

Review

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Review

Integration of Liposomal Carriers, Nanoparticles, Oral Dosage Technologies, and Controlled Release Formulations in Modern Drug Delivery

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Abstract

Modern drug delivery systems' evolution has drastically altered the paradigm from traditional dosage forms to the corresponding engineered technologies that are specifically made for controlled, targeted, and patient-centered therapies. The present article encompasses those liposomal carriers, nanoparticulate systems, oral fast dissolving technologies, and controlled release formulations that altogether shape the future of the therapeutic delivery. The intro gives a deciphering of the ideas of logical drug design and controlled targeting. The vesicular and liposomal systems are discussed in terms of their structural, biomedical, and clinical importance, after which the particle-based methods that sharpen therapeutic precision and conquer the barriers to macromolecular delivery are discussed. Lipid-based nanocarriers like solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs) show their edge over others by maintaining exceptional stability, encapsulation efficiency, and continuous drug release characteristics. Besides that, oral fast-acting systems—which consist of mouth-dissolving tablets, films, and effervescent preparations—are characterized by their quick start and increased patient compliance coupled with chewable forms for easier acceptance. Among these reliable and sustained-release techniques are microencapsulation, pulsatile multiparticulate systems, and matrix-based designs that provide constant pharmacokinetic performance and help in keeping the patient. The article ends with clinical viewpoints on nanocarrier usage that are connecting preclinical innovations with clinical success. This whole synthesis marks that the interplay between formulation science and therapeutic outcomes is very strong and points out the fact that a patient-oriented approach is essential in pushing the next-generation drug delivery systems forward.

Keywords: liposomal drug delivery; nanoparticles; oral fast-dissolving systems; controlled release formulations; targeted therapeutics

1. Introduction to Advanced Drug Delivery Systems

The current era of pharmaceutical research and development is mainly devoted to the conception of sophisticated and targeted drug delivery systems, which are capable of achieving a much higher therapeutic effectiveness along with a considerable reduction of the adverse effects. The argument which justifies such delivery methods was put forward by Sengar [1], who said that the selection of the active pharmaceutical ingredient's exact location would be carried out through the best vehicles thus letting the other parts of the body remain free from the drug. As a result, the toxicity to the whole body is lowered. Different techniques have been developed, these are classified into passive and active targeting, to keep the disease under control and hence the use of drugs will be less, in turn, patient compliance will increase.

Vyas and Khar [2] came up with new ideas regarding the concepts of controlled drug delivery, pointing out the fact that the formulation science innovations are responsible for the prolonged release, the predictable bioavailability, and the therapeutic consistency. The new era of drug delivery

has completely changed the way of drug administration; instead of giving the drug at fixed times, one can use engineered systems that can modulate the drug release kinetics, thus achieving both the time and location control within the body.

2. Vesicular and Liposomal Drug Delivery Systems

Vesicular drug delivery was originally based on the research and development of liposomes, which were accidentally discovered by Bangham and his team in 1965, who also demonstrated the diffusion of ions across phospholipid lamellae, thus paving the way for the use of phospholipid carriers in the medical field [3]. Liposomes, which consist of two layers of lipids surrounding a water core, have been widely researched for their structural versatility, biocompatibility, and, thus, application in drug delivery. Akbarzadeh et al. [4] have divided liposomes into several categories, including conventional, stealth, and targeted, and also brought to light different methods of preparation, which are, for instance, thin-film hydration and solvent dispersion, determining their size, lamellarity, and encapsulation efficiency.

Torchilin [5] illustrated the possibility of using liposomes to enhance pharmacokinetics and therapeutic outcomes by allowing site-specific delivery and protecting the drugs that have been incorporated from being degraded. Similarly, Allen and Cullis [6] the clinical translation of liposomal formulations with those employed in anticancer and antifungal therapies, pointing out their role in connecting laboratory design with patient applications.

Proniosomes, a concept introduced by Sengar et al. [7], are considered to be one step ahead of the traditional forms of liposomes and niosomes, offering improved stability, reproducibility, and the convenience of hydration before administration. These dosage forms that are prepared as vesicles enhance drug instability and prolong the period of drug availability, making them suitable for mass production.

