Review

Advancements in Drug Delivery Systems: Targeting Strategies, Nanotechnology, and Vesicular Innovations

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Review

Advancements in Drug Delivery Systems: Targeting Strategies, Nanotechnology, and Vesicular Innovations

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Abstract: Innovative drug delivery systems are revolutionizing contemporary pharmacotherapy with better bioavailability, controlled delivery, and better patient compliance. This review covers some advances in nanoparticle-based drug delivery against the background of liposomal and vesicular systems for precision therapeutics. This review further checks the oral formulation, including chewable, effervescent, and film-based delivery, against the advantageous ease of administration and the rapid onset of the drug's action. In addition, strategies of naso-pulmonary and antibiotic drug delivery are further described in terms of respiratory health and infection management in relation to nanocarrier-based formulations. Moreover, herbal therapeutics are incorporated as demonstrated with Tribulus terrestris in urolithiasis treatment, which in turn, actually merges traditional medicine delivery with modern drug delivery platforms. Based on clinical applications, advantages, and disadvantages, comparative analysis of nanocarriers including liposomes, polymeric nanoparticles, niosomes, and dendrimers has been presented. In the future, it will be all about the biodegradable AI-driven stimuli responsive nanocarrier supporting the precision of medicine and personalized care. This review provides insight into recent developments, challenges, and future directions in advanced drug delivery systems for developing more effective and patient-friendly therapeutic solutions.

Keywords: Nanoparticle-Based Drug Delivery**;** Liposomal and Vesicular Systems**;** Naso; Pulmonary Drug Delivery**;** Herbal Therapeutics in Medicine**;** Advanced Nanocarriers

1. Introduction

In the past decades, the drug delivery sector has made leaps and bounds in development. It has understood the innovation of conventional systems from simple to quite sophisticated targeted ones. The ultimate goal of any system of drug delivery should be to transport the therapeutic agent to the location of action by the most appropriate route, while reducing its toxic effects and potentiate its performance [1]. For many decades, the delivery strategies based on conventional drugs suffered from issues including poor bioavailability, systemic toxicity, and non-specificity. It has therefore been in extreme need for newer delivery strategies capable of offering a better profile for therapeutic outcomes profiles [2].

Nanotechnology is revolutionizing drug delivery, and drugs are now possible to be targeted accurately to the appropriate location and released in a controlled manner. The promising carriers include nanoparticles, liposomes, and other vesicular systems, which enhance the stability of drugs, improve bioavailability, and enhance therapeutic effectiveness [3]. Among these, liposomal drug delivery systems are increasingly popular since it can carry hydrophilic and hydrophobic drugs with controlled release and targeted therapy [2,4]. The primary applications of such systems lie in cancer, infectious diseases, and chronic illness treatment where localized delivery of drugs becomes most important [3].

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Naso-pulmonary delivery system is another drug delivery innovation in the treatment of respiratory diseases with non-invasive administration routes. It has effectively administered small molecules and biologics to the lungs, giving it a faster onset of action and improved compliance from patients [4]. Similarly, the chewable and effervescent tablet formulations are gaining importance due to ease in drug administration, improvement in patient compliance, particularly among the pediatric and geriatric populations, etc. [5].

As the researches advance with drug delivery integrated with targeted therapies, nanotechnology, and advanced formulation strategies, these promise to redefine and enable the delivery of drugs with optimal therapeutic benefits and minimum adverse effects. To understand these concepts, this review will explore the new advances according to the targeted drug delivery, nanoparticle-based carriers, liposomal vesicular systems, and emerging oral and pulmonary formulations [1-5].

2. Targeted and Nanoparticle-Based Drug Delivery

The field of modern medicine has emerged as a significant drug delivery approach by targeting the therapy with a concurrent reduction in systemic toxicity. As opposed to traditional drug delivery systems, which basically result in side effects due to systemic distribution, targeted delivery approaches aim at the delivery of drugs to the desired site of action [6]. Such therapies are particularly useful where controlled drug release and cellular specificity are required, especially in cancers, autoimmune disorders, or chronic diseases.

