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A Review on Novel Drug Delivery System

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Abstract: *Although traditional methods of drug delivery are widely used, they often lack the efficiency seen in more advanced and innovative techniques. Many drugs are only effective within a specific concentration range — too much can be toxic, while too little may have no therapeutic benefit.With limited progress in treating serious diseases using conventional methods, there's an increasing demand for integrated, multidisciplinary approaches to drug delivery that can target tissues more precisely. Emerging drug delivery and targeting strategies aim to minimize drug breakdown, enhance bioavailability, reduce side effects, and increase the amount of drug reaching the intended area in the body. Upgrading a medication from a standard formulation to a specialized delivery system can greatly improve its effectiveness, safety, and patient compliance. However, delivering drugs at an exact location and controlled rate presents challenges that well-designed novel drug delivery systems (NDDS) can help overcome. NDDS are designed to maintain therapeutic drug levels over extended periods and, when necessary, transport the drug directly to the site of action. Motivated by the need to improve drug performance and reduce adverse effects, pharmaceutical companies are investing heavily in the development of these advanced delivery platforms.*

Keywords: Targeted drug delivery; Controlled release; Nanoparticles; Liposomes; Niosomes; Bioavailability; Drug carriers

I. INTRODUCTION

Remarkable progress in pharmaceutical science has led to the emergence of advanced drug delivery systems, offering creative and efficient methods of administering medications to patients. Novel drug delivery systems (NDDS) refer to state-of-the-art techniques and technologies aimed at increasing the therapeutic benefits of drugs, lowering the risk of side effects, and enhancing patient adherence to treatment. These systems are carefully designed to transport drugs accurately and in a controlled manner to the specific site where they are needed. Traditional drug delivery methods—such as pills or injections—often face challenges like failing to sustain drug release over time, difficulty reaching the targeted area at effective concentrations, and causing unwanted effects in other parts of the body. To overcome these drawbacks, modern systems apply advanced tools like nanoparticles, specialized drug carriers, targeted delivery methods, and implantable devices. These cutting-edge delivery approaches, often grouped under the term drug delivery systems (DDS), bring together knowledge from polymer science, biomedical engineering, and other scientific fields to create more precise, efficient, and patient-friendly drug therapies. Let me know if you want this version adjusted for a specific tone—academic, professional, or simplified for easier understanding. Fields such as pharmaceutics, bioconjugate chemistry, and molecular biology play a vital role in the development of novel drug delivery systems. These innovative systems enhance drug stability, offer controlled and targeted release, and significantly improve bioavailability through advanced technologies like nanoparticles, liposomes, microneedle patches, and implantable devices. Such advancements not only improve therapeutic outcomes but also increase patient comfort and adherence to treatment. In areas like cancer treatment, infectious diseases, chronic illnesses, and personalized medicine, the introduction of these advanced delivery techniques has far-reaching implications. They have the potential to revolutionize drug administration by opening up more precise, effective, and individualized treatment options. The design and development of these cutting-edge drug delivery platforms offer the promise of maximized therapeutic

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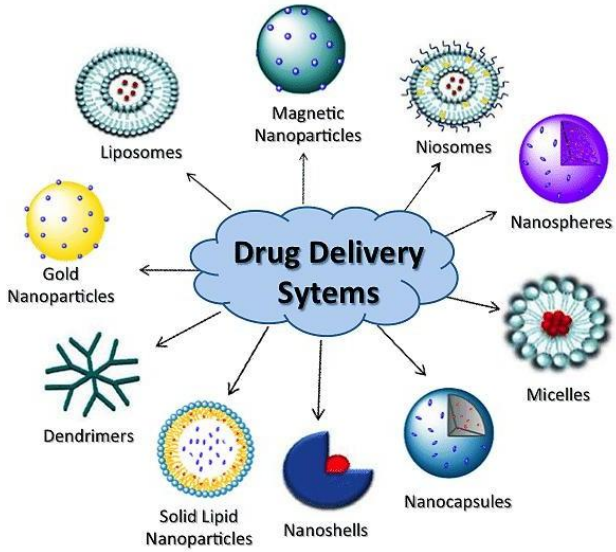
benefits, reduced adverse effects, and customized therapies, aligning perfectly with the goals of modern precision medicine and personalized healthcare.

