Review

Advancements in Drug Delivery Systems from Chewable Tablets to Nanomedicine

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Advancements in Drug Delivery Systems from Chewable Tablets to Nanomedicine

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Abstract: Development of drug delivery systems has revolutionized drug formulation in pharmaceuticals to provide enhanced drug efficacy and compliance. The subsequent article describes the revolution from classic chewable tablets to emerging nanomedicine-based drugs. Chewable tablets are an inexpensive oral drug delivery in pediatric and geriatric patients with notwithstanding stability and formulation constraints. Targeted drug delivery revolutionized therapeutic specificity by reducing systemic side effects and enhancing drug bioavailability. Liposomal and particulate-based drug delivery systems have advanced therapeutic modality to a greater extent to realize FDA-approved nanomedicines with enhanced therapeutic performance. Naso-pulmonary drug delivery has also emerged to the forefront for respiratory care management using inhaled nanoparticles for direct and effective drug delivery. Regardless of all these technologies, regulatory approval, scale-up formulation of the product, and long-term safety issues remain at the center of attention. Theranostic approaches and image-guided drug delivery are revolutionizing the fate of drug delivery through real-time diagnosis and therapy. These new technologies hold the promise of precision medicine with enhanced targeting, monitoring, and patient response. With ongoing research, overcoming current challenges will unlock the potential of the next generations of drug delivery systems.

Keywords: drug delivery systems; nanomedicine; chewable tablets; liposomal carriers; targeted therapy

1. Introduction to Drug Delivery Systems

Drug delivery systems have evolved, from the old-fashioned oral tablet to the new nanocarrier-based drugs. The focus has been on improving drug stability, drug delivery targeting, and minimizing side effects. Nanoparticles and liposomes are some of the developments that have transformed drug delivery by enhancing bioavailability as well as minimizing systemic toxicity [1].

1.1. Evolution from Conventional Tablets to Modern Drug Delivery Techniques

Pharmaceutical products in the past were based on single dosage forms such as immediate-release tablets and capsules. Abnormally absorbent and insoluble forms, though, were difficult for these to counteract, and thus there was space for innovative techniques such as drug carriers to targeted tissues and controlled release systems [1]. Nanoparticles dominate currently since they can diffuse through biological barriers and deliver medicines to the cellular level [2]. Liposomal carriers, however, offer a biocompatible drug encapsulation with increased stability and longer half-life circulation in the body [3].

1.2. Importance of Patient Compliance and Therapeutic Effectiveness

Patient compliance is an important issue in pharmacotherapy since erratic consumption of medicines may result in less-than-ideal treatment effects. Researchers have been attempting to reverse this trend by designing patient-compliant dosage forms such as chewable tablets and inhaled drugs, which are simple to consume and convenient [4]. Controlled release systems also ensure the

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delivery of medications with a consistent concentration in the bloodstream, decreasing the frequency of dosing and enhancing therapeutic effect [5].

2. Chewable Tablets as an Effective Oral Drug Delivery System

Chewable tablets are increasingly demanded as a patient-friendly dosage form with convenience and ease, particularly in pediatric and geriatric patients. In contrast to traditional solid tablets, chewable drug products dissolve rapidly in the mouth such that swallowing huge pills becomes less of a challenge and offers an enjoyable drug dosage form. Development of chewable tablets has emphasized the optimization of taste, texture, and dissolution profiles for enhanced patient acceptability [6].

2.1. Formulation, Benefits, and Challenges of Chewable Tablets

Chewable tablet formulation involves the use of high concentrations of excipients like flavoring agents, sweeteners, and disintegrants to impart a good taste and mouthfeel. The tablets need to have a balance between mechanical strength and quick disintegration, which is one of the key formulation issues [6]. One of the advantages of chewable tablets is that they are able to avoid first-pass metabolism in certain instances, which results in increased bioavailability. Nevertheless, stability is maintained, grit prevention, and active ingredient stability are still a huge barrier to their production [7].

Table 1. Formulation, Benefits, and Challenges of Chewable Tablets.