2.1. Nanotechnology in Targeted Drug Delivery

The most critical application in drug delivery system development has been nanotechnology since it ensures that drugs are targeted accurately at the molecular and cellular level. Nanoparticles have proved to be mighty drug carriers; they are tiny in size, large surface area, and capable of functionalizing with targeting ligands [6]. Such engineered nanoparticles may bypass physiological barriers, enhance drug solubility, and prolong systemic circulation to elevate the bioavailability of drugs [7].

Lipid-based carriers, including liposomes, solid lipid nanoparticles, and nanoemulsions, have been explored extensively with regards to their biocompatibility and ability to deliver both hydrophilic and hydrophobic drugs [6,7]. Polymeric nanoparticles of biodegradable materials like polylactic acid (PLA) and polyethylene glycol (PEG) allow for the controlled and prolonged release of drugs in chronic diseases, which are the objectives of most drug delivery technologies [8].

Table 1. Clinical Applications and Future Prospects of Nanoparticle-Based Drug Delivery.

S. No.	Application	Details	Advantages	Examples
1	**Oncology**	Liposomal formulations like doxorubicin and paclitaxel-loaded nanoparticles improve chemotherapy efficacy.	Reduces cardiotoxicity and enhances drug accumulation in tumors [7].	Liposomal Doxorubicin, Paclitaxel [7]
2	**Antibiotic Therapy**	Nanoparticle-based drug delivery enhances penetration into bacterial biofilms, reducing resistance.	Overcomes bacterial resistance by improving drug delivery to infection sites [9].	Nanoparticle-mediated antibiotics [9]
3	**Future Advancements**	Development of stimuli-responsive nanoparticles that release drugs based on pH, temperature, or enzyme activity.	Enables controlled, site-specific drug release, minimizing side effects [6].	pH-responsive nanoparticles [6]
4	**Personalized Medicine**	Integrating nanotechnology with patient-specific drug	Ensures higher therapeutic precision and better patient outcomes [6-9].	Personalized nanomedicine approaches [6-9]

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	formulations for individualized treatment.

3. Liposomal and Vesicular Drug Delivery Systems

Liposomal and vesicular drug delivery systems help improve the stability, bioavailability, and targeted action of drugs. These include encapsulating drugs within lipid bilayers for their controlled release with improved therapeutic efficacy [10].

3.1. Structure and Composition [11]

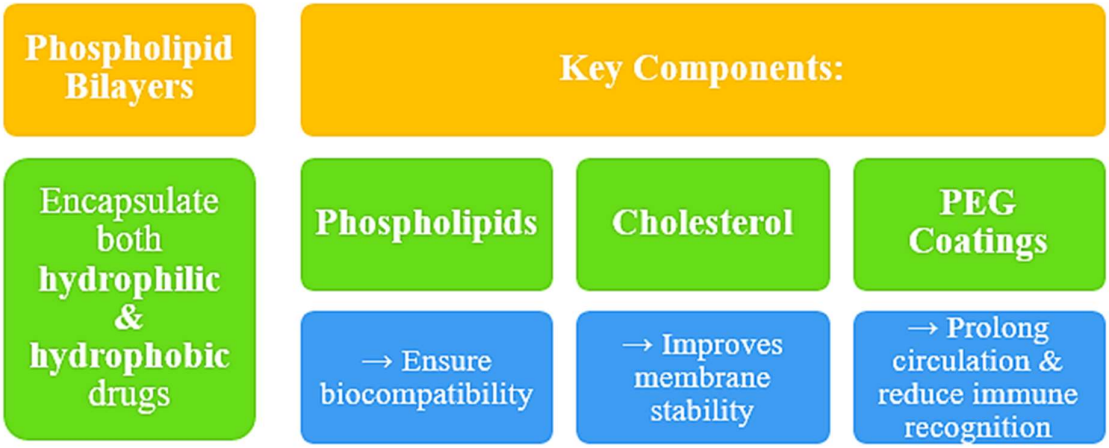

Figure 1. Structure & Composition of Liposomes.