The various nano drug carriers shown in the given **Fig. 01** as below followings:



This future, once a mere dream, is rapidly becoming a reality thanks to the ingenuity of NDDS. This review serves as your guide to this fascinating realm, illuminating the diverse array of systems and exploring their distinct advantages

- Nano-sized warriors: Nanoparticles, micelles, and liposomes, smaller than the width of a hair, infiltrate diseased tissues with targeted precision, delivering their healing payloads directly to the source.
- Controlled release champions: Polymeric implants and biodegradable patches transform drug delivery into a marathon, not a sprint, releasing medications in a sustained and controlled manner for extended periods.
- Gene therapy pioneers: NDDS act as Trojan horses, ferrying therapeutic genes into cells to correct genetic malfunctions or activate the immune system against cancer.
- Personalized pioneers: 3D printing technology joins forces with NDDS, creating customized dosage forms with precise drug release profiles, tailored to individual patient needs. s the review unfolds, it not only celebrates recent successes and clinical milestones but also critically examines the challenges and potential future directions in NDDS. The convergence of interdisciplinary research, bringing together expertise from materials science, pharmacology, and engineering, emerges as a key catalyst for the ongoing evolution of drug delivery systems. In summation, this comprehensive review serves as a beacon in the ever-evolving domain of NDDS. By synthesizing knowledge from various fronts, it aims to inspire researchers, academicians, and pharmaceutical professionals to explore and contribute to the unfolding narrative of precision drug delivery . NDDS exhibit various characteristics that aim to enhance therapeutic outcomes, improve patient compliance, and minimize side effects. These characteristics discuss in the given **Table. 01** as below followings:

Table 01: The list of characteristics, description, example and their application of novel drug delivery system

Characteristic	Description	Example	Application
Controlled release	Drug is released at a predetermined rate over an extended period of time.	Transdermal patches, Implants, Oral extended-release tablets	Chronic diseases (e.g., hypertension, diabetes), Pain management, Vaccines
Targeted delivery	Drug is directed to a specific site in the body, reducing side effects and increasing efficacy.	Liposomes, Nanoparticles, Antibody- drug conjugates	Cancer therapy, Gene therapy, Infectious diseases

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Mucoal delivey	Drug is absorbed through the mucosal membranes of the nose, mouth, or lungs.	Nasal sprays, Inhalers, Buccal patches	Allergies, Asthma, Pain relief
Transdermal delivery	Drug is absorbed through the skin.	Patches, Gels, Creams	Pain relief, Hormone replacement therapy, Smoking cessation
Implantable delivery	Drug is released from a device implanted in the body.	Biodegradable implants, Pumps	Cancer therapy, Chronic pain management, Contraception
Responsive delivery	Drug release is triggered by a specific stimulus, such as changes in pH, temperature, or enzymes.	Glucose-responsive insulin delivery systems, Tumor-activated drug delivery systems	Diabetes, Cancer therapy

This review article summarized the basics of novel drug delivery system, their classification, recent advancement in the NDDS with the marketed view on the various novel drug carrier.

TYPES OF NOVEL DRUG DELIVERY SYSTEM –

Novel Drug Delivery Systems (NDDS) encompass a wide variety of cutting-edge methods designed to improve how medications are administered, enhance their effectiveness, and boost patient adherence. One example is liposomes—tiny, lipid-based vesicles that encapsulate drugs, helping to increase both solubility and bioavailability. Another key category is nanoparticles, which are ultra-small particles measured in nano meters. These can be precisely engineered to transport drugs to specific tissues or cells, enabling highly targeted treatment. NDDS offer innovative solutions to the limitations of traditional drug delivery methods, paving the way for more efficient and focused therapeutic approaches. They can be classified into several types based on how they work and the routes through which they deliver medication. Two major categories within Novel Drug Delivery Systems are **Carrier-Mediated Delivery Systems** and **Transdermal Delivery Systems**. Carrier-mediated systems employ various carriers—such as **liposomes**, **nanoparticles**, or **polymers**—to enclose and transport drugs throughout the body. These carriers not only shield the drug from degradation but also enable targeted delivery to specific sites and regulate the release rate, ensuring prolonged therapeutic effects. On the other hand, **Transdermal Delivery Systems** administer drugs through the skin, either for local treatment or systemic absorption. The skin functions as a depot for gradual drug release, reducing the reliance on oral or injectable methods and enhancing patient adherence to treatment.