Moreover, naso-pulmonary vesicular systems have been recognized as a future-oriented way of local and systemic drug delivery. As reported by Sengar, Jagrati, and Khatri [8], these formulations allow better targeting to the respiratory tract, greater absorption through mucosa, and decreased first-pass effect—all of which make them very useful in the treatment of respiratory and neurological diseases.

Table 1. Vesicular and Liposomal Drug Delivery Systems.

Subtopic	Description	Key Advantages / Contributions	References
Origin of Vesicular Systems (Liposomes)	Liposomes were discovered accidentally by Bangham et al. in 1965, who demonstrated ion diffusion across phospholipid lamellae, establishing phospholipid-based carriers for medical use.	Foundation of modern vesicular delivery; first demonstration of phospholipid bilayer encapsulation; inspired pharmaceutical liposome design.	[3]

Structure & Classification of Liposomes	Liposomes consist of a phospholipid bilayer surrounding an aqueous core. Akbarzadeh et al. classified liposomes as conventional, stealth, and targeted, and described preparation methods such as thin-film hydration and solvent dispersion.	Versatility in size, lamellarity, and encapsulation efficiency; ability to tailor formulation based on therapeutic need.	[4]
Therapeutic Potential of Liposomes	Torchilin described liposomes as enhancers of pharmacokinetics and therapeutic outcomes via site-specific delivery and protection of labile drugs.	Improved drug stability; prolonged circulation; targeted delivery; reduced degradation.	[5]
Clinical Translation of Liposomes	Allen & Cullis demonstrated the success of liposomes in anticancer and antifungal therapies, bridging laboratory innovation with clinical application.	Real-world clinical adoption; approved formulations (e.g., Doxil®); significant role in oncology and infectious diseases.	[6]
Proniosomes	Introduced by Sengar et al., proniosomes are dry, stable formulations that convert to niosomes upon hydration.	Enhanced stability; ease of storage and transport; reproducibility; suitability for large-scale manufacturing.	[7]
Naso-Pulmonary Vesicular Systems	Reported by Sengar, Jagrati & Khatri, these vesicular formulations target respiratory tissues and allow rapid mucosal	Non-invasive administration; improved local/systemic absorption; ideal for	[8]

	absorption while avoiding first-pass metabolism.	respiratory and neurological drug delivery.	
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3. Nanoparticle-Based Therapeutic Platforms

At the heart of modern pharmaceuticals, along with enlargement of the possibilities for drug biodistribution, release kinetics, and cellular uptake, are nanoparticles. Kaur and Mehta [9] pointed out considerable advancements in both polymeric and inorganic nanoparticles, specifying their adjustable size, surface charge, and capacity to hold both to water and not to water drugs. These properties not only improve the stability and the bioavailability but also reduce the toxicity of the systemic circulation.

The authors Prajapati et al. [10] pointed further to the fact that the future of drug delivery is being shaped by the development of nanoparticle technologies, which provide site-specific targeting and sustained release platforms. They revealed the use of hybrid nanocarriers using both organic and inorganic materials and that the former optimized drug loading and release while the latter ensured biocompatibility, which is very crucial for translational research towards clinics.

Among the obstacles in oral drug delivery, the first one is the degradation of peptides and proteins in the gastro-intestinal tract. Zhu et al. [11] discussed methods to tackle these limitations, such as polymeric nanoparticles and absorption enhancers that protect sensitive biomolecules and encourage intestinal uptake. The ultimate goal of these strategies is to replace the invasive parenteral route with a more convenient oral administration.

Sengar et al. [12], in their study, also looked into effervescent-assisted nanoparticle dispersion systems as a complement to the above advancements. The mechanism of effervescence here is to break the nanoparticles down into smaller sizes and disperse them in aqueous environments. This new strategy leads to higher dissolution rates, quicker absorption, and incorporation of nanoparticles in fast-acting oral formulations.

4. Lipid-Based Nanocarriers

SLNs are the solid lipid nanoparticles with their different characteristics such as stability, biocompatibility, and controlled drug release to be the very attractive lipidic delivery system. The production and design of SLNs using physiologically compatible lipids that remain solid at both room and body temperatures were introduced by Müller et al. [13]. The nanoparticles serve as a lipid matrix which retains the drug for stable and controlled release. Furthermore, SLNs can attract both hydrophilic and lipophilic drugs to their surfaces while at the same time providing less burst release and higher drug entrapment efficiency.

The state-of-the-art in this area has resulted in the development of nanostructured lipid carriers (NLCs), which are the successors of SLNs that consist of a combination of solid and liquid lipids to overcome the problems of low drug loading and possible drug loss during storage. Has and Sunthar [14] discussed the modern lipid systems in detail and the high-pressure homogenization, microemulsion methods, and solvent evaporation as the cutting-edge preparation techniques. These methods ensure uniform particle size distribution and reproducibility while maintaining physicochemical stability.

To sum up, SLNs and NLCs are marking the next turning point in the technology of nanocarrier. They not only provide more availability but also allow release kinetics to be manipulated. Their extensibility among topical, oral, and parenteral routes proves their growing clinical importance in the delivery of both conventional and biopharmaceutical agents.

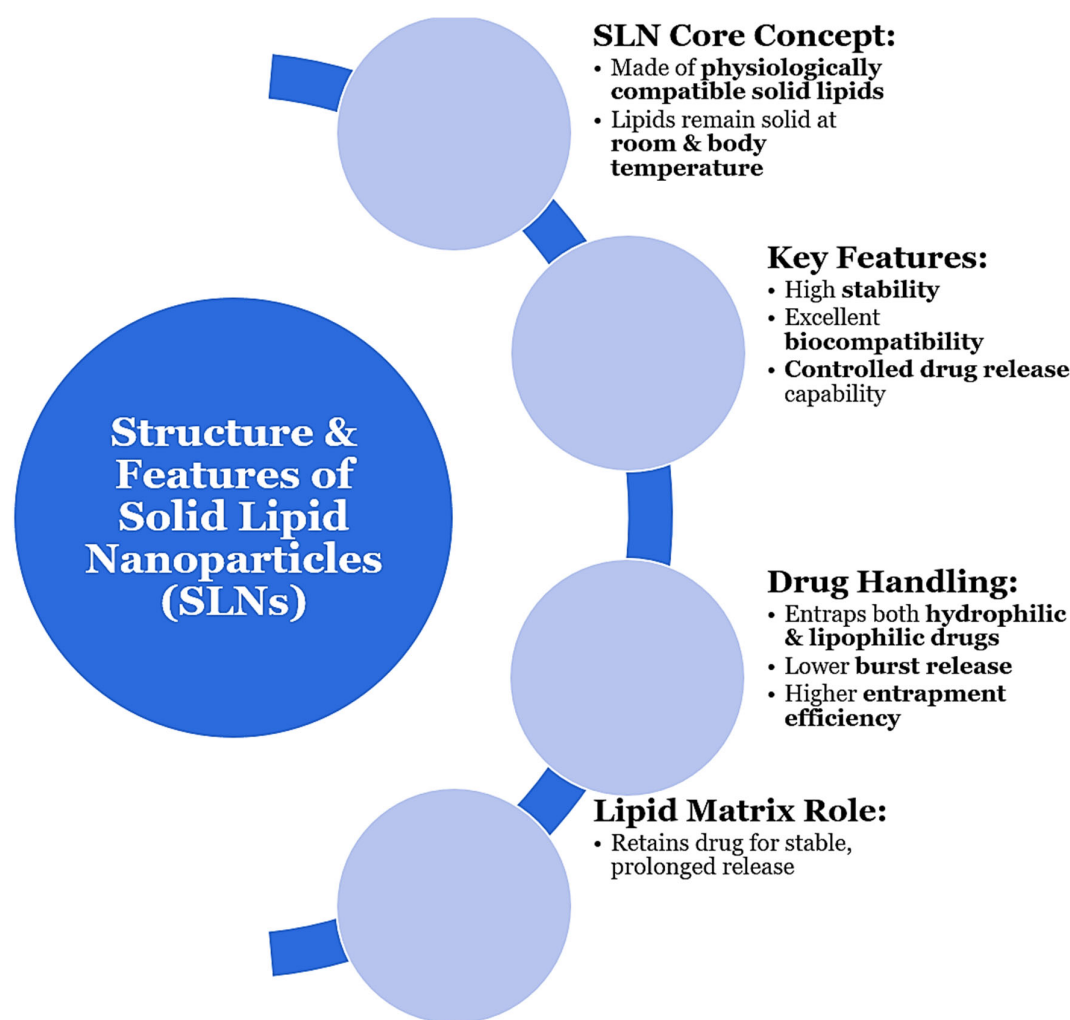


Figure 1. Structure & Features of Solid Lipid Nanoparticles (SLNs).

