapy, gene delivery.

7.2 Metal-Organic Frameworks (MOFs) :

Description: Hybrid materials combining organic linkers with metal ions.

Advantages: High drug-loading capacity, controlled release.

Applications: Imaging, cancer, and infection drug delivery.

RECENT DEVELOPMENTS & FUTURE PROSPECTS: NANO DRUG DELIVERY SYSTEM:

Over the past decade, tremendous research has revolutionized drug delivery systems by focusing on delivering therapeutic agents and natural active compounds directly to the targeted site for the treatment of various diseases. Although the prevailing drug delivery systems have found immense applications, problems including drug stability, bioavailability, and precise targeting continue to persist. Such limitations open up avenues for more advanced technologies to emerge to discover higher efficacy and safety of the therapy. Nano-based drug delivery systems have emerged as promising options in improving the solubility and controlled-release delivery of drugs and targeted site delivery. By encapsulating therapeutics within Nano carriers, it shields therapeutic agents from degradation while ensuring their delivery to the target site and, thereby minimizing the side effects with maximum effectiveness. Nanotechnology is now in the pipeline day by day in search of the precise aspect of its potential in medicine, promising to make a revolution in chronic and complex diseases into more efficient and personalized therapies.[5]

1. Recent Developments in Mitochondria-Targeting NDDS for Liver Cancer[9]

Recent developments in mitochondria-targeted NDDS have emerged with new approaches improving the efficacy of therapy and surmounting drug resistance. This research is underpinned by the specific delivery mechanisms developed for circumventing poor accumulation of therapeutic agents, coupled with hypoxia-related resistance as seen in liver cancer.

1.1 Overcoming Efflux Proteins and Controlled Drug Release:

One of the more innovative aspects of NDDS is the design of NDDS such that it can outwit efflux proteins. Efflux proteins, like P-glycoproteins, pump out drugs from cells

actively and help in achieving MDR. The novel strategies discussed here exploit lipophilic cations and peptides to promote the cellular uptake and retention so that therapeutic agents are adequately accumulated in the hematoma cells. Controlled release within mitochondria increases selectivity, minimizes systemic toxicity, and maximizes therapeutic benefits.

1.2 Counteract Hypoxia in Tumor Microenvironment (TME):

Hypoxia is an important issue in the treatment of liver cancer because hematoma cells consume massive amounts of oxygen to create a hypoxic TME. Such an environment supports resistance to drugs, induction of epithelial-mesenchymal transition (EMT), and angiogenesis through increased expression of HIF-1α and VEGF. Recent designs of NDDS focus on interfering with these pathways by delivering inhibitors of ROS generation, HK2 activity, and mitochondrial fission proteins like Drp1. A two-pronged approach of interference with TME rules out the possibility of enhancing angiogenesis besides suppressing immune suppression by altering the regulatory activities of the regulatory T cells and M2 macrophages.

1.3 Multifunctional Nano carriers:

Advanced NDDS integrated Nano carriers with multifunctionality, lipophilic cations like TPP, combined with biocompatible materials to be targeted better. These conjugates may self-assemble and respond to mitochondrial conditions such as high ROS levels or GSH. Some of these include modified Dendrimers having a surface modified with TPP and loaded into self-assembled curcumin micelles. They are capable of inducing mitochondrial apoptosis pathways by reducing MMP while recruiting caspase cascades.

1.4 New Trends in Peptide-Based Delivery Systems:

Mitochondrial-targeted peptides (MTPs), for instance, mitochondrial penetrating peptides (MPPs), are new tools emerging for efficient drug delivery. These would increase the penetration ability of NDDS across mitochondrial membranes and permit targeted drug delivery directly to the mitochondrial matrix, thus improving bioavailability and actually pointing out or targeting exactly where their pharmacological effects are to be rendered while bringing down systemic side effects.

1.5 Future Directions:

Now, the focus is on less neurotoxic and more targeted ligands for new mitochondria-targeting ligands. Simultaneously, there are researches that probe into the combination therapies where the NDDS is combined with immunotherapeutic agents to improve the total efficacy. All these will be breached in not too distant future by the advanced nanotechnology for overcoming the hypoxia and efflux mechanisms and granting further effectiveness to the treatments of liver cancer.

2. Curcumin Nano vesicles in the Treatment of Ulcerative Colitis: Latest Results[10]

Ulcerative colitis is a chronic inflammatory bowel disease in which one cannot rehabilitate the underlying causes of the pathology, such as breached intestinal barriers, deregulated immune systems, and some imbalance of the gut microbiota. A new promising treatment involving the employment of Nano vesicles of curcumin and targeting inflammation, while rescuing the intestinal barrier along with the modulation of gut microbiota, may be proposed.

2.1 Mechanism of Action :

- Restoring the Intestinal Barrier: The TNVs help in restoring the epithelial barrier and decrease intestinal permeability, thus preventing the translocation of pathogens that is very relevant in the management of UC.
- Gut microbiota regulation: The TNVs restore gut homeostasis by increasing the beneficial bacterial populations; as seen in the 16S rRNA sequencing, thus reducing inflammation.
- Polarization of Macrophages: TNVs, effectively cause the polarization of macrophages into an anti-inflammatory M2 instead of the pro-inflammatory one, M1 that reduces pro-inflammatory cytokines and increases tissue repair.

2.2 Preclinical Studies:

In-vitro and in-vivo studies with DSS-induced colitis in mouse model demonstrated a reduced inflammation and clinical symptoms with TNVs. Imaging studies indeed affirm that the TNVs can be effectively delivered to the sites of inflamed colon.

2.3 Clinical Implications:

TNVs is an utterly holistic approach for the treatment of UC as they assist in restoring the integrity of the intestinal barrier and modulating the immune system by reconstituting the beneficial microflora with minimum adverse effects as compared to conventional treatments. Natural composition of drugs makes an immense appeal over synthetic chemicals.

2.4 Future Perspective:

- Clinical trials. Challenges for the future would include testing clinical efficacy, safety, as well as optimal dosing of TNVs in UC patients, from preclinical discovery to real-world therapeutic application.
- Scalability and Production: Mass production with identical formulations of TNVs is another very important aspect on which TNVs can be clinically used on a large scale.
- Combination with Conventional Therapies: TNVs can be combined with the mainstream UC drugs like corticosteroids and biologics and thus may help to

have better treatment outcomes and thereby reduce the requirement to use high doses of synthetic drugs.

- Personalized Medicine: Further detailed studies on how TNVs interact and alter the gut microbiota as well as associated biomarkers may finally lay the basis to devise personalized therapies where TNVs will be designed for the needs of a patient.
- Wider Therapeutic Implications: Considering the natural origin of the TNVs and their roles in controlling inflammatory processes as well as the microbiota, TNVs have wider therapeutic implications beyond the diseases mentioned above, especially Crohn's disease and irritable bowel syndrome when there is chronic inflammation.

TNVs are a promising, multi-targeted UC therapeutic with a body of preclinical work supporting their utility. Continued research may provide a paradigm shift in the management of UC and other chronic inflammatory diseases by offering these patients a safer alternative to traditional medicine.

3. Overcoming Multidrug Resistance in Breast Cancer with Nano drug Delivery Systems (NDDS)[11]

BC is still among the most frequently diagnosed malignancies in women worldwide. Chemotherapy continues to be the cornerstone of many treatments even to this day. Among some of the most important problems in clinical management of breast cancer is the development of MDR, which may potentially reduce effectiveness of chemotherapy. MDR is best described as the process by which cancer cells become resistant to a wide range of chemotherapeutic drugs, often after an initial positive response, and with this, treatment failure, relapse, and dismal patient prognosis.

3.1 Mechanisms of MDR in Breast Cancer :

MDR is a result of a complex network of cellular and molecular mechanisms that protect tumor cells against chemotherapy-induced cytotoxic effects. Some of these are:

- Drug Efflux Pumps overexpression: Overexpression of efflux transporters, such as P-glycoprotein P-gp, pumps chemotherapy drugs out of the cancer cell, thus lowering the intracellular concentration of the drug.
- Altered Drug Metabolism: Changes in drug-metabolizing enzymes can render chemotherapy drugs less potent because they are not as effective at reaching their sites of action.
- Altered Apoptotic Pathways: Cancer cells can avoid apoptosis by altering apoptosis pathways so that they survive even after exposure to chemotherapeutic drugs.
- Improved Drug Deconjugation: Over-expression of deconjugating enzymes detoxify chemotherapeutic agents that prevent its action.

3.2 Nano drug Delivery Systems (NDDS) To Overcome MDR:

Its potential lies in the accumulation of drugs within the tumor cells, anti-efflux mechanisms, and targeting anticancer drugs towards cancerous cells. It can encapsulate anticancer drugs along with protecting them from degradation and sustained release at the tumor site, which can thus eliminate side effects while enhancing treatment results.

3.3 Current Research and Future Development :

The present study focuses on the advanced development of NDDS including key mechanisms contributing to MDR of breast cancer. Some of the approaches are thus mentioned below;

- Inhibition of Efflux Pumps especially P-gp.
- Enhanced Penetration of drugs into the cancerous cells.
- Gene Therapy or RNA Interference based on alteration of molecular pathways during the process of MDR.

These strategies attempt to reverse MDR, to improve drug distribution, and provide more durable therapeutic outcomes.

4. Nano drug Delivery Systems (NDDS) in Coping with Barriers in Non-Infectious Uveitis Treatment[12]

Uveitis remains one of the major causes of irreversible blindness globally. NIU, due to autoimmune and inflammatory diseases, can lead to severe loss of vision if left untreated. Hitherto, corticosteroids, immune suppressive drugs, and biologic therapies remain the principal agents against preventing inflammation and tissue damage. However, the anatomy of the eye is quite complex. Therefore, effective delivery of drugs is very challenging and adverse side effects complicate long-term treatment efficacy.

4.1 Challenges in the Treatment of NIU:

The anatomy of the eye is pretty complicated and mainly because of this, there are serious barriers toward achieving the effective delivery of therapeutic agents. With such strong barriers of blood-retinal, corneal epithelial, and conjunctival, the ability of drug penetration is weak toward the tissues in the eyes, and so the efficiency of most treatments becomes less efficient. In fact, most of these systemic therapies are associated with severe side effects like cataract formation, increased intraocular pressure, and systemic immunosuppression, which has limited the treatment options for long-term care of NIU.

4.2 Nano-based DDS that could offer a way across these barriers:

Thus, scientists have consequently emphasized designing new Nano-based DDS that can enhance drug bioavailability,

the therapeutic outcome, and concurrently decrease the toxic effect encountered in the treatment of NIU. Such DDS as compared to the traditional delivery systems possess certain advantages – targeted delivery, increased bioavailability, sustained release of drug, and reduced systemic side effects. Application of nanotechnology-based DDS involves bypassing the ocular barriers, thus increasing the local concentration of drugs at the inflammation site and hence results in overall efficacy enhancement of treatment.

4.3 Current Nanotechnology-Based DDS for NIU Treatment:

There are a number of Nano carrier systems that are currently being explored to overcome the problems associated with traditional ocular drug delivery systems. The ones include:

- Liposomes: Liposomes are Nano carriers made up of a lipid-based material, which can carry a drug in both hydrophilic as well as lipophilic solvents. It follows controlled release, and with the help of biocompatibility along with penetration ability of the drug, it will be suitable for the ocular drug delivery system.
- Dendrimers: These are ultra-branched nanoscale polymers that offer ultra-high surface areas for drug loading and can be functionalized for specific targeting to ocular tissues. This system may be able to enhance solubility and stability of drugs while enhancing delivery into the target site.
- Hydrogels: Hydrogels have the potential to acquire a gel-like appearance after interaction with ocular tissues and allow sustained release along with elongated residence times of the drug. Such hydrogels have the capability for better drug stability and bioavailability, making them ideal candidate formulations for ocular inflammatory conditions.
- Nanoparticles and Nano micelles Nanoparticles and Nano micelles are the delivery agents with the best carrying capability for hydrophobic drugs. They improve the solubility and stability of poorly soluble compounds. The ocular Nano carriers could penetrate the tissues and create a higher concentration of the drug in the site of inflammation.
- Nano suspensions and Nano emulsions: Nano suspensions and Nano emulsions are two of the most interesting DDS, which can help dissolve poorly soluble lipophilic drugs along with improving their bioavailability. The systems are stable and have controlled release. So, they may be applied in ocular drug delivery.

Nano drug delivery systems are potential solutions to solve problems occurring in the case of non-infectious uveitis during treatment. Based on the nanotechnology, DDS developed with increased targeted drug delivery and overcoming ocular barriers with little or no systemic side effects can significantly make therapeutic outcomes from NIU treatments better. In this regard, more advancements in the developments of Nano medicines bring these DDS closer to truly paving the way toward more effective and safe management of ocular inflammation, giving hope for improved vision and quality of life among patients afflicted with NIU.

5. Nanoparticle-Based Tendon Targeted Drug Delivery System to Improve Healing[6]

Tendon injury is a common cause of significant functional impairment following poor healing outcomes. Although tendon injuries occur at a high frequency, as do poor recovery rates, there is currently no pharmacological intervention to promote healing. Hitherto, treatments are not very effective; besides systemic drugs encounter problems related to poor tendon homing, which decreases the effectiveness of potential therapeutic agents. Researchers investigate new paradigms, such as DDS nanoparticle-based drug delivery systems, to target specifically the healing tendon and enhance recovery outcomes.

