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Innovative Strategies in Therapeutic Delivery Including Liposomes Nanoparticles Fast Dissolving Dosage Forms and Effervescent Formulations

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Innovative Strategies in Therapeutic Delivery Including Liposomes Nanoparticles Fast Dissolving Dosage Forms and Effervescent Formulations

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Abstract

The sustained development of science in drug delivery has transformed contemporary therapeutics towards targeted, controlled and patient-centred therapy. In this review, the authors analyze the development and incorporation of liposomal, nanoparticulate, and oral fast-dissolving systems as new drug delivery systems. The paper starts with the rationale and strategic principles of the controlled delivery, then proceeds to discuss vesicular delivery vehicles (liposomes, proniosomes, and niosomes) and their structural benefits and pharmaceutical importance. Both polymeric and inorganic nanoparticles are also discussed due to their ability to improve bioavailability, oral peptide delivery, and effusive dispensation of drugs. Solid lipid system in the form of Solid lipid Nanoparticles (SLNs) and Nanostructured Lipid Carriers (NLCs) provide even greater stability and biocompatibility to support sustained and localized therapeutic effects. In addition, the introduction of dissolvable, effervescent and chewable dosages, improve patient compliance and guarantee the fast onset of a pharmacological effect, especially in patients with swallowing problems. The combination of formulation technology and nanomedicine is manifested through controlled and sustained-release approaches, which are combined with vesicular nanocarriers. The final part of the review is dealing with the translational issues, regulatory approaches, and future opportunities of incorporating nanocarrier-based therapeutics in clinical practice. Taken together, these inventions represent a paradigm shift of more effective, safer and more personalized pharmaceutical treatment that will be in line with the trends in precision medicine around the world.

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TOC

1. Overview of Modern Therapeutic Delivery

The basis of the contemporary therapeutic delivery is formulating rational approaches to delivering targeted drugs in a manner that ensures maximum effectiveness and minimum exposure to the system. By understanding the physiological barriers and idealizing carrier systems, methods of targeting are formulated with precise goals, to deliver the correct drug, at the correct concentration, to the correct site of action. The reasoning and rationale supporting such an approach is because it is

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necessary to surpass the traditional dosage restrictions, enhance bioavailability, and selective pharmacological reactions [1].

With this argument, the development of controlled drug delivery systems has become a scientific and technological advancement that allows controlled and predictable release of drugs. These systems incorporate pharmacokinetic regulation and compliance in individuals through the use of new carriers, release-altering agents, and design-based delivery systems. Not only will these developments ensure therapeutic focus during prolonged periods but will also ensure a lower dosing frequency, which indicates the fundamental guidelines of the sophisticated pharmaceutical development [2].

2. Advanced Vesicular Carriers

Vesicular systems Vesicular systems began with the groundbreaking finding of lipid vesicles (also called liposomes) by Bangham et al. that has served as the basis of today's lipid-based carriers in drug delivery. These popular self-assembling vesicles resemble biological membranes, and provide a special setting of hydrophilic drug encapsulation as well as lipophilic drug encapsulation [3].

The liposomes over the decades have become complex classifications with multilamellar, small, and large unilamellar vesicles, each with the aim of maximizing the efficiency of drug entrapment and drug release properties. Their use is not limited to controlled and sustained drug delivery but to gene and vaccine delivery due to the high levels of biocompatibility and tailorable surface characteristics [4].

The developments in liposomal technology have allowed the development of tight targeting with the modification of the surface with ligands and polymers, enhancing the pharmacokinetics and site-specific accumulation. Improvements in this regard have made liposomes one of the most useful and clinically acceptable nanocarrier in the contemporary therapy [5]. More so, their success in clinical preparations of cancer, antifungal, and vaccine treatments has been established through translational studies, which acts as an intermediary between laboratory novelty and clinical use [6].

In addition to the conventional liposomes, proniosomal systems have also been developed as dry and stable precursors, which convert to niosomes upon reaction with water. These carriers unite structural strength of the surfactant-based systems and increased physical stability and cost-effectiveness, thereby conquering many of the major drawbacks of the traditional liposomes [7].

Moreover, naso-pulmonary vesicular delivery systems have been of interest in the treatment of respiratory diseases because they are easy to administer in a non-invasive manner, fast absorption, and local delivery. They involve liposomal and niosomal vesicles to enhance drug residence and drug efficacy in tissues of the lungs [8].

3. Nanoparticles in Drug Delivery

It has now been seen that nanoparticles have become a game changer in terms of delivering therapeutic agents because it is able to control pharmacokinetic profiles and also improve bioavailability. Nanoparticles made of polymer and inorganic offer controlled release of molecules, targeted transport of drugs and enhance stability of labile molecules. These systems take advantage of nanoscale sizes to enable the cells to take up these systems, and to accumulate at a specific site in vivo, minimizing systemic side effects and dosage frequency [9].

