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MODERN APPROACHES IN DRUG DELIVERY COVERING VESICULAR CARRIERS NANOPARTICLES SOLID LIPID SYSTEMS AND INNOVATIVE ORAL DOSAGE STRATEGIES

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ABSTRACT

Innovations in drug delivery systems have revolutionized therapeutic treatments by enhancing bioavailability, targeting efficacy, and patient compliance. New approaches incorporate vesicular carriers, nanoparticles, solid lipid systems, and innovative oral dosage forms to overcome the deficiencies of traditional formulations. Vesicular systems such as liposomes, proniosomes, and niosomes provide controlled and targeted drug delivery, whereas naso-pulmonary approaches provide non-invasive delivery with rapid systemic absorption. Polymeric and inorganic nanoparticles impart increased solubility, stability, and targeted treatment potential, while oral delivery of proteins and peptides is maximized using nanoparticulate carriers to suppress enzymatic

hydrolysis and limited permeability. Solid lipid particles and nanostructured lipid carriers provide controlled release, stability, and biocompatibility for both hydrophilic and lipophilic drugs. Advanced oral dosage forms like mouth dissolving tablets, effervescent products, chewable tablets, and pulsatile/multiparticulate systems enhance patient compliance, quick onset, and therapeutic efficacy. Sustained and controlled release technologies like microencapsulation and liposomal systems further advance the accuracy and predictability of drug action. All these notwithstanding, translational issues, clinical scalability, and regulatory matters are still vital in large-scale implementation. Future directions focus on multifunctional carriers that combine targeting, controlled release, and patient-focused designs to address changing therapeutic needs. This review summarizes recent advances, strategies, and future directions in contemporary drug delivery, presenting a broad overview for researchers and clinicians seeking to maximize pharmaceutical therapies.

KEYWORDS: Drug delivery systems, Liposomes and vesicular carriers, Nanoparticles, Solid lipid systems, Innovative oral dosage forms.

1. Introduction to modern drug delivery systems

The principle behind drug targeting is to maximize therapeutic effect while reducing systemic toxicity. Targeting strategies assist in the delivery of the active pharmaceutical ingredient to the desired location in a controlled fashion, thus enhancing the outcome of the treatment. Several strategies including passive, active, and physical targeting have been developed to bypass the limitations of traditional drug delivery.[1]

Controlled drug delivery has become a vital innovation to produce prolonged and site-specific release of the drugs. Such systems preserve desired drug levels in the systemic circulation and prevent the elimination of drug plasma levels, which enhances patient compliance and therapeutic efficacy to a great extent.[2]

2. Vesicular drug delivery systems

2.1 Liposomes: history, classification, preparation, applications

Liposome discovery traces its roots to the work of pioneers Bangham and colleagues, who initially proved the diffusion of ions through phospholipid bilayers, thus setting the vesicular carrier foundation in place.[3]

Later developments resulted in the division of liposomes into traditional, stealth, cationic, and immunoliposomes. Preparation methods like thin-film hydration, reverse-phase evaporation, and extrusion have been made consistent to create vesicles with differing physicochemical characteristics appropriate for drug entrapment.[4]

Liposomes have been highly promising drug carriers because they can enhance the solubility, stability, and bioavailability of drugs. They also enable the targeted and sustained release of the drug, thereby increasing their applications in cancer treatment, gene therapy, and vaccination.[5]

The transition of liposomal drug delivery into clinical application has been successful with various formulations finding their way to the market. Clinical evidence highlights their function in minimizing side effects as well as maximizing therapeutic effects, making liposomes one of the most trustworthy vesicular carriers.[6]

2.2 Proniosomes and niosomes: principles and advantages

Proniosomes, as dehydrated formulations to give niosomes upon hydration, are a convenient and stable replacement for traditional vesicular carriers. Their composition is in the form of nonionic surfactants blended with cholesterol, which is more stable, convenient for transport, and has higher entrapment efficacy. They have been identified as a potential system owing to their biocompatibility and capacity to avoid stability problems connected with liposomes.[7]