Aspect	Description	Key Benefits/Challenges	Reference
Formulation	Uses flavouring agents, sweeteners, and disintegrants	Ensures palatable taste and mouthfeel	[6]
Benefits	Bypasses first-pass metabolism in some cases	Improved bioavailability	[6]
Challenges	Stability, grittiness, and active ingredient degradation	Requires optimization for patient compliance	[7]

2.2. Pharmacokinetics and Therapeutic Applications

Pharmacokinetics of chewable tablets is regulated by drug solubility, absorption location, and formulation properties. By partial oral mucosa permeation before they can access the gastrointestinal tract, they can exhibit more rapid action than regular tablets [8]. They have extensively been utilized in analgesic, vitamin, and antacid delivery with easy and efficient delivery for numerous therapeutic applications [9].

Table 2. Pharmacokinetics and Therapeutic Applications of Chewable Tablets.

Category	Description	Key Benefits/Challenges	Reference
Pharmacokinetics	Influenced by solubility, absorption site, and formulation	Faster onset due to partial oral mucosal absorption	[8]
Therapeutic Applications	Used in analgesics, vitamins, and antacids	Convenient, patient-friendly administration	[9]

3. Targeted Drug Delivery Approaches

Targeted drug delivery is a state in which optimal therapeutic effect is achieved with least cost of systemic side effects by directing drugs against the diseased tissue. Targeted formulations have especially found singular usefulness in cancer treatment, where they are capable of evading normal cell toxicity while providing maximal drug concentration at tumor sites [10]. A range of strategies,

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from ligand-based targeting to pH-sensitive carriers, has been developed to achieve optimal drug localization and therapeutic effect [11].

3.1. Rationale and Strategies for Targeting Drug Delivery

This is due to the fact that the traditional therapies are constrained by the non-specific delivery most commonly involved in side effects. With cell-disease specific molecular markers, drugs can be delivered selectively, improving efficacy and safety [10]. Passive targeting approaches, such as the enhanced permeability and retention (EPR) effect, allow nanoparticles to become entrapped in tumors, while active targeting approaches utilize ligands specific for target cell-related receptors [11].

3.2. Role of Nanotechnology in Improving Drug Targeting

Nanotechnology has transformed drug delivery by allowing controlled particle size, surface characteristics, and mechanism of drug release. Nanoparticles can be engineered to respond to stimuli like pH or enzymes to allow drug delivery only at the target location [12]. Moreover, nanoparticles that can execute real-time imaging and therapy together, i.e., theranostic systems, offer real-time feedback about drug delivery and therapeutic response [13].

Table 3. Targeted Drug Delivery Approaches and Strategies.

Category	Description	Key Benefits/Challenges	Reference
Targeted Drug Delivery	Directs drugs to diseased tissues to minimize side effects	Enhances therapeutic efficacy, reduces toxicity	[10]
Passive Targeting	Utilizes the EPR effect for nanoparticle accumulation in tumors	Improves drug concentration at tumor sites	[11]
Active Targeting	Uses ligands to bind to specific cell receptors	Enhances drug localization and uptake	[11]
Nanotechnology in Drug Targeting	Enables precise control over drug release and particle behavior	Ensures site-specific drug action	[12]
Theranostic Systems	Combines therapy and imaging for real-time treatment monitoring	Allows personalized and adaptive treatments	[13]

4. Liposomal and Nanoparticle-Based Delivery Systems

Liposomal and nanoscale drug delivery systems have revolutionized the field of health with improved solubility, stability, and affinity towards the target of the drug. These systems have ubiquitous applications in oncology, infectious disease, and gene therapy because these systems are able to encapsulate and deliver the drug [14].

4.1. Liposomes as Vesicular Carriers for Drug Transport

Liposomes are phospholipid vesicles that carry hydrophobic as well as hydrophilic drugs and also act as drug delivery platform for a wide array of drugs. Their biocompatibility along with the avoidance of immunoclearance by PEGylation means that they make excellent drug carriers for long-circulating drugs [14]. Their enhanced permeability and retention effect also enhance their concentration in tumor tissue and make them an essential platform utilized in chemotherapy as well as in targeted therapy treatments [15].