5. Oral Fast-Acting and Effervescent Dosage Technologies

The development of oral fast-acting dosage forms has remarkably improved the way drugs are administered by making it more pleasant for the patients and at the same time, the quick therapeutic effects. Patel and Patel [15] were the first ones to come up with the idea of making mouth-dissolving tablets of cinnarizine using superdisintegrants that were optimally chosen to get the disintegration and dissolution done fast without the use of anything, which is a very important step for the old and the little ones. Mishra and Patel [16] also pointed out that in order to be both strong and fast to get dispersed would give the advantage of releasing drug uniformly.

Sengar et al. [17] were the ones who came up with mouth-dissolving propranolol hydrochloride films and they were the ones who stopped prescribing tablets and thus in an indirect way, they caused a more patient-friendly scenario through the drugs being more accessible, faster absorption by the oral mucosa, and through their easy-to-take nature. Yadav and Mote [18] did more than just showing the involvement of β -cyclodextrin in the designs of ondansetron's taste masking and solubility improvement. Kamboj et al. [19] have done a lot of work on the optimization of the formulation and the use of various superdisintegrants in the making of the tablets for amlodipine besylate with the main emphasis being on the versatility of the formulation for the different pharmacokinetic profiles.

The effervescent tablets, highlighted by Kumar and Singh [20], are the ones that use acid-base reactions to produce carbon dioxide, hence accelerating the disintegration process and improving the

patient's acceptance especially for those medicines that need to be taken in higher doses, e.g. paracetamol. Likewise, chewable tablets have been an attractive option because of their taste and ease of administration. In their review, Sengar et al. [21] addressed in detail the chewable systems, with the emphasis on the problems of formulation such as the aspects of texture, taste, and mechanical integrity, all essential in keeping the product's acceptance and therapeutic effectiveness. All these novel dosage forms point to the consumer's demand for quick acting, easy to use oral administration, and patient-centered approaches as the driving forces of modern pharmaceuticals.

6. Controlled and Sustained Release Formulations

Controlled and sustained release formulations have become one of the main principles of modern pharmaceuticals, namely the delivery of drugs in a regulated manner over a long period of time in order to get the best therapeutic effect. Sharma and Pawar [22] showed that the low-density multiparticulate system could be used to release meloxicam pulsatile, which is with the body's circadian rhythm. Thus, the release of drug can be time-specific according to the body's rhythm. This system may prove beneficial for the chronopharmacological controlling of drugs that are effectively involved.

Microencapsulation is one of the techniques that Singh et al. [23] highlighted as a reliable method to control the release of active ingredients. This is achieved by wrapping drugs in polymeric shells. The method not only provides a shield to the very sensitive bioactives which might otherwise be destroyed but also does away with the adverse effects of the active ingredient while ensuring its activity over a prolonged period.

Gupta and Mishra [24] have pointed out the collaboration between fast- and sustained- release profiles in the emerging trend of matrix- based formulations that consist of a single dosage form. These hybrid systems, beside allowing the initial fast onset, also release drugs in a controlled manner later which, in turn, improves both the drug's bioavailability and patients' adherence.

Among the various carriers used in the sustained-release technology, liposomal vesicular carriers have turned out to be the most important ones. According to Jagrati and Sengar [25], the steady drug diffusion, enhanced bio-distribution, and reduced dosing frequency are the benefits that are attributed to liposomal encapsulation. This method has been gaining importance with drugs like chemotherapy, peptides, and other biopharmaceuticals whose therapeutic effects require a longer presence in the body.

The above-mentioned systems in terms of the multiparticulate, encapsulated, and vesicular delivery systems have made a remarkable turn in the direction of precision-controlled pharmacotherapy thereby making the efficient utilization of drugs along with their safety and the patients' compliance in the design of continuous therapy.

Table 2. Controlled and Sustained Release Formulations.

