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Nanoparticle-delivered antivirals: Enhancing efficacy and bioavailability.

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Introduction

The global burden of viral diseases—from influenza and HIV to emerging threats like SARS-CoV-2—has underscored the urgent need for effective antiviral therapies. While conventional antivirals have made significant strides, they often suffer from limitations such as poor bioavailability, systemic toxicity, rapid degradation, and the emergence of drug resistance. In response, nanotechnology has emerged as a transformative approach to drug delivery, offering nanoparticle-based systems that enhance the pharmacokinetics, targeting, and therapeutic efficacy of antiviral agents [1].

Nanoparticles (NPs) are submicron-sized carriers that can encapsulate, adsorb, or conjugate therapeutic agents. Their small size, high surface area, and tunable physicochemical properties make them ideal for overcoming biological barriers and delivering drugs to specific tissues or cells. In antiviral therapy, NPs can protect drugs from enzymatic degradation, improve solubility, and facilitate controlled release, thereby enhancing bioavailability and reducing dosing frequency [2].

Several classes of nanoparticles have been explored for antiviral applications: Made from biodegradable polymers like PLGA or chitosan, these NPs offer sustained release and biocompatibility. Liposomes and solid lipid nanoparticles (SLNs) mimic biological membranes and are widely used for encapsulating hydrophobic drugs. Silver, gold, and zinc oxide NPs possess intrinsic antiviral properties and can be functionalized for targeted delivery. Composed entirely of drug particles stabilized by surfactants, nanocrystals improve solubility and retention of poorly water-soluble antivirals. Each type offers unique advantages depending on the target virus, drug properties, and desired release profile [3].

Bioavailability—the proportion of a drug that reaches systemic circulation—is a critical determinant of therapeutic success. Many antiviral drugs suffer from low oral bioavailability due to poor solubility, first-pass metabolism, or degradation in the gastrointestinal tract. One of the most powerful features of nanoparticle systems is their ability to deliver drugs selectively to infected cells or tissues. This is achieved through: Surface modification with antibodies, peptides, or sugars that bind to viral receptors or infected cells. NPs that release drugs in response to pH, temperature, or enzymatic activity in infected microenvironments. Exploiting enhanced permeability and retention (EPR) effects in inflamed or infected tissues [4].

Controlled release mechanisms also ensure sustained drug levels, reducing the need for frequent dosing and improving patient compliance. Nanoparticle-delivered antivirals have shown promise across a range of viral diseases: Long-acting NP formulations of antiretrovirals like tenofovir and efavirenz improve adherence and reduce viral load. Lipid-based NPs carrying oseltamivir or siRNA have demonstrated enhanced efficacy in preclinical models. Polymeric NPs delivering nucleoside analogs or gene-editing tools offer targeted liver delivery. These multifunctional NPs offer dual benefits—drug delivery and antiviral action—potentially reducing the need for high drug doses. Ensuring sufficient drug encapsulation without compromising NP stability is a technical challenge. Addressing these issues is essential for translating laboratory success into clinical impact. The future of nanoparticle-delivered antivirals is bright, with several exciting

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developments on the horizon: Delivering gene-editing tools to excise viral genomes from host cells [5].

Conclusion

Nanoparticle-delivered antivirals represent a paradigm shift in infectious disease management. By enhancing bioavailability, enabling targeted delivery, and offering controlled release, these systems overcome many limitations of conventional therapies. As research advances and clinical translation accelerates, nanoparticle-based antivirals are poised to become a cornerstone of modern medicine—combining precision, potency, and safety in the fight against viral diseases.

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