4.2. FDA-Approved Nanomedicines and Their Clinical Significance

A number of nanomedicine products have also been FDA-approved and have proven clinical significance. Liposomal doxorubicin (Doxil®) was the initial FDA-approved nanodrug, which demonstrated lower cardiotoxicity than free doxorubicin [16]. A few other nanoparticle-based

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therapeutics like polymeric micelles and lipid nanoparticles have also proven successful for cancer therapy, gene therapy, and vaccine delivery [17].

5. Innovations in Naso-Pulmonary Drug Delivery

Naso-pulmonary delivery of medication has been achieved as a forthcoming gadget to combat pulmonary disorders and system diseases. Naso-pulmonary medication delivery is delivering the drug right into lungs and exhibiting instant response along with having lesser system side effects [18]. Improved potency of pulmonary systems for drug delivery has been facilitated as a consequence of novel types of formulations, which include dry powder inhaler systems and aerosol-based nanoparticulates.

5.1. Advances in Respiratory Health Management

Recent developments in pulmonary drug delivery target higher drug retention and absorption in the lungs. Lipid formulations and inhalable nanoparticles are newer emerging devices for long-term respiratory conditions like cystic fibrosis, COPD, and asthma [18]. They have increased drug deposition inside the alveolar space with increased therapeutic benefit and less wastage.

5.2. Role of Nanoparticles in Pulmonary Therapeutics

Nanoparticles are one of the most significant components in pulmonary drug delivery since they can induce controlled and targeted drug release. Nanoparticles engineered by design also possess the ability to cross over physiological barriers, improving maximum bioavailability of the drug with minimum side effects [19]. Surface modification like PEGylation also stabilizes particles and prolongs circulation time and therefore could be strong contenders for inhalation drug delivery systems.

6. Future Perspectives and Challenges in Drug Delivery

The future of pharmaceutical drug delivery is changing with new technologies aimed at treatment and diagnostics. Targeted medicine, gene therapy, and nanotechnology are new frontier technologies that are propelling personal drug delivery technologies [20]. But still the inhibitors of innovations are regulatory complexities, manufacturing processes, and safety assurances.

6.1. Theranostics and Image-Guided Drug Administration

Theranostic platforms also integrate diagnosis with treatment so that drug delivery and therapeutic response are tracked in real time. Theranostic platforms employ nanoparticles with imaging probes to enable monitoring of drug localization, increasing the precision of treatment [20]. Image-guided drug delivery, particularly in cancer, provides better tumor targeting, reducing off-target toxicity and improving the patient's outcome.

Table 4. Future Perspectives and Challenges in Drug Delivery.

Aspect	Description	Key Challenges
Targeted Medicine	Personalized drug delivery based on genetic and molecular markers	Regulatory hurdles, cost of development
Gene Therapy	Uses genetic modifications to treat diseases	Ethical concerns, precise targeting issues
Nanotechnology in Medicine	Enhances drug delivery and bioavailability	Manufacturing complexities, stability concerns
Theranostics	Combines therapy and diagnostics for real-time tracking	High development costs, integration with imaging
Image-Guided Drug Delivery	Utilizes imaging techniques to improve targeting	Equipment availability, need for specialized expertise

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7. Conclusions

Pharmaceutical evolution, from chewable tablets to novel nanomedicine, has changed therapeutic efficacy and patient compliance enormously. Chewable tablets are compliant patient therapy and easy intervention, particularly in pediatrics and the elderly, with improved drug administration and absorption. Formulation stability and taste are research areas. Combination of various targeted drug delivery approaches has also optimized treatment by reducing systemic side effects and maximizing drug bioavailability.

Liposomal and nanoparticle-based systems are now promising carriers, with controlled and site-specific delivery of drugs, as observed in FDA-approved nanomedicines. The technologies have opened new paths to innovation in naso-pulmonary drug delivery, optimizing respiratory management of health by inhalation of nanoparticles and lipid-based pharmaceuticals. Regulatory sophistication, safety, and issues regarding large-scale production are yet to be addressed for broader clinical acceptance.

Theranostics and targeted drug delivery with the help of imaging technology can possibly transform precision medicine in the next few years by observing real-time and customized treatment. As the trend is to advance drug delivery technology in a progressively simpler manner, future pharmacy will be able to see further developments in efficiency, safety, and targeting therapeutically.

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