1. Controlled Drug Delivery Systems

Definition: Deliver drugs at a predetermined rate, for a specified period.

Examples:

Osmotic pumps

Transdermal patches

Extended-release tablets

2. Sustained Release Drug Delivery Systems

Definition: Maintain drug concentration within the therapeutic window over an extended time.

Application: Reduces dosing frequency and improves compliance.

3. Targeted Drug Delivery Systems

Definition: Deliver the drug specifically to the site of action, reducing systemic side effects.

Examples:

Monoclonal antibody-drug conjugates

Ligand-targeted nanoparticles

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4. Transdermal Drug Delivery Systems (TDDS)
Definition: Delivers drugs across the skin into the bloodstream.
Examples:
Patches (e.g., nicotine, fentanyl)
Microneedles

5. Nanotechnology-Based Drug Delivery
Definition: Uses nanoscale carriers for enhanced drug solubility, targeting, and controlled release.
Types:
Nanoparticles
Liposomes
Niosomes
Dendrimers
Solid Lipid Nanoparticles (SLNs)

6. Liposomal Drug Delivery Systems
Definition: Spherical vesicles with phospholipid bilayers encapsulating drugs.
Advantages: Improved drug solubility and reduced toxicity.

7. Microparticulate Drug Delivery Systems
Definition: Drug encapsulated in microspheres or microcapsules for controlled release.
Used in: Vaccines, injectable depots.

8. Ocular Drug Delivery Systems
Goal: Enhance drug residence time and penetration in the eye.
Examples:
In situ gels
Ocular inserts
Nano eye drops

9. Pulmonary Drug Delivery Systems
Method: Inhalation route to deliver drugs directly to the lungs.
Examples:
Dry powder inhalers (DPI)
Metered-dose inhalers (MDI)
Nebulizers

10. Buccal and Sublingual Drug Delivery
Definition: Drugs absorbed through the mucosa of the mouth.
Advantage: Avoids first-pass metabolism.
Examples:
Buccal films
Sublingual tablets

11. Implantable Drug Delivery Systems
Definition: Devices placed under the skin or within the body to release drugs over long periods.
Example: Hormonal implants (e.g., Norplant)

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12. Injectable Drug Delivery Systems
Includes:
Depot injections
Long-acting injectables (LAIs)
Biodegradable polymer carriers

13. Gastroretentive Drug Delivery Systems (GRDDS)
Goal: Prolong drug retention in the stomach.
Mechanisms: Floating, mucoadhesive, or swelling systems.

14. Mucoadhesive Drug Delivery Systems
Definition: Use of polymers to adhere drugs to mucosal surfaces for prolonged action.
Used in: Buccal, nasal, ocular, and vaginal routes

COMPARISON TABLE OF NDDS TYPES
Novel drug delivery system comparison table discussed in the given **Table. 02** as followings:

Type	Key Feature	Example	Advantages
Controlled Release	Constant drug release	Osmotic pump tablets	Reduces dosing frequency
Sustained Release	Slow, prolonged drug release	Matrix tablets	Prolonged therapeutic effect
Transdermal	Drug passes through skin	Nicotine patch, Fentanyl patch	Avoids GI tract, improves compliance
Nanoparticles	Nanoscale carriers	Polymeric NPs, SLNs	Enhanced solubility, targeting possible
Liposomes	Phospholipid vesicles	Doxil (liposomal doxorubicin)	Biocompatible, reduces toxicity
Niosomes	Non-ionic surfactant vesicles	Anti-cancer drug carriers	Stable, low cost
Dendrimers	Branched macromolecules	PAMAM dendrimers	Precise targeting, multivalency
Microparticles	Micro-scale drug carriers	Microspheres for vaccines	Controlled release, injectable
Implants	Long-acting devices under skin	Norplant (levonorgestrel)	Long-term release
Buccal/Sublingual	Absorption via mouth mucosa	Nitroglycerin tablet	Rapid onset, avoids first-pass metabolism
Pulmonary	Inhalation to lungs	DPI, MDI, Nebulizers	Direct to lungs, fast action
Ocular	Eye-specific delivery	Eye inserts, gels	Prolonged action in eye
Gastroretentive	Retains drug in stomach	Floating tablets	Local action, improved absorption
Mucoadhesive	Adheres to mucosal surfaces	Vaginal films, nasal sprays	Prolonged contact and release

