

Hybrid Nanostructures as Advanced Therapeutics – A Promise of Future

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ABSTRACT

Nature has provided various biological materials that are used in traditional medicine for treating innumerable ailments, for over many eras and even now they have gained global reputation. However, they tend to have some limitations when used on their native form in aspects like solubility and stability. These therapeutics when integrated with nanotechnologies can circumvent the issues of potency and efficacy. The integral medicines as nano formulations, has an improved mechanical and biochemical properties with an overall evolution in therapeutics.

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INTRODUCTION

Biological molecules from plants, animals, insects and microbes in combination with metals and minerals procured from nature have been formulated to products for various therapeutic and cosmetic applications in the traditional medicine, a practice known for centuries. Around 73% of products at use today are derived from natural products (Wangchuk, 2018). Products derived from nature are used in treating various kinds of disorders due to their diverse pharmacological properties (Chopra & Dhingra, 2021). However, they have some limitations like poor solubility, bioavailability, and stability, which hinder the effective treatment. Combining the nanotechnology with the traditional system of medicine and formulating their therapeutics as nanomaterials, cumulates their individual properties and yield a synergistic advantage which improves the overall properties that broaden the application in various fields.

The interjection of biological molecules in a nano scale gives rise to a scope for abundant applications, by means of hybrid nanoparticles, Photodynamic therapy, Drug delivery and gene delivery etc., (Nguyen & Zhao, 2015). The hybrid nanoparticles help to bring about harmonious effects of all components present which make them efficient for specific applications. They are preferred for various reasons like increasing efficacy, solubility, stability, reducing side effects, and biocompatibility (Anwar et al., 2021; Nguyen & Zhao, 2015).

Hybrid Nanostructures in Regenerative Medicine and Wound Healing

Hybrid nanostructures which combine natural biomaterials like collagen, chitosan, alginate, etc, with nanoengineered scaffolds helps in improving mechanical strength, degradation, and porosity for tissue regeneration and wound repair (Nguyen & Zhao, 2015; Perán et al., 2012; Zarrintaj et al., 2017). Conventional biomaterials used in regenerative medicine have problems in mechanical properties, degradation, and immunogenicity. Modifying the surfaces with nanoparticles, and using them as cell delivery vehicles, helps to overcome these limitations and improve cell proliferation, differentiation and survival. Nanoscaffolds are used in bone and cartilage regeneration (Perán et al., 2012).

Types of Hybrid Nanostructures for Therapeutic Applications

Hybrid nanostructures have been emerged as promising platform in modern therapeutics by combining two or more types of material to achieve synergistic functions such as controlled release, targeted drug delivery, and imaging (Park et al., 2020; Rahman et al., 2022; Yanar et al., 2023). Organic- inorganic hybrid nanoparticles such as liposome or polymeric carriers encapsulating inorganic materials like gold or magnetic particles, which enhance the bioavailability, stability and target release by reducing toxicity (Yanar et al., 2023; Ali et al., 2022; Majeed et al., 2022; Reinsalu et al., 2024). Research on hybrid nanostructures, integrate chemotherapy, imaging, and in-vivo gene editing. Engineered exosome- liposome hybrid merge the targeting ability and

biocompatibility of exosome membranes with the tunable properties of liposome. The liposome hybrid can deliver CRISPR-Cas9 system in MSCs and paves a promising way towards in-vivo gene manipulations (Lin et al., 2018). Collectively research studies show that hybrid nanostructure can improve therapeutic efficacy, and reduce side effects.

Safety, Toxicity, and Regulatory Considerations

The safety of hybrid nanostructures depends on multiple factors that includes size, shape, surface charge, stability and composition. Nanoparticle have unique property and interact with biological system differently. Toxicity is also one of the concerns in the field of nanotechnology, oxidative stress, reactive oxygen species, inflammation, DNA damage, mitochondria dysfunction and accumulation of nanoparticles in organs that leads to toxicities (Nguyen and Zhao, 2015; Kashapov et al., 2021). Regulation consideration includes evaluation of the nanoparticle by clinical trial and following the international, national guidelines (Desai et al., 2025; Prajapati, 2025).

CONCLUSIONS

Hybrid nanostructures in nanotechnology therapeutics represent a transformative strategy in modern therapeutics. The versatility of hybrid nanostructure enables the approaches using nanoparticles, metal-based nanoparticle and lipid-based nanoparticle that enhanced the therapeutic solution. Despite their significant potential the clinical trials for nanotherapeutics are still being challenged for its safety, toxicity and regulatory concern.

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