

Review

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Review

Pharmaceutical Delivery Innovations: Uniting Nanocarriers, Liposomes, Targeted Formulations, and Advancements in Tablet Technologies

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Abstract

Drug delivery systems have come to be precise, effective, and patient-friendly—the very design features of modern treatment. The current review covers a wide range of topics, such as the use of nanocarriers, vesicular systems, solid lipid nanoparticles, and new oral dosage forms in pharmaceutical practice. Liposomes, proniosomes, and naso-pulmonary vesicular carriers not only protect unstable drugs but also enable delivering the drug right to the site and thus increasing its bioavailability. Besides its great potential for both hydrophilic and hydrophobic drugs, the system based on nanoparticle power maximizes the efficacy of drug action by penetrating through biological barriers and altering pharmacokinetic profiles in a favorable way. The solid lipid systems, consisting of SLNs and NLCs, provide controlled release and stability while ensuring biocompatibility. The oral dosage innovations, for example, mouth dissolving tablets, films, effervescent, and chewy ones, not only improve patient compliance but also offer either rapid or sustained drug action. Controlled and sustained release technologies, which include polymeric and vesicular strategies, make it possible to attain therapeutic effect for a longer time, maintain plasma concentrations predictable, and hence reduce dosing frequency. All these technologies together represent a credible changeover in part towards precise therapeutics, wherein formulation science is merged with nanotechnology to resolve clinical issues in contemporary medicine. The review brings out the great importance of the advanced drug delivery systems in the enhancement of the treatment outcomes, reduction of the side effects, and increased patient adherence, also being a future hope in personalized and targeted therapies.

Keywords: drug delivery; nanocarriers; liposomes; solid lipid nanoparticles; innovative oral dosage forms

1. Introduction to Modern Drug Delivery Systems

Pharmaceuticals distribution systems have undergone a complete change due to their continuous development, which has resulted in the delivery of very precise, targeted, and efficient therapeutic outcomes. Modern methods are directed toward producing drug concentrations that are most suitable at the site of action, reducing side effects in the whole body, and thereby increasing patient compliance [1]. The concept behind the drug target is to deliver the therapeutic agents to the diseased tissues only by using the appropriate physiological, biochemical, or molecular mechanism. Not only does this approach enhance the effect of the drug but also lessens the toxicity by limiting the drug action to small regions [1].

The drug delivery system is a major breakthrough in this sector aiming at the longer duration of plasma drug levels besides less frequent dosing [2]. This principle is based on the release of drugs from dosage forms that are of different rates, times, and sites, finally improving the pharmacokinetics and pharmacodynamics of the drugs. The systems being developed just now and for the future depend on biological compatibility, polymeric material, and novel carrier technologies in order to achieve the desired therapeutic outcome [2].

Hence, the modern drug delivery system is built on rational design strategies that combine targeting, controlled release, and biocompatible carriers, thus changing the approach from traditional to advanced precision medicine.

2. Vesicular Drug Delivery Systems

Vesicular drug delivery systems have played a very crucial role in the development of the pharmaceutical agents applications by virtue of their potency, stability and targeted delivery. Liposomes, which were first described by Bangham et al., are two-layered phospholipid vesicles that can hold both water-soluble and water-insoluble drugs thus providing them with the advantage of being protected from enzymatic degradation and having the possibility of controlled release [3]. Their structural flexibility allows to make surface modifications which not only enhance the circulation time but also enable specific tissue targeting making them very versatile for a wide range of therapeutic applications [4].

Lately, most of the scientific attention has been focused on liposome formulation optimization so as to achieve the enhancement of drug loading, stability, and pharmacokinetic profiles. Among the many technological advancements that liposome preparations have undergone are the production of stealth liposomes, which are poorly identified by the reticuloendothelial system, and also the development of functionalized liposomes designed for receptor-mediated targeting [5,6]. The vast application of liposome technology is evident in oncology, infectious diseases, and vaccine delivery, thus the great number of clinical benefits it brings [6].