2.3 Naso-pulmonary vesicular approaches

Naso-pulmonary drug delivery systems have also been highlighted as non-invasive methods for respiratory health management. Liposomal and vesicular carriers that are administered through nasal or pulmonary routes give direct access to systemic circulation, bypass first-pass metabolism, and ensure quick onset of action. Recent findings highlight their importance in the treatment of respiratory disorders and the delivery of vaccines via localized and systemic routes.[8]

3. Nanoparticle-based drug delivery

3.1 Polymeric and inorganic nanoparticles

Nanoparticles are now multipurpose delivery systems since they can be engineered to size, surface character, and encapsulate almost all therapeutic molecules. Both inorganic and

polymeric nanoparticles provide greater solubility, stability, and targeted delivery, making the drug more bioavailable and decreasing systemic toxicity.[9]

Recent advances are aimed at the use of biodegradable polymers, lipid nanoparticles, and hybrid particles that take advantage of the strengths of two or more ingredients. Such nanoscale systems are making advances in cancer therapy, gene delivery, and vaccine formulation, suggesting their status as a pillar of nanomedicine.[10]

3.2 Oral peptide and protein delivery challenges

The delivery of proteins and peptides via mucosa is still a formidable challenge owing to the fact that they are subject to enzymatic degradation, possess low permeation through the epithelial layer within the intestines, and are also unstable in the gut environment. Methods like the application of protective nanoparticles, mucoadhesive delivery systems, and absorption enhancers are being looked for to reverse these hurdles. The formation of these kinds of systems can transform the treatment of metabolic and immune disorders.[11]

3.3 Targeted nanoparticles for improved efficacy

Targeted nanoparticles are tailored to deliver therapeutic compounds only to the diseased cells or tissues, thus preventing off-targeting effects. Surface modification with peptides, antibodies, or ligands allows nanoparticles to identify and bind the target receptors, increasing their therapeutic index enormously. Targeted therapy maximizes therapeutic efficacy while minimizing side effects, thus making them extremely effective for modern drug delivery systems.[12]

4. Solid lipid systems

4.1 Solid Lipid Nanoparticles (SLNs)

Solid Lipid Nanoparticles (SLNs) are lipid-based submicron biocompatible carriers that are solid at room and physiological temperatures. SLNs provide controlled release of the drug, increased stability of labile molecules, and increased penetration into the skin and are thus applied for cosmetic, dermatological, and pharmaceutical purposes.[13] SLNs also reduce the risk of systemic toxicity and allow the loading of hydrophilic and lipophilic drugs and have emerged as a promising platform for a range of different therapeutic applications.[13]

4.2 Nanostructured Lipid Carriers (NLCs)

Nanostructured Lipid Carriers (NLCs) are next-generation lipid nanoparticles designed to correct the limitations of SLNs, particularly low loading capacity and polymorphic transition. NLCs, based on a blend of solid and liquid lipids, have improved drug entrapment efficiency and higher control over release. Current studies highlight that NLCs can be enhanced through cutting-edge preparation techniques to improve stability, particle size distribution, and therapeutic efficacy.[14]

5. Innovative oral dosage forms

5.1 Mouth dissolving tablets

Mouth dissolving tablets (MDTs) are designed to disintegrate rapidly in the mouth without water intake, which increases patient compliance among pediatric and geriatric patient populations. Formulations of cinnarizine have indicated the potential for rapid disintegration and improved bioavailability with the use of superdisintegrants.[15,16]

Similarly, propranolol hydrochloride mouth-dissolving films have shown rapid rates of dissolution and convenient delivery, showing a good option for hypertensive patients that require quicker action.[17] Oral films and ondansetron tablets have been formulated to enhance patient convenience and reduce first-pass metabolism, showing effective antiemetic activity.[18] Superdisintegrants-based mouth-dissolving tablets of amlodipine have shown rapid disintegration and uniform drug release, showing better therapeutic compliance.[19]

