Nanotechnology-Enabled Drug Delivery: Emerging Platforms, Challenges, and Future Perspectives

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Abstract:

Introduction

Nanotechnology has transformed drug delivery systems by leveraging nanoscale materials to achieve precise, targeted therapeutic administration, thereby enhancing efficacy while reducing adverse effects. Key platforms include nanoparticles, liposomes, micelles, and hydrogels, which enable site-specific delivery for chronic ailments such as cancer, cardiovascular diseases, and neurological disorders. These systems improve drug bioavailability, solubility, and stability, allowing controlled release and the ability to traverse biological barriers like the blood-brain barrier.

Methods

Recent advancements emphasize smart, stimuli-responsive nanomaterials that react to pH, temperature, or enzymes for on-demand delivery. Integration with green chemistry principles—using natural biomaterials like plant extracts or microorganisms—promotes eco-friendly synthesis, minimizing toxicity and environmental impact in "green nanomedicine." Applications extend to imaging-guided theranostics, combining diagnostics and treatment.

Results

Nanotechnology-enabled drug delivery systems demonstrate improved drug targeting and controlled release, effectively overcoming biological barriers and enhancing therapeutic outcomes. These approaches show promise in applications ranging from chronic disease treatment to theranostics, offering multifunctionality and sustainable synthesis methods.

Conclusion

However, challenges persist, including scalability, regulatory approval, long-term biocompatibility, and potential immunogenicity. Future directions involve multifunctional hybrids, personalized medicine via AI-optimized designs, and clinical translation to address unmet needs in global health. This comprehensive overview underscores nanomedicine's potential to revolutionize patient care through innovative, sustainable, and precisely targeted therapeutic strategies.

Keywords: nanotechnology, nano, nano-drug delivery system, nanoparticles, targeted therapy

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