As soon as liposomes came into the picture, proniosomes were introduced as a very promising drug delivery system. They are powders that can be mixed with water to convert them into niosomes right after the administration process, thus, having the properties of longer shelf life, more convenient storage, and greater absorption [7]. Proniosomes can be made for transdermal, oral, and parenteral delivery thus broadening the application of vesicular carriers.

Additionally, the naso-pulmonary vesicular systems are the non-invasive technique for accurate drug delivery to the lungs and bronchial tree. The application of these systems results in rapid drug absorption, local therapeutic effects, and reduced systemic exposure, thus making them the primary mode of treating respiratory diseases [8].

The vesicular systems such as liposomes, proniosomes, and naso-pulmonary carriers provide the drug delivery modern advantages like versatility, efficiency and, most of all, clinical significance. They offer protection, targeted action, and enhanced bioavailability, while overcoming a number of therapeutic obstacles.

Table 1. Vesicular Drug Delivery Systems.

System	Description	Advantages	References
Liposomes	Phospholipid-based vesicles capable of encapsulating hydrophilic and hydrophobic drugs.	Protects drugs from degradation, enables targeted delivery, improves bioavailability.	[3,5,6]
Proniosomes	Dry, free-flowing powders that form niosomes upon hydration.	Longer shelf life, convenient storage, enhanced absorption; suitable for transdermal, oral, and parenteral delivery.	[7]
Naso-Pulmonary Vesicular Systems	Non-invasive carriers for lung and bronchial drug delivery.	Rapid drug absorption, localized therapeutic effect, reduced systemic exposure; effective for respiratory diseases.	[8]
Overall Significance	Combination of vesicular systems offers modern drug delivery advantages.	Versatility, efficiency, protection, targeted action, enhanced bioavailability, clinical relevance.	[3,7,8]

3. Nanoparticle-Based Drug Delivery

Nanoparticle delivery systems are one of the major advances in the pharmacy industry and they provide a very efficient drug delivery through the stability, controlled release, and specific targeting of the tissues. Polymeric and inorganic nanoparticles are, consequently, the most effective carriers, as they are able to hold both hydrophilic and hydrophobic drugs, thus elevating their bioavailability and clinical efficacy [9]. The nanoparticles are able to cross physiological boundaries and release the drug at the exact anatomical location, this way minimizing the drug side effects and allowing maximum therapeutic effect at the target area [9].

Research over the past years has been primarily focused on producing non-toxic and bio-resorbable nanoparticles that possess the right surface treatments for receptor-mediated targeting and stimuli-responsive release [10]. The integration of smart materials such as PEG, PLGA, and chitosan has greatly widened the application range in areas like cancer therapy, gene delivery, and vaccine development [10].

Besides, one of the major challenges for the oral route of administration still remains the enzymatic degradation of the macromolecules like peptides and proteins, and the poor permeability across the intestinal membranes [11]. The newly developed nanoparticle systems are now being made with the help of absorption promoters, enzyme conflicts, and mucoadhesive coverings that guard the guest while making it easier for the drug molecules to get through the gut wall and enter the bloodstream [11].

Moreover, the application of gas-producing mechanisms in the nanoparticle oral formulations is one of the recent developments in this field that not only helps with the dispersion but also with the dissolution rate and acceptance from the patients [12]. Eventually, the nanoparticle-based delivery systems continue to open up new ways of therapeutics by merging the qualities of precision, stability, and patient-oriented design.

Table 2. Nanoparticle-Based Drug Delivery.