3.2. Advanced Vesicular Systems [12, 13]

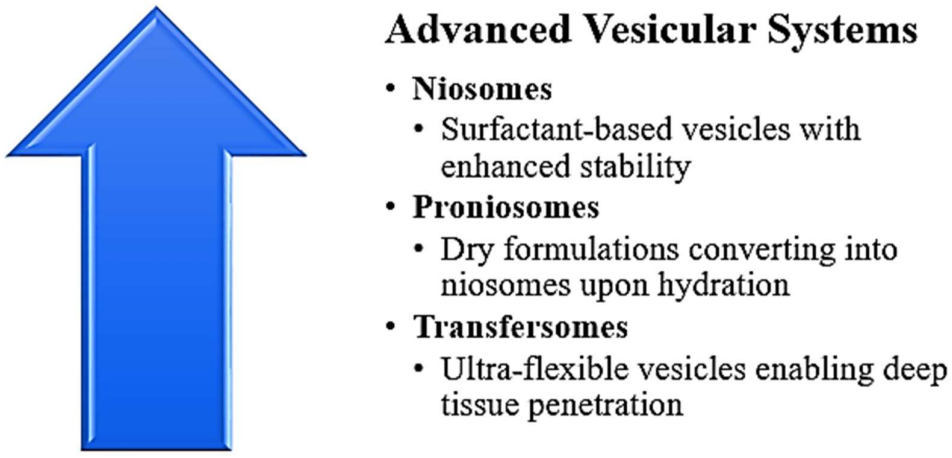

Figure 2. Comparative statements on Advanced Vesicular Systems.

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4. Oral Drug Delivery Systems: Chewable, Effervescent, and Films

4.1. Chewable Tablets [5]

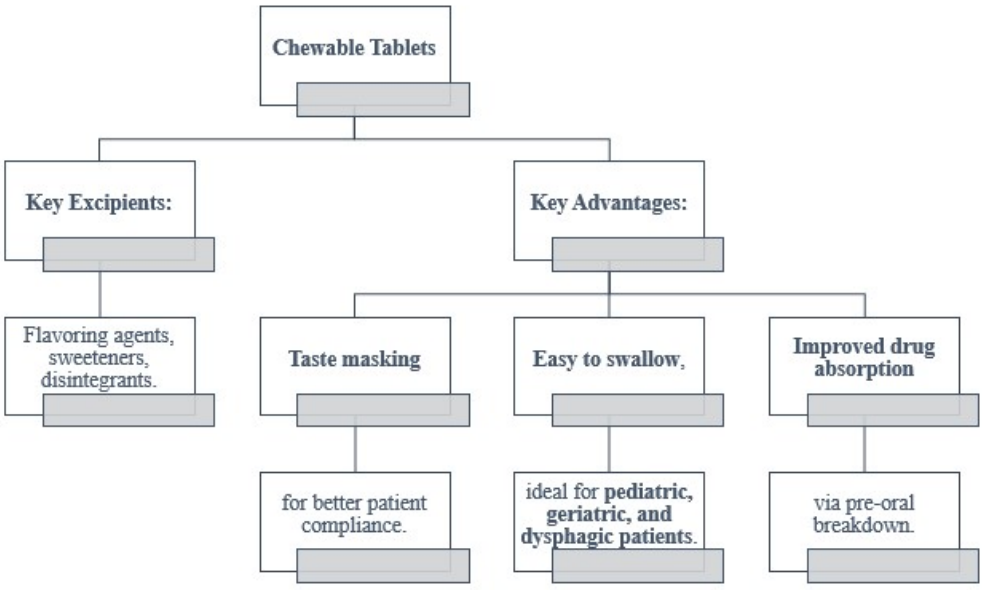

Figure 3. Hierarchical Diagram of Chewable Tablets: Key Excipients and Advantages.

4.2. Effervescent Tablets [14]

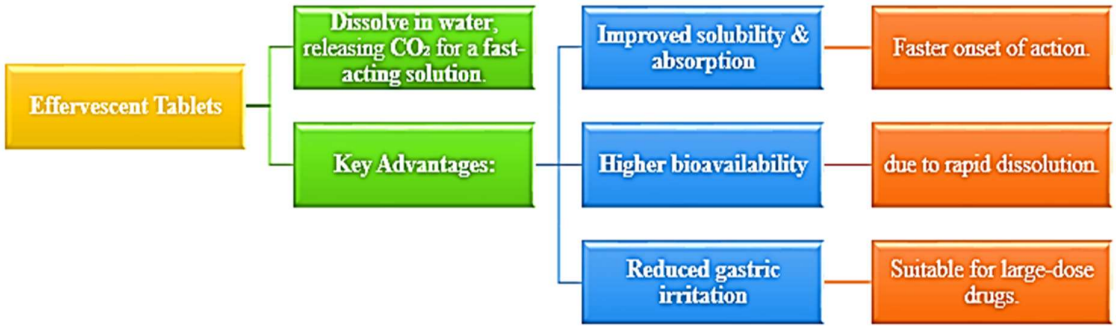

Figure 4. Hierarchical Diagram of Effervescent Tablets: Mechanism and Advantages.

4.3. Mouth-Dissolving Films

Oral films are thin, pliable strips which dissolve rapidly on the tongue in order to rapidly deliver the medication with systemic absorption, without using water. It is ideal for patients who encounter difficulty in intake of solid forms of dosage. They consist of polymers including hydroxypropyl methylcellulose, plasticizers in order to create flexibility and quick dissolution [15].

5. Advancements in Naso-Pulmonary and Antibiotic Drug Delivery

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Table 2. Advancements in Naso-Pulmonary and Antibiotic Drug Delivery.

S. No.	Category	Innovation	Advantages	Applications
1	**Naso-Pulmonary Drug Delivery**	Nanoparticle-Based Inhalers	Enhances drug retention in the lungs and provides sustained release [17].	Asthma, COPD [17]
2	**Naso-Pulmonary Drug Delivery**	Liposome-Encapsulated Pulmonary Drugs	Improves deep lung penetration, reducing systemic side effects [17].	Pulmonary infections, lung cancer [17]
3	**Naso-Pulmonary Drug Delivery**	Nasal Drug Delivery for CNS Disorders	Utilizes the nose-to-brain pathway for targeted therapy [16].	Neurodegenerative diseases, migraines [16]
4	**Antibiotic Drug Delivery**	Liposomal Antibiotics	Enhances stability and enables targeted bacterial eradication [18].	Bacterial infections, MRSA, resistant strains [18]
5	**Antibiotic Drug Delivery**	Inhalable Antibiotics	Improves lung drug delivery for respiratory infections [18].	Tuberculosis, cystic fibrosis [18]
6	**Antibiotic Drug Delivery**	Stimuli-Responsive Antibiotic Systems	Enables site-specific drug release triggered by pH or enzymes [18].	Targeted infection treatment [18]

6. Herbal and Alternative Therapeutics in Drug Delivery

Herbal medicine is gaining much momentum as a complimentary and alternative modality in drug delivery. Traditional, plant-based preparations, when used with modern technology in drug delivery, enhance the bioavailability and targeted delivery at the site with reduced side effects. For example, Tribulus terrestris has been noted for the cure of urolithiasis or kidney stone [19].

7. Comparative Analysis of Nanocarriers

Table 3. Comparative Analysis of Nanocarriers.

Nanocarrier Type	Advantages	Limitations
Liposomes	Biocompatible, suitable for hydrophilic & hydrophobic drugs, prolonged circulation	Stability issues, high production costs [20]
Polymeric Nanoparticles	Controlled drug release, improved drug solubility	Possible toxicity, complex synthesis [21]
Niosomes	Stable, cost-effective alternative to liposomes	Lower entrapment efficiency compared to liposomes [22, 23]
Dendrimers	High drug-loading capacity, precise targeting	Potential cytotoxicity, high production costs [21]

Conclusion

This review covered targeted and nanoparticle-based drug delivery in greater depth, mentioning liposomal and vesicular systems for enhanced therapeutic efficacy. Advanced oral formulations in the form of chewable, effervescent, and film-based delivery have been considered from the patient compliance and rapid drug action point of view. The naso-pulmonary and antibiotic drug delivery were stressed in terms of focusing on respiratory treatment and infection therapy. The herbal therapeutics, specially Tribulus terrestris, the paper discussed an alternative medicine-based drug delivery. It also presented a comparative analysis of pros and cons about nanocarriers such as liposomes, polymeric nanoparticles, and dendrimers. Emerging trends are mainly biodegradable, AI-driven, and hybrid nanocarrier systems toward precision medicine and next-generation formulations.

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