CARRIER BASED DRUG DELIVERY SYSTEM-
In pharmaceutical science, carrier-based drug delivery systems utilize specialized carriers to improve the precision, effectiveness, and safety of delivering drugs. These carriers help enhance drug solubility, stability, and targeted transport, resulting in improved therapeutic outcomes. Common examples include liposomes, polymeric micelles, micro- and nanoparticles, and capsules. These carriers encapsulate drugs and deliver them to specific sites within the body, enabling controlled release and prolonged drug action, while maintaining optimal drug levels in the bloodstream.
arrier

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Based Drug Delivery System
1. Nanoparticles,
2. Microspheres
3. Liposomes
4. Niosomes
5. Monoclonal Antibodies
6. Resealed Erythrocytes as Drug carriers

1. Nanoparticles-

Nanoparticles (NPs) are colloidal drug delivery systems composed of natural, synthetic, or semi-synthetic polymers. Their particle sizes typically range from 10 to 1,000 nano meters. When designing nanoparticles, key considerations include controlling particle size, surface properties, and drug release profiles, with the goal of achieving targeted delivery of medications at an optimal therapeutic dose and rate.

These systems enhance site-specific drug delivery by evading the reticuloendothelia l system, utilizing the enhanced permeability and retention (EPR) effect, and employing active targeting mechanisms

Nanoparticles can be characterized as
1. Solid lipid nanoparticles (SLNs)
2. Liposomes
3. Nanostructured lipid carriers
4. Fullerenes
5. Nanoshells
6. Quantum dots
7. Super paramagnetic nanoparticles

2. Microspheres

Microspheres are typically sized between 200 and 500 micrometers and are often composed of biodegradable proteins or synthetic polymers. Various techniques are available for their preparation, allowing for precise control over drug release and enhancing the overall therapeutic effect of the medication. Microspheres offer a solution to many of the limitations associated with conventional drug therapies by enabling sustained and controlled drug release to specific target areas. Their ability to deliver drugs in a consistent and prolonged manner makes them valuable in a wide range of pharmaceutical applications.

They are classified into two types
1. Synthetic Polymers
2. Natural polymers
1. Synthetic polymers are further divided into:
Non-biodegradable polymers e.g. Poly methyl methacrylate(PMMA), Acrolein, Glycidyl methacrylate Epoxy polymers
Biodegradable polymers e.g. Lactides, Glycolides their co-polymers Polyalkyl cyanoacrylates, Polyanhydrides
2. Natural polymers may be obtained from different sources like proteins, carbohydrates and chemically modified carbohydrates.
Proteins: Albumin, Gelatin, and Collagen
Carbohydrates: Agarose, Carrageenan, Chitosan, Starch
Chemically modified carbohydrates: Poly dextran, Poly starch.

3. Liposomes-

Liposomes are tiny vesicles in which an aqueous core is fully enclosed by lipid bilayer membranes. Also referred to as vesicles or colloidal spheres, liposomes are made from a variety of components such as cholesterol, non-toxic surfactants, sphingolipids, glycolipids, long-chain fatty acids, membrane proteins, and therapeutic agents.

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Their characteristics—such as size, surface charge, lipid composition, and the method of preparation—can differ significantly. The fluidity or rigidity of the lipid bilayer, as well as its electrical charge, depends on the specific components used in their formulation.

Liposomes are capable of encapsulating both hydrophilic (water-soluble) and hydrophobic (fat-soluble) drugs, protecting them from degradation. They also allow for targeted and efficient release of the drug at specific sites, making them valuable for both research and commercial drug delivery applications.

4. Niosomes

When synthetic non-ionic surfactants are hydrated, they form **niosomes**—non-ionic surfactant vesicles—regardless of whether cholesterol or other lipids are present. These vesicles can encapsulate both hydrophilic and lipophilic drugs, enhancing drug retention and prolonging their presence in the body. A typical niosome consists of an amphiphilic non-ionic surfactant (such as Span-60) that is often stabilized with cholesterol, along with a small amount of an anionic surfactant (like diacetyl phosphate) to further stabilize the structure. Although niosomes and liposomes both have a bilayered structure, niosomes offer greater stability due to the specific materials used in their preparation. The two main components required for niosome formulation are:

Non-ionic surfactant (amphiphile)

Cholesterol (and sometimes a stabilizing agent such as an anionic surfactant)

Cholesterol helps maintain rigidity and structural integrity in niosome formulations. Surfactants are crucial components in niosome formation, as they largely determine the vesicle's characteristics. Typically, non-ionic surfactants are employed in the preparation of niosomes.

- Spans (span 60, 40, 20, 85, 80)
- Tweens (tween 20, 40, 60, 80)
- Brijs (brij 30, 35, 52, 58, 72, 76)

5. Monoclonal Antibodies

Monoclonal antibodies (MAbs) are uniform antibody molecules that specifically bind to a particular antigen. They are typically produced by fusing a B-cell with a single clone of cells that express a specific antibody gene. When linked with cytotoxic drugs, monoclonal antibodies targeting specific antigens can selectively deliver these drugs to cancer cells, minimizing damage to healthy tissues (usually administered through infusion).Beyond therapeutic use, monoclonal antibodies and their complexes are being explored as highly sensitive probes capable of targeting specific cells or organs. They have also been utilized to transport enzymes or cytotoxic agents to particular cell types.Antibodies targeting different subsets of T lymphocytes, particularly suppressor cells, are anticipated to remain highly valuable for diagnosing and treating conditions such as multiple sclerosis, certain heart diseases, various forms of leukemia, and malaria.

6. Released Erythrocytes as Drug Carriers –

Red blood cells (RBCs), or erythrocytes, have attracted significant interest as potential carriers for drug delivery and as drug-loaded microspheres. These modified cells, known as "resealed erythrocytes," are prepared by collecting blood from the target organism, separating the erythrocytes from the plasma, loading the desired drug into the cells, and then resealing them to form cellular carriers.Erythrocytes are capable of encapsulating a wide variety of biologically active substances, typically ranging in molecular weight from 5,000 to 600,000 Da. These molecules may be polar, hydrophilic, nonpolar, or hydrophobic in nature. Once reinjected, the drug-loaded erythrocytes act as slow-release depots in circulation, deliver the drug selectively to the reticuloendothelial system (RES), protect the encapsulated drug from enzymatic degradation, help maintain steady-state drug levels, and minimize drug-related side effects.

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The advancement in formulation of novel drug delivery carriers-

The development of innovative drug delivery carriers is a fast-progressing area with the potential to transform modern medicine. These advanced carriers aim to address the shortcomings of conventional drug delivery systems by offering improved performance and targeted delivery. The different preparation techniques for liposomes, niosomes, nanoparticles (NPs), and microspheres as novel drug delivery carriers are discussed in the given work.

Advance Carrier	Method	Description
Liposomes	Thin-film hydration	A lipid film is formed by evaporating a solution of phospholipids and cholesterol in organic solvent. The film is then hydrated with an aqueous solution containing the drug, resulting in the formation of liposomes.
	Reverse-phase evaporation	An aqueous solution of the drug is mixed with a solution of lipids in organic solvent. The organic solvent is then evaporated, leading to the formation of liposomes.
	Microfluidics	This technique uses microfluidic channels to precisely control the formation of liposomes with defined size and properties.
Niosomes	Thin-film hydration	Similar to the liposome preparation method, a thin film of the surfactant is hydrated with an aqueous solution containing the drug, leading to the formation of niosomes.
	Solvent evaporation	The drug and surfactant are dissolved in a common organic solvent, which is then evaporated, resulting in the formation of niosomes.
	Bubble extrusion method	A mixture of the drug, surfactant, and water is passed through a membrane with tiny pores under pressure. The pressure forces the mixture through the pores, forming niosomes of uniform size.
	Nanoprecipitation	A drug solution is mixed with a polymer solution under controlled conditions, leading to the formation of nanoparticles through spontaneous precipitation.
Nanoparticles (NPs)	Emulsion-solvent evaporation	The drug and a polymer are dissolved in separate organic phases, which are then emulsified. The organic solvent is evaporated, resulting in the formation of nanoparticles.
	Microfluidic synthesis	Similar to liposome preparation, microfluidic channels can be used to precisely control the formation of nanoparticles with defined size and properties.
Microspheres	Spray-drying	A solution of the drug and polymer is sprayed into a hot drying chamber, where the solvent evaporates rapidly, forming microspheres.
	Solvent evaporation	Similar to the nanoparticle preparation method, the drug and polymer are dissolved in a common organic solvent, which is then evaporated, resulting in the formation of microspheres.
	Double-emulsion technique	An aqueous solution of the drug is emulsified in an organic solution containing the polymer. This double emulsion is then poured into another aqueous solution, leading to the formation of microspheres.

