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PROCEEDINGS ABSTRACT

Ocular drug delivery: a review of emerging approaches and advances

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Ocular drug delivery still presents a major pharmaceutical challenge. Structures such as the corneal epithelium, the conjunctiva, the tear film, and the nasolacrimal drainage system, all restrict drug diffusion and shorten drug retention times, while quick blinking and high-speed tear turnover can dilute the applied drugs and remove them, resulting in poor drug absorption. Furthermore, the static and dynamic barriers such as the blood–aqueous and the blood–retinal barriers restrict drug penetration into deeper ocular tissues, particularly the posterior segment. These factors collectively contribute to a low therapeutic efficiency and necessitate frequent dosing. The aim of this review is to comprehensively assess conventional ophthalmic formulations alongside advanced, emerging drug delivery systems, so as to highlight recent progress in overcoming the anatomical barriers of the eye, enhancing therapeutic efficacy, and improving patient compliance. Conventional ophthalmic dosage forms, including eye drops, suspensions, and ointments, are widely used in clinical practice due to their ease of administration and patient acceptance. However, these formulations are associated with significant disadvantages. For example, the bioavailability of topically applied agents is typically very poor, often less than or equal to 5%, due to rapid precorneal loss and the lack of corneal permeability. Suspensions, which may enhance drug retention time, often induce irritation by making the cornea shift or by giving rise to inconsistent dosing patterns. Ointments, whilst providing a prolonged contact with the ocular surface, impair vision and hinder patient acceptability. These conventional systems lack the ability to facilitate the drug penetration into the posterior segment of the eye, thereby precluding their use in diseases such as the age-related macular degeneration and diabetic retinopathy. Consequently, invasive treatments in the form of intravitreal injections are often necessary, introducing the likelihood of causing an infection, retinal damage, and discomfort to the patient. In order to overcome these limitations, novel advanced drug delivery systems have been developed with the aim of enhancing ocular bioavailability, prolonging drug residence time, and enabling targeted delivery. Nanotechnology-based carriers (namely, nanoparticles, liposomes, and nanoemulsions) offer improved permeability and controlled drug release, thereby allowing the carried drugs to penetrate ocular barriers more effectively. The surface modification of nanoparticles can further enhance mucoadhesion and cellular uptake, consequently improving therapeutic outcomes. Another promising approach involves the use of microneedle-based systems, enabling a minimally invasive delivery of drugs to both the anterior and the posterior segments while reducing the risks associated with conventional injections. *In situ* gels, implants, and biodegradable depots can also provide sustained drug release, thereby minimizing dosing frequency and improving patient compliance. Furthermore, emerging drug delivery strategies are now

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exploring systemic drug delivery to the eye by modulating physiological barriers such as the blood–retinal barrier and enabling drugs administered *via* systemic routes to achieve therapeutic concentrations at the ocular tissues. Such an advanced ocular drug delivery system can be realized through the use of ligand-receptor interactions and cell-penetrating peptides that enhance drug uptake by specific ocular tissues. Novel drug delivery strategies employing methods involving the use of antibody–drug conjugates, aptamer-based targeting, and receptor-mediated endocytosis can help drugs accumulate and target disease-affected cells while sparing healthy ones; this selectivity is particularly valuable when treating retinal diseases and intraocular tumours. Despite promising progress, challenges related to safety, scalability, and regulatory approval remain, necessitating continued interdisciplinary research in order to translate these innovations into clinical practice. In this context, artificial intelligence could prove very helpful in designing treatments and predicting responses.

Keywords

advanced drug delivery systems; bioavailability; eye permeability; nanoparticles; ocular drug delivery

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Conflicts of interest statement

None to declare.

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