Subtopic	Description	Key Advantages / Contributions
Chronopharmacological Multiparticulate Systems	Sharma & Pawar demonstrated that low-density multiparticulate systems can release meloxicam in a pulsatile pattern aligned with circadian	Time-dependent drug release; improved chronopharmacological control; enhanced therapeutic efficacy for rhythm-dependent diseases.

	rhythm, enabling time-specific therapy.	
Microencapsulation Technology	Singh et al. highlighted microencapsulation as a technique where active drugs are enclosed within polymeric shells, providing protection and regulated release.	Protects sensitive actives; minimizes side effects; enables long-term activity; controlled and predictable drug release.
Hybrid Matrix Systems (Fast + Sustained Release)	Gupta & Mishra discussed hybrid matrix-based formulations that combine an initial fast release with prolonged sustained release within a single dosage unit.	Rapid onset + long-lasting therapeutic effect; improved bioavailability; increased patient adherence.
Liposomal Vesicular Carriers for Sustained Release	Jagrati & Sengar showed that liposomal carriers help achieve steady diffusion, enhanced biodistribution, and reduced dosing frequency, especially for chemotherapy, peptides, and biopharmaceuticals.	Prolonged circulation; more consistent therapeutic levels; minimized dosing frequency; reduced systemic toxicity.
Overall Impact on Precision Pharmacotherapy	Multiparticulate, encapsulated, and vesicular systems collectively improve controlled release, optimize drug utilization, and enhance patient compliance.	Better safety profile; precise therapeutic control; improved long-term treatment outcomes.

7. Translational Prospects and Future Outlook

Turning laboratory innovations into advanced drug delivery systems is the ultimate goal of modern pharmaceuticals. Sengar, Jagrati, and Khatri [8] pointed out the naso-pulmonary vesicular delivery route as a clinically effective approach that provides non-invasive access to systemic circulation with increased patient comfort and decreased first-pass metabolism. Moreover, such systems are very much suited for respiratory and systemic diseases where quick and localized drug absorption is a must.

Both polymeric and inorganic nanoparticles have made a remarkable move toward the clinic because of their adjustable surface properties and suitability for targeted therapy. Kaur and Mehta [9] pointed out that the regulatory and scale-up issues are still major obstacles; however, the gap is quickly closing due to continuous improvements in biocompatibility and manufacturing standards.

Zhu et al. [11] envisaged the time to come for oral macromolecular delivery through the application of nanocarriers and proposed the use of new permeability enhancers and mucoadhesive systems to defeat the gastrointestinal barriers. Notably, this progress is crucial for the positioning of peptides, proteins, and other biologics, which have often been facing degradation issues.

Müller, Radtke, and Wissing [13] pointed out that the clinical significance of lipid-based nanocarriers based on their attributes of stability, skin compatibility, and controlled release, which are already used in dermatological and cosmetic formulations. Similarly, Jagrati and Sengar [25] showed liposomal vesicular carriers to be versatile and clinically proven delivery systems that could not only encapsulate a wide variety of bioactives but also improve pharmacokinetics and lessen systemic toxicity. These combined achievements in nanocarrier technology development not only represent the adoption of precision medicine—where formulation design and patient-specific therapeutic goals entwine for the drug delivery that is optimized, safe, and effective.

8. Conclusions

The combination of several sophisticated delivery methods is a huge change in pharmaceutical formulation technology. The controlled and targeted delivery systems ensure better therapeutic outcomes through the combination of good drug design and delivery to specific sites. Only the use of liposomal and vesicular carriers has improved pharmacological performance by making drugs more available and less toxic to the whole body. Besides, nanoparticle-based systems whether they are polymeric, inorganic, or lipidic push this innovation further by offering precision targeting, controlled kinetics, and better adherence to the therapy. The development of oral fast-dissolving and effervescent dosage forms is a big step towards more patient-friendly therapies since it allows the rapid onset of the effect of the drug and also better compliance. The same applies to microencapsulation and sustained-release platforms that guarantee steady drug levels in the body, thus making the frequency of dosage less and the clinical outcome better.

All these advancements together create a common platform for the future drug delivery—where liposomes, nanoparticles, and new oral systems are merged to facilitate personalized and effective therapy. The translational capability of these technologies is getting bigger and bigger continuously by the reasons of nanotechnology, material science, and regulatory flexibility. The combination of this approach not only increases the therapeutic effectiveness but also sets the stage for the coming era of smart, patient-centered, and clinically feasible drug delivery solutions.

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