Advantages of Novel Drug Delivery Systems –

- **Improved therapeutic efficacy:**

NDDS ensures that the drug reaches its target site in the required concentration, enhancing treatment effectiveness.

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- **Controlled and sustained release:**

These systems allow for gradual and controlled drug release, maintaining steady plasma drug levels over time.

- **Reduced side effects:**

By targeting specific tissues or cells, NDDS minimizes drug exposure to healthy tissues, lowering adverse effects.

- **Enhanced patient compliance:**

Fewer doses and convenient administration routes improve patient adherence to treatment regimens.

- **Better bioavailability:**

NDDS can enhance the solubility and absorption of poorly water-soluble drugs, improving their overall bioavailability.

- **Protection of drugs from degradation:**

Sensitive drugs (e.g., peptides, proteins, or nucleic acids) are protected from enzymatic or chemical degradation before reaching their target.

- **Targeted drug delivery:**

NDDS enables site-specific drug delivery, such as to tumor cells or specific organs, improving selectivity and therapeutic outcomes.

- **Reduction in dose frequency and quantity:**

Controlled-release formulations can reduce the total drug dosage needed to achieve therapeutic effects.

- **Enhanced stability of pharmaceutical compounds:**

Formulations in NDDS can improve the shelf-life and stability of drugs that are otherwise unstable in conventional forms.

- **Potential for novel routes of administration:**

NDDS supports innovative delivery methods like transdermal, nasal, ocular, pulmonary, or implantable systems.

Disadvantages of Novel Drug Delivery Systems –

- **High development cost:**

The research, design, and production of NDDS are often expensive, increasing the overall cost of therapy.

- **Complex manufacturing process:**

Formulation and large-scale production require advanced technology, strict control, and skilled personnel.

- **Stability issues:**

Some NDDS formulations (like liposomes or nanoparticles) may face stability challenges such as aggregation, leakage, or degradation during storage.

- **Limited drug loading capacity:**

Certain carriers can only encapsulate a small amount of drug, which may reduce effectiveness.

- **Potential for toxicity:**

The materials used (e.g., polymers, surfactants, or nanoparticles) may cause toxicity or immunogenic reactions in the body.

- **Difficult regulatory approval:**

Complex formulations require extensive testing and documentation, leading to longer approval timelines from regulatory authorities.

- **Challenges in targeting and release control:**

Achieving precise site-specific delivery and maintaining controlled release in vivo can be difficult.

- **Scale-up and reproducibility problems:**

Techniques effective at the laboratory level may be hard to reproduce consistently on an industrial scale.

- **Storage and handling limitations:** Some NDDS products require special storage conditions (e.g., refrigeration or protection from light), affecting their practicality.

- **Patient acceptability issues:** Novel routes of administration (like implants or injections) may cause discomfort or lower patient acceptance.

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II. CONCLUSION

A Novel Drug Delivery System (NDDS) integrates advanced techniques with newly developed dosage forms that significantly surpass conventional ones. These systems enhance therapeutic effectiveness by decreasing toxicity, increasing bioavailability, and minimizing the frequency of doses, thereby addressing issues related to patient noncompliance. Nanoparticulate drug delivery systems, in particular, hold great promise for applications such as vaccine delivery, radiation therapy, antibiotics, cancer treatment, protein and gene therapy, AIDS treatment, and as carriers capable of crossing the blood-brain barrier.

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