5.2 Effervescent tablets

Effervescent tablets, for example, paracetamol, possess the advantage of rapid dissolution in water with increased onset of action and improved patient acceptability. The formulation methods involve effervescent agent/binder ratio to achieve desired disintegration time and palatability.[20] Chewable effervescent products also support patient convenience and compliance with flexible administration in the case of water unavailability.[21]

5.3 Chewable tablets and patient compliance

Chewable tablets are now preferred for dysphagia patients for conventional tablets. They provide good dosing, taste, and improved compliance with therapy, which is especially important in children and the elderly.[21]

5.4 Pulsatile and multiparticulate release systems

Pulsatile and multiparticulate delivery systems provide controlled release of drugs in a timely manner, which can be synchronized to circadian rhythms or therapeutic windows. Microencapsulation procedures and low-density multiparticulate systems provide controlled drug release, reduced side effects, and enhanced pharmacokinetic profiles.[22,23]

6. Controlled and sustained release technologies

6.1 Microencapsulation techniques

Microencapsulation is one of the prominent methods in obtaining controlled and sustained drug release. Microencapsulation facilitates rate and site control of drug release by encapsulating active drug compounds into polymeric or lipidic matrices, thus enhancing therapeutic efficacy and decreasing dosing frequency.[24]

6.2 Controlled drug delivery concepts and advances

Advancements in drug delivery systems such as vesicular and nanoparticulate carriers have enabled targeted and sustained drug delivery. Liposomal vesicular systems, in fact, offer biocompatible, biodegradable, and tunable platforms to administer hydrophilic and hydrophobic drugs with decreased systemic toxicity.[25]

7. Future perspectives and clinical implications

Despite dramatic technological progress in drug delivery, translational challenges continue to keep up with reproducible clinical performance, large-scale manufacture, and regulatory acceptability. Timeless foundation work on lipid bilayers and vesicular carriers continues widely to inspire today's innovation, emphasizing biocompatible and scale-up platforms.[3]

Naso-pulmonary and other non-invasive delivery routes provide new promise for rapid systemic uptake and site-directed therapy, especially for respiratory infections and vaccine delivery.[8] Sustained advancement of nanoparticle-based carriers can provide customized medicine and targeted therapy with increased bioavailability and diminished off-target effect.[9] In addition, oral delivery approaches for proteins and peptides are defining therapeutic pathways for chronic as well as systemic diseases and require multicomponent approaches that integrate stability, absorption, and target-specific delivery.[11]

The future research needs to concentrate on the development of these systems for clinical use, safety profiling, and investigating multi-functional carriers that offer targeting, controlled release, and patient-friendly delivery.

CONCLUSION

Modern drug delivery is an interdisciplinary science involving vesicular carriers, nanoparticles, solid lipid systems, and new oral dosage forms. Vesicular systems like liposomes, proniosomes, and naso-pulmonary carriers offer controlled, targeted, and biocompatible delivery. Nanoparticles improve solubility, stability, and targeted therapy and delivery routes of oral proteins and peptides overcome significant biological barriers. Solid lipid nanoparticles and nanostructured lipid carriers provide stability, controlled release, and enhanced bioavailability. New dosage forms of oral drug delivery such as mouth dissolving, effervescent, chewable, and pulsatile systems improve patient compliance and therapeutic effects. Controlled and prolonged release technologies like liposomal vesicular systems and microencapsulation maximise further the performance of drugs, reducing dosing frequency and systemic toxicity. All these combined integrated technologies constitute the edge of pharmaceutical science, providing clinically meaningful solutions maximising efficacy, safety, and patient-focused attributes. The science moves towards multifunctional, scalable, and personalised platforms for delivery, going beyond today's limitations and creating new avenues for therapeutic innovation.

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