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Hair Therapy and Transplanatation

Short Communication

Nanotechnology-Based Drug Delivery Systems for Scalp Disorders

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DESCRIPTION

Scalp disorders such as androgenetic alopecia, seborrheic dermatitis, folliculitis and alopecia areata remain challenging to treat due to limited drug penetration through the scalp's stratum corneum and the potential for systemic side effects. In recent years, nanotechnology-based Drug Delivery Systems (nano-DDS) have shown promise in enhancing drug targeting, improving follicular penetration and reducing toxicity for a variety of scalp conditions [1,2]. Lipid-based nanocarriers like Solid Lipid Nanoparticles (SLNs), Nanostructured Lipid Carriers (NLCs), liposomes, transferosomes and ethosomes have been used to enhance the delivery of active pharmaceutical ingredients such as minoxidil and finasteride to hair follicles. These systems exploit the follicular reservoir, allowing drug accumulation near hair bulbs and deeper dermal layers without increasing systemic absorption [3]. For instance, SLNs loaded with minoxidil demonstrated significantly higher drug retention in the scalp compared to conventional topical solutions [4].

Ethosomes, which contain high concentrations of ethanol, disrupt lipid bilayers and improve penetration through the skin and follicular openings. Transferosomes, due to their deformable structure, can squeeze through intercellular pores and reach the follicular base more efficiently. Studies have shown that transferosomes loaded with minoxidil and caffeine not only enhance follicular uptake but also promote hair regrowth in murine models [5]. Polymeric nanoparticles, including chitosan and PLGA (Poly(Lactic-co-Glycolic Acid)), are biocompatible and biodegradable carriers that have been employed for the sustained release of corticosteroids, immunomodulators and natural bioactives. These particles improve drug stability and prolong scalp contact time, important for chronic inflammatory scalp disorders like seborrheic dermatitis and psoriasis [6]. Chitosan-coated nanoparticles, in particular, show strong mucoadhesive properties and enable targeted delivery to the follicular epithelium [7].

A notable advancement includes nanocarriers co-loaded with natural agents and pharmaceuticals. For example, transfersomes containing finasteride and garlic oil, incorporated into an Aloe vera gel base, showed a 3-fold increase in scalp penetration efficiency and significant antibacterial activity against Propionibacterium acnes, which plays a role in folliculitis [8]. Additionally, nanocarriers are being investigated for their role in immune modulation. Cyclosporine A-loaded nanoparticles, intended for alopecia areata, have been shown to penetrate immune-affected follicular units and reduce perifollicular inflammation in preclinical models [9].

Inorganic nanoparticles, such as silver and zinc oxide nanoparticles, offer antimicrobial properties beneficial for infectious scalp disorders, while magnetic nanoparticles are being explored for externally guided drug delivery. However, safety concerns surrounding accumulation and cytotoxicity have limited their clinical translation [10]. While preclinical results are encouraging, most of these technologies have not yet advanced beyond experimental stages. There is a pressing need for large-scale, controlled human studies to validate safety, reproducibility and long-term efficacy. Additionally, regulatory challenges, particularly around defining nanocarrier classification and drug-device combinations, remain unresolved.

CONCLUSION

Nanotechnology-based drug delivery systems offer a paradigm shift in the treatment of scalp disorders. By enhancing penetration, targeting follicles and reducing systemic side effects, nano-DDS present substantial therapeutic potential. Lipid-based and polymeric carriers have demonstrated promising results in increasing drug accumulation at the desired site, especially for conditions like androgenetic alopecia, seborrheic dermatitis and folliculitis. Despite the current progress in formulation development and animal testing, further clinical validