

Review

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Posted Date: 30 October 2025

doi: 10.20944/preprints202510.2284.v1

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Review

Drug Delivery Research Exploring Liposomal Systems, Nanoparticle Technologies, Oral Formulations, and Controlled Release Mechanisms

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Abstract

Drug delivery systems have come a long way and have developed tremendously with the introduction of bioavailability, targeted delivery, and patient compliance challenges. The article gives a comprehensive review of the recent technological advancements in vesicular carriers, nanoparticle platforms, solid lipid systems, and new oral dosage forms. Liposomal and proniosomal vesicular systems allow delivery of sensitive drugs, targeted delivery, and controlled release while nasal-pulmonary routes open up the treatment methods for respiratory diseases. The use of polymeric and inorganic nanoparticles has removed the barriers in oral administration of peptide and protein and allowed the delivery to specific sites, thus increasing therapeutic efficacy. Solid lipid nanoparticles and nanostructured lipid carriers have the property of being both biocompatible and sustained release, and hence they can serve both systemic and local drug delivery needs. Mouth-dissolving tablets, effervescent formulations, chewable tablets, and multiparticulate/pulsatile systems are among the innovative oral dosage forms that not only improve patient adherence but also permit customizable pharmacokinetic profiles. Along with controlled and sustained release strategies, like fast-dissolving tablets and liposomal vesicular carriers, material science is fused with clinical needs, leading to decreased dosing frequency and supporting chronotherapeutic regimens. The technologies used in oral dosage forms collectively show a shift towards precision medicine in the sense that they are patient-centric and result in better therapeutic outcomes. These systems not only point out the possible scenario of safer, more effective, and convenient therapies but at the same time also show a good link between the pharmaceutical innovation and clinical application. Novel oral drug delivery systems, nanocarriers, and vesicular platforms research would still be the potential areas in which drug delivery efficiency would be further enhanced and clinical impact stretched across various therapeutic areas.

Keywords: drug delivery systems; liposomes; nanoparticles; oral dosage forms; controlled release

1. Introduction to Modern Drug Delivery Systems

The objective of modern drug delivery systems is to increase therapeutic efficacy and at the same time, reduce systemic side effects through very specific targeting and controlled release. The drug targeting strategies, therefore, play a major role in directing drugs to particular tissues or cells, resulting in better bioavailability and fewer interactions with off-targets [1]. Depending on the specific patient's condition and drug-related issues, a combination of various targeting approaches such as passive, active, and stimulus-responsive targeting methods are used [1].

Table 1. Modern Drug Delivery Systems.

Aspect	Description	Advantages / Significance	References
Objective	Enhance therapeutic efficacy while reducing systemic side	Improves bioavailability and reduces off-target interactions.	[1]

	effects through precise targeting and controlled release.	
Targeting Strategies	Passive targeting, active targeting, and stimulus-responsive methods, selected based on patient condition and drug characteristics.	Directs drugs to specific tissues or cells for optimal therapeutic effect. [1]
Controlled Drug Delivery Systems	Platforms capable of continuous and predictable drug release.	Reduces dosing frequency, improves patient compliance, optimizes absorption, distribution, and metabolism. [2]
Technological Basis	Integration of materials science and pharmaceutical technology.	Overcomes limitations of conventional methods while maintaining safety and efficacy. [2]

The controlled drug delivery systems are capable of producing continuous and predictable release profiles, so that the dosing frequency is reduced and patient compliance is improved. The implementation of these systems is a merger of materials science and pharmaceutical technology, which in turn is determining the pattern of drug absorption, distribution, and metabolism [2]. Advanced delivery platforms are created in a way that they can break through the restrictions that are imposed by the conventional methods and still be able to deliver the desired drugs in an optimum way, keeping the safety and effectiveness intact [2].

2. Vesicular Drug Delivery Systems

Vesicular drug delivery systems have indeed advanced the targeted therapy by enclosing, controlling release and making the drugs more stable by using lipid bilayers. The liposomal concept, described in 1965, revealed the ability of the phospholipid bilayers to form closed vesicles that can hold both the water-loving and water-hating molecules [3].

There are different types of liposomes and they are categorized by size, lamellarity, and composition, and the diverse pharmaceutical applications are made possible by several preparation methods such as thin-film hydration, reverse-phase evaporation, and microfluidics [4]. Drug carriers have the capability to improve drug solubility, protect unstable drugs against degradation and provide even release through controlled and sustained profiles [5].

The modern liposomal formulations have gradually moved from being just a concept to being used in clinics, and they showed their effectiveness in treating cancer, infectious diseases, and delivering vaccines [6]. Apart from liposomes, proniosomes are another form that offers the benefits of better stability and convenience in storage. Moreover, proniosomes are easily converted to niosomes through hydration for efficient drug delivery [7].

Naso-pulmonary vesicular methods utilize the vast surface area and the abundant blood supply of the nasal and pulmonary routes, thus increasing the process of drug absorption both systemically and locally. Moreover, these systems are aimed at respiratory disorders that give a quick onset of action, lessened systemic toxicity, and increased patient compliance [8].

3. Nanoparticle-Based Drug Delivery

Nanoparticles are now considered as the most versatile drug delivery carriers; their benefits include increased drug solubility, localized and targeted drug delivery, and release rate control. Polymeric and inorganic nanoparticles are the most common types used in drug delivery of small molecules, nucleic acids, and hydrophobic drugs due to their adjustable size, surface chemistry, and biodegradability [9]. The application of advanced nanoparticles leads to better therapeutic outcomes because of their ability to increase bioavailability and at the same time decrease systemic toxicity [10].

In the case of oral administration of peptides and proteins, there are certain difficulties related to enzyme activity and low absorption in the intestine. One can regard nanoparticle encapsulation, mucoadhesive coating, and enteric protection as some of the methods for overcoming this problem, thus allowing for the administration of fragile biomolecules systemically [11]. What is more, using functionalized nanoparticles it is possible to carry out targeted therapy by attaching ligands, antibodies, or peptides onto the nanoparticle's surface, which in turn leads to improved cellular uptake and therapeutic specificity [10,12].

4. Solid Lipid Systems

Solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs) are the two main types of lipid-based delivery systems that provide controlled release and increased stability. The reason for their stability is mainly due to SLNs which consist of solid lipid matrix that shields the treatment from getting weak, while these NLCs when added along with the liquid lipids upsurge the crystallinity-related drawbacks thus carrying more drug and quicker release [13].

Newer concepts in preparation techniques such as high-pressure homogenization, microemulsion, and solvent evaporation have been able to master the properties of particle size, its distribution, and the effectiveness of drug encapsulation. Besides, the lipid-based systems offer a variety of routes for drug administrations such as topical, oral, and parenteral which all together serve the purpose of extending the applicability in clinics [14].

5. Novel Oral Dosage Forms

Novel oral dosage forms contribute to the basically good compliance of patients, better bioavailability and in the end either rapid or gradual release of drugs. Mouth-dissolving tablets (MDTs) and films are such an example of variations that can dissolve in the oral cavity very fast, requiring no water, thus being suitable for infants and older adults. In vitro and in vivo studies on cinnarizine show very rapid dissolution and heightened patient acceptability, thus affirming their therapeutic potential [15,16]. Propranolol hydrochloride films have been developed similarly to ensure even deliverance and quick onset of action [17]. Ondansetron and amlodipine mouth-dissolving pills do well to demonstrate the use of MDTs, inherent characteristics, better dissolution plus superdisintegrants being very effective for rapid release [18,19].

Effervescent tablets are medicines such as paracetamol that not only dissolve quickly but also taste better and enable accurate dosing [20]. On the other hand, chewable tablets have become a great helper in the compliance process, especially for children and elderly patients, mainly because of the fun and even distribution of the drug facilitated by modern taste protection techniques [21].

Modern multiparticulate and pulsatile systems render the occasional drug release that is precise and thus important for chronotherapy possible. The case of low density multiparticulate carriers for meloxicam substantially supports this as they provide a release that is both delayed and controlled according to the circadian rhythms [22]. Microencapsulation also forms a part of such strategies; the encapsulation of drugs in polymeric or lipid matrices can lead to sustained or targeted delivery, hence reducing the systemic side effects [23].

6. Controlled and Sustained Release Technologies

Controlled and sustained release technologies not only aim at but also promise to maximize therapeutic effects by manipulating the rate, time and location of drug release. Among the various systems which have been developed, the fast-dissolving tablet (FDT) systems have received lots of interest because of their quick dissolution and patient-friendly characteristics especially in case of patients having difficulty in swallowing. The most recent advancements in this field include the use of cosolvents, superdisintegrants, novel excipients, and optimized compression techniques which not only assure uniformity in drug release but also ensure maximum bioavailability [24].

Simultaneously, the use of vesicles like liposomes is a sustainable and targeted delivery strategy. Lipid-based systems hold and mix hydrophilic and lipophilic drugs, thus, letting them out gradually and at the right place while keeping them alive. The pharmacokinetics, the therapeutic index, and systemic toxicity have all been significantly improved by such systems [25].

The merging of the polymers with vesicular systems permits the release kinetics to be controlled through two means. In this manner, the technologies can be customized to provide the drugs instantly or for a longer time, just right for supporting chronotherapeutic regimens and lessening dosing frequency. Nonetheless, the platforms for controlled and sustained drug delivery are the result of a merger of material science and pharmaceuticals, thus, giving precision therapy a push and improving patient-centric outcomes.

Table 2. Vesicular and Controlled Drug Delivery Systems.

Aspect	Description	Advantages / Significance
Vesicular Drug Delivery	Use of liposomes and other lipid-based vesicles to encapsulate hydrophilic and lipophilic drugs.	Gradual and site-specific drug release; improved pharmacokinetics, therapeutic index, and reduced systemic toxicity.
Polymer-Vesicle Integration	Combining polymers with vesicular systems to control release kinetics.	Allows customization for immediate or prolonged drug release; supports chronotherapeutic regimens; reduces dosing frequency.
Technological Basis	Fusion of materials science and pharmaceuticals.	Enables precision therapy and enhances patient-centric outcomes.

7. Conclusions

Extensive and up-to-date drug delivery systems have been reviewed in this article, which includes gated containers, nanoparticle technologies, solid lipid systems, and novel oral dosage forms among others. Among the various products of vesicular systems like liposomes, proniosomes, and naso-pulmonary carriers only the latter offer hydrophilic and lipophilic drugs. Their very nature consists of the attributes of enhanced bioavailability, targeted delivery, and reduced systemic toxicity, thus, they act as versatile platforms for [3–8]. Applied to this issue, nanoparticles, whether they are polymeric or inorganic, are able to solve the critical challenges in the oral delivery of peptides/proteins as well as they allow the precise targeting of cells for improved therapeutic outcomes [9–12]. Furthermore, solid lipid and nanostructured lipid carriers present another opportunity for the lipid-based delivery industry as they not only are biocompatible but also have the controlled release capability [13,14].

Novel oral delivery systems, like mouth-dissolving tablets, effervescent preparations, chewable forms, and multiparticulate/pulsatile designs, not only facilitate patient adherence but also provide the option of customizing release profiles for different therapeutic needs [15–23]. Among such controlled release and sustained release technologies, fast-dissolving tablets and liposomal vesicular carriers are capable of executing chronotherapeutic strategies and are thus reducing the frequency of dosing, making a synergy between material science and clinical practice [24,25].

In general, these developments serve as a clear indication of the transition to the so-called "precision drug delivery" approach, where the formulation strategies are more and more directed by the physicochemical properties of the drug and the needs of the patient. The combination of nanocarriers, vesicular systems, and new oral dosage forms symbolizes the mingling of the three fields: pharmaceuticals, biotechnology, and clinical medicine, thus rejuvenating the promise of therapeutics that are not only safe and effective but also comfortable for the patient.

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