Aspect	Description
Overview	Nanoparticle delivery systems provide efficient drug delivery via enhanced stability, controlled release, and tissue-specific targeting. Polymeric and inorganic nanoparticles can encapsulate both hydrophilic and hydrophobic drugs, improving bioavailability and therapeutic efficacy [9].
Mechanism of Action	Nanoparticles cross physiological barriers and release drugs at precise anatomical sites, minimizing off-target effects and maximizing therapeutic outcomes [9].
Material Design	Focus on non-toxic, bio-resorbable nanoparticles with surface modifications for receptor-mediated targeting and stimuli-responsive drug release [10].
Smart Materials Integration	Use of PEG, PLGA, chitosan, and other functional materials enables applications in cancer therapy, gene delivery, and vaccine development [10].
Challenges in Oral Delivery	Macromolecules like peptides and proteins face enzymatic degradation and poor intestinal permeability. Strategies include absorption promoters, enzyme inhibitors, and mucoadhesive coatings to protect and enhance uptake [11].
Recent Innovations	Gas-producing nanoparticle oral formulations improve drug dispersion, dissolution rates, and patient acceptability [12].
Significance	Nanoparticle-based systems combine precision, stability, and patient-centric design, opening new avenues in therapeutics [12].

4. Solid Lipid Systems

Solid lipid systems which include Solid Lipid Nanoparticles (SLNs) and Nanostructured Lipid Carriers (NLCs) are in fact the main development in the area of nanotechnology-based drug delivery. They managed to unite the pros of conventional liposomes and polymeric nanoparticles while limiting drug leakage and compatibility issues. The SLNs consist of physiological lipids that keep

their solid structure at the temperatures of the environment and the human body, thus providing very good physical stability and controlled release of the drug [13]. This unique characteristic of SLNs makes them suitable for the co-encapsulation of both lipophilic and hydrophilic drugs with the subsequent enhancement of bioavailability, protection of drugs against degradation and the possibility of delivering the drugs in the certain area like topical and transdermal systems [13].

The evolution from SLNs to NLCs actually shows the incorporation of both solid and liquid lipids to make a second-generation system of a crystalline matrix with a less-ordered structure. This change leads to an increase of the drug loading capacity and a reduction of the expulsion during storage [13]. These systems are of great assistance in the case of the poorly water-soluble drugs through achieving sustained release and thus improving therapeutic outcomes.

Moreover, the developments in lipid formulation and preparation techniques, namely high-pressure homogenization, microemulsification, and solvent emulsification, to mention only a few, have been the factors that led to better control over particle size, stability and release kinetics [14]. All of the above-mentioned technological improvements have, in a great way, extended the use of lipid carriers from the field of cosmetics to pharmaceuticals, nutraceuticals, and targeted delivery systems, for example [14].

In summary, the solid lipid systems act as a link between the old emulsions and the new nanocarriers. They present a versatile and stable platform for controlled and site-specific drug delivery.

5. Modern Oral Dosage Forms

Modern oral dosage forms have changed the way drugs are delivered in all aspects; patient compliance, onset of action, and therapeutic efficiency have all been improved significantly. Among them, mouth-dissolving tablets (MDTs) have become very important because of their ability to disintegrate quickly in the mouth without water and thus provide the drug release and absorption through the mucosal surface immediately. The addition of superdisintegrants such as croscopovidone, croscarmellose sodium, and sodium starch glycolate to the formulation increases the disintegration rate and thus the bioavailability especially for the drugs with low solubility like cinnarizine [15,16].

Mouth-dissolving films (MDFs) are the latest invention, and they provide a very flexible and patient-friendly alternative to tablets. They have similar properties in terms of drug delivery despite being different in their form, thus they are rapid in the onset of action, uniform in dosing, and more stable. The right choice of film-forming polymers and plasticizers makes sure that there is mechanical strength as well as the optimal dissolution profiles, which is evident from the case of DOS of propranolol hydrochloride MDFs [17].

Compounding techniques like the inclusion of β -cyclodextrin have made it possible to present the solubility and dissolution rate of poorly water-soluble drugs, such as ondansetron hydrochloride, thus, allowing the absorption through mouth to be enhanced [18]. In the same way, the picking of superdisintegrants and excipients in a manner that is deliberately allows the MDT formulations to be improved in terms of both mechanical integrity and the aspect of being palatable [19].