5.1 Challenges in Tendon Healing and Drug Delivery :

Tendon injuries commonly heal through a fibrotic healing pathway and result in the formation of scar tissue rather than a restoration of healthy tendon fibers. Traditional treatments suffer from poor tendon homing, meaning therapeutic agents are not efficiently delivered to the site of injury. Consequently, healing is delayed, and functionally, there is limited recovery. There is a critical need for targeted drug delivery systems that can bypass systemic limitations and provide better healing outcomes for tendons.

5.2 Nanoparticle-Based Drug Delivery Systems to Promote Tendon Healing:

Recently, nanoparticle-based drug delivery systems have been presented as solutions for the challenges of tendon healing. Tendon healing spatial transcriptomic datasets were used by researchers for the identification of areas enriched for the expression of Acp5, an enzyme, in tendon healing. This eventually led to the formulation of a novel targeted drug delivery approach. The TRAP-binding peptide (TBP)-functionalized nanoparticle (NP) DDS was created to target and deliver therapeutic agents specifically to the healing tendon.

5.3 Existing Research and Applications of Nanoparticle DDS for Tendon Healing :

To illustrate the potential of this DDS, researchers targeted the healing tendon with nucleoside (NEN), an S100a4 inhibitor. While in the case of free NEN, there were no visible enhancements when administered systemically, dramatic improvements were seen when NEN was delivered using TBP-functionalized nanoparticles (TBP-NPNEN). The nanoparticle-based DDS dramatically enhanced both functional recovery and mechanical

properties of the healing tendon. The current DDS not only showed a capacity for overcoming conventional issues with drug delivery by ensuring high concentrations of therapeutic agents at the site of injury but also efficiently modulated the healing process.

5.4 Future Prospects and Potential Applications:

Achievement of enhanced tendon healing through the use of TBP-functionalized nanoparticle DDS constitutes an important milestone in the design of targeted therapies for tendon injuries. It provides a promising platform for the delivery of an entire pharmacological arsenal of agents directly to injury sites to enhance tissue repair and reduce fibrosis. Future research will be focused on optimizing formulations of nanoparticles, ensuring adequate stability, and increasing the range of therapeutic agents available for administration via this system. Moreover, by integrating DDS with gene therapy or physical therapy, the healing outcome of tendons may be further enhanced. Nanoparticle-based drug delivery systems are a new and promising approach that is being looked into as a possible solution to the problems encountered in tendon healing, especially when fibrosis is a significant impediment to recovery. This DDS could revolutionize the treatment of tendon injuries by improving therapeutic efficacy due to enhanced delivery to the healing tendon. The successful application of TBP-functionalized nanoparticles to deliver nucleoside serves as a proof-of-concept example that can provide a pathway to much more effective and targeted therapies in the future.

CONCLUSION

NDDS are reflections of the latest innovation in modern medicine, and thus a revolutionary solution to age-old problems of drug delivery. Due to their small size, large surface area, and versatility, NDDS have proven effective in improving the bioavailability and stability of the therapeutic agents by targeted delivery. In treating diseases like cancer and autoimmune conditions, in addition to tissue injuries, the potential offered by these systems has been immense in enhancing the efficacy of treatment methods.

Nanotechnology overcomes obstacles like poor drug solubility and inefficient targeting of drugs as well as side effects from systemic treatments in order to work more effectively and safely as drug delivery systems. The different types of Nano carriers – liposomes, Dendrimers, nanoparticles, and hydrogels-carry unique properties that can be exploited for targeted therapy applications and allow for controlled drug release. Another versatile quality attributed to NDDS is the possibility of combining therapy and diagnostics, known as theranostics.

With all these gains, there are still great challenges that lie ahead in the actualization of NDDS in its full potential, more specifically on issues of nanoparticle safety and biocompatibility. Additional studies on these systems are still required to improve their targeting capabilities to ensure safe entry into clinical use. With time, nanotechnology will grow; hence, the more advance and sophisticated drug delivery systems tailored to each patient are needed, and this will eventually translate into higher efficacy drugs with fewer side effects.

This holds a promising treatment of vast diseases as medicine is destined for further progressions in NDDS. Nanotechnology shall thus be able to revolutionize the delivery method in a way that drugs would be administered in a more effective manner, personalized, and therefore reachable to patients all over the world.

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