New developments in the manufacturing of nanoparticles in recent times including solvent evaporation, nanoprecipitation and microemulsion have enhanced the drug loading capacity, and uniformity at the surface. Custom particle size and surface chemistry can now be used to control drug release kinetics and tissue penetration. Biocompatible polymers and biodegradable matrices are also incorporated into the domain of modern research, which allows stimuli-responsive delivery of drugs and opens the way to personalized therapeutics [10].

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Oral delivery of peptides and proteins is one of the greatest challenges because it is subjected to degradation by enzymes and ineffective availability across the intestinal barriers. Novel nanoparticle systems have been invented to offer protection to such biomolecules with the use of mucoadhesive coatings, enzyme inhibitors and absorption enhancers to bypass degradation in the gastrointestinal system. These nanocarriers play a much better role in enhancing availability of biologics that are passed orally [11].

Additionally, nanoparticle preparations that are assisted using effervescence are a new modality that increases the dispersion and drug dissolution when given. The effervescence effect enhances quick dissolution and distribution of nanoparticles, as well as absorption and compliance by patients. This system builds on the advantage of effervescent systems with nanoscale delivery, which is a potentially viable pathway to fast and effective drug delivery [12].

4. Lipid-Based Formulations

Multifunctional drug delivery systems that are lipid based drug delivery systems have been very popular because they are able to enhance the solubility of poorly soluble drugs in water, their stability, and bioavailability. Solid Lipid Nanoparticles (SLNs) are one of them, and they are deemed as being at the forefront of the future of lipid nanocarriers that are a fusion of conventional colloidal carriers and lipid matrices. SLNs offer a system of controlled drug delivery, chemical stability, and elimination of degradation of sensitive molecules. It is the backbone of solid lipids that enable them to be gradually liberated and remain highly biocompatible, thus becoming particularly useful in dermatological and cosmetic formulations and the treatment of the body as a whole [13].

However, despite their strong sides, SLNs have such limitations as expelling of drugs stored in a store and attempting to load certain compounds. To address these shortcomings, Nanostructured Lipid Carriers (NLCs) were developed as an improved generation of lipid based systems. NLCs contain a mixture of solid and liquid lipids, and this causes structural defects of the lipid backbone and enhances the touch of drugs and reduces crystallinity. This is one of the significant design changes that increase improved drug loading and stability of the drug during the long-term use [13].

Recent advances on the preparation of lipid-based nanocarriers have introduced new technologies such as high-pressure homogenization, solvent emulsification evaporation and microfluidization. With these methods it is possible to control the size of particles, surface morphology and encapsulation efficiency. Besides, introduction of liposomal principles into lipid-based nanocarriers has enhanced their applications in other areas of therapeutics, including gene therapy, vaccine delivery, and localized drug delivery [14].

5. Oral Fast-Acting and Effervescent Dosage Forms

The development of fast-acting oral dosage forms is also a breakthrough innovation in the domain of patient-centric provision of drugs, as it has addressed the issue of swallowing inconveniences and improved the dose effect onset. MDTs have become a viable option as an effective way to deliver drugs, since they dissolve rapidly when exposed to saliva and will be absorbed by all of the oral mucosa more rapidly without first-pass metabolism. As the preliminary investigations showed, the cinnarizine mouth-dissolving tablets could be developed with the help of the superdisintegrants and direct compression methods to enhance bioavailability and compliance rate in patients [15,16].

Nonetheless, with this thought continued, the mouth-dissolving films (MDFs) have been made as thin and flexible polymeric structures, which quickly dissolve in the tongue. The release propranol hydrochloride films have exhibited correct dosing, rapid drug release and stability that is a novel method of improving adherence to the drug particularly in children and geriatric patients [17]. Similarly, ondansetron hydrochloride inclusion complexes with 2-cyclodextrin have been used to improve solubility, mask taste and high disintegration and acceptance by patients [18,19].

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Just like the fast-dissolving dosage forms, effusive tablet forms have been of interest in the delivery of fast disintegration by gas-generating reactions that enhance the dissolution and bioavailability. Effervescent tablets of paracetamol are some of the examples of optimized formulation methods that are more patient-friendly and palatable [20].

Besides these, the chewable tablets have also been repositioned as helpful oral systems that are flexible in terms of dosing, and increased compliance. They combine both mechanical integrity, and sensory appeal, and therefore are particularly suitable to nutraceutical and children applications [21]. In addition, site-specific delivery, reduced gastrointestinal toxicity and modulated kinetic drug release of multiparticulate and microencapsulated systems have also been established as new oral delivery approaches [22,23].

Combined, these classes of oral dosage innovations are quick acting and are effusive, which highlights the trend of patient-centric drug delivery, which ensures higher therapeutic efficacy, owing to the convenience, stability, and bioavailability of such classes of doses.

6. Controlled and Sustained Release Approaches

The recent developments in the controlled and sustained release drug delivery system have therefore added a lot towards the improvement of therapeutic efficacy, reduced dosing frequency and low side effects. Among them, there are fast-dissolving and sustained matrix technologies that have become highly important with the opportunity to control drug release and improve patient compliance. The way that fast-dissolving systems have replaced their traditional delineation has also involved the use of polymeric matrices, and new excipients that enable not only immediate and immediate-prolonged release phases in a single formulation [24]. They are particularly applicable in dealing with drugs which have limited therapeutic indices or short half-lives and the plasma concentrations of which must be kept constant, or in which toxicity is probably dose-dependent.

Simultaneously, liposomal vesicular carriers have now emerged as multi-purpose delivery systems when it comes to long-term and targeted delivery. The structure of their bilayered phospholipids enables the encapsulation of both hydrophilic and lipophilic soluble drugs, which, on the other hand, motivates the gradual diffusion of the drug and increases the retention of the drug in the body by the system. They have been demonstrated to have the potential in increasing the localization of the drug to areas of disease, decrease systemic exposure and providing extended therapeutic effect [25]. In addition, liposomal delivery system has been used successfully in various therapeutic categories, including anticancer, antifungal and vaccine preparations, indicating their applicability and clinical utility.

Overall, a combination of Matrix-based sustained release and vesicular nanocarriers is a significant advance in the modern pharmaceutics that is to give a compromise between the rapid action and the constant concentration of the therapeutic concentration. All these inventions are directed to make the most of the pharmacokinetic profile and enhance patient-centered drug delivery outcome.

Table: Future Directions and Clinical Translation of Drug Delivery Systems

Aspect	Description	Significance / Advantages	References
Vesicular Models (Liposomes)	Early vesicular systems provided insights into phospholipid membrane dynamics and drug encapsulation.	Foundation for targeted, site-specific delivery; improved stability and pharmacokinetics.	[3]

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Naso-Pulmonary Drug Delivery	Non-invasive platforms for systemic and localized therapies via respiratory epithelium.	Rapid therapeutic onset; bypasses hepatic metabolism; expands translational potential of vesicular and nanoparticulate systems.	[8]
Polymeric & Inorganic Nanoparticles	Engineered carriers with surface modifications, stimuli-responsive release, and enhanced cellular uptake.	Tailored delivery; active targeting; improved therapeutic index; precision therapy.	[9]
Oral Macromolecule Delivery	Nanoparticle-assisted oral delivery of proteins and peptides.	Overcomes enzymatic degradation and poor intestinal permeability; enables transcytosis across epithelial barriers.	[11]
Clinical Translation & Scalability	Emphasis on manufacturing, regulatory standardization, and long-term safety validation.	Ensures reproducible, safe, and scalable nanocarrier therapies; supports patient-specific, sustained treatments.	–
Future Outlook	Integration of nanotechnology, biotechnology, and personalized medicine.	Enables targeted, sustained, patient-specific therapies with improved efficacy and reduced adverse effects.	–

Conclusions

The landscape of modern drug delivery has transitioned from conventional dosage forms to sophisticated nanocarrier-based and patient-responsive systems. Beginning with targeted and controlled release principles [1,2], the integration of liposomes and vesicular carriers [3–8] has demonstrated exceptional potential for site-specific delivery, reduced toxicity, and enhanced bioavailability. The inclusion of nanoparticles—polymeric, inorganic, and hybrid types [9–12]—has

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expanded the realm of delivery efficiency, supporting both macromolecular therapeutics and effervescent-assisted formulations.

Simultaneously, lipid-based carriers such as SLNs and NLCs [13,14] have improved drug solubility, stability, and sustained-release profiles. The development of oral dosage innovations including mouth-dissolving, effervescent, and chewable tablets [15–23] has further advanced patient compliance and ease of administration, ensuring rapid pharmacodynamic responses. Emerging controlled and sustained-release platforms [24,25] integrate these concepts with vesicular nanocarriers to balance immediate relief and prolonged therapeutic action.

Looking forward, the clinical translation of nanocarrier systems will rely on scalable manufacturing, biosafety validation, and harmonized regulatory frameworks. The convergence of nanotechnology, biotechnology, and pharmaceutical formulation science promises an era of personalized, efficient, and minimally invasive therapeutic delivery. Thus, the innovations discussed herein mark not only technological evolution but also a step toward precision-driven, patient-adapted pharmacotherapy—the true future of modern drug delivery.

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