In addition to dosage forms that dissolve in the mouth, effervescent tablets have come up as a way of making drugs more appealing and also of improving their absorption characteristics. They dissolve quickly due to their effervescence which is caused by acid-base reactions; thus, this leads to rapid disintegration and better absorption in the gastrointestinal tract [20]. Likewise, chewable tablets have been designed as a comfortable dosage form for both children and the elderly, thus combining the advantages of easy administration with proper taste and acceptable mouthfeel [21].

Furthermore, low-density multiparticulate systems and microencapsulation techniques have been studied for the purpose of obtaining controlled and pulsatile release, which would typically mean drug delivery to a specific site and better pharmacokinetic control [22,23]. These newly developed oral dosage forms are the clear indicators of a change of the paradigm from conventional tablets to advanced, patient-centric formulations that integrate convenience, efficacy, and precision in therapeutic delivery.

6. Controlled and Sustained Release Technologies

The technologies of controlled and sustained release have come to be recognized as one of the most influential advancements in the pharmaceutical industry. Their primary objective is to keep plasma drug concentrations at the steady level, improve bioavailability and cut down on the number of dosing times. These systems are of great help in dealing with chronic illnesses where compliance with the treatment by the patient and long drug action are very important. Besides, they provide the required pharmacokinetics through controlled delivery at the rate and location of drug release, while minimizing side effects [24].

Different approaches have been used to get these results such as employing polymers, matrix systems, osmotic pumps and coating technologies. These mechanisms give rise to predictable and extended-release patterns that are in tune with the therapeutic window of the drug. Sustained release matrices made of hydrophilic polymers like hydroxypropyl methylcellulose (HPMC) or ethylcellulose are among the common oral dosage forms utilized for controlling the diffusion and erosion rates of drugs thus giving the prolonged therapeutic effect [24].

Vesicular systems like liposomes, on the other hand, have been recognized as major vehicles for advanced controlled release as well as their gaining a lot of attention. They offer the protection by their bilayered lipid structure which can accommodate both hydrophilic and lipophilic drugs and at the same time, enable drug release at the desired site. When liposomes are prepared to be responsive to certain physiological conditions such as pH, temperature or enzyme activity, they become very functional and suitable for targeted and sustained delivery [25].

In essence, gradual and regulated release technologies represent the shift away from standard dosage forms and towards precision drug delivery systems. The combination of the polymeric and vesicular methods allows these systems to guarantee not only prolonging drug action but also better safety, effectiveness, and patient-friendly results in contemporary pharmaceutical care.

7. Conclusions

The improvements in pharmaceutical drug delivery have been the beginning of a new era of precision, efficiency, and patient-centered therapy. Modern drug delivery systems are based on targeted approaches that not only assure maximum therapeutic efficacy but also reduce systemic side effects to a minimum [1,2]. The vesicular carriers such as liposomes, proniosomes, and the naso-pulmonary delivery systems are the platforms that provide the most versatility for site-specific and sustained release applications, protecting the labile drugs and allowing to achieve the improved bioavailability [3–8]. The nanoparticle-based systems take these capabilities even further by permitting the encapsulation of various drug classes, including proteins and peptides, overcoming physiological barriers and allowing targeted delivery [9–12]. Solid lipid systems, which are comprised of SLNs and NLCs, are characterized by their biocompatibility and controlled release properties; thus, they provide a stable and efficient alternative to traditional carriers [13,14].

Mouth-dissolving tablets, films, chewable formulations, effervescent tablets and pulsatile release systems are the new inventions in oral dosage forms which target patient convenience and compliance alongside rapid or controlled drug release [15–23]. The combination of polymeric matrices and vesicular carriers in controlled and sustained release technologies allows for prolongation of therapeutic action, still predictable pharmacokinetics, and less frequent dosing [24,25]. All these being tactics signify the merging of formulation science, nanotechnology, and patient-centered design, hence marking a shift in the direction of the sophisticated, targeted, and adaptable therapeutic systems from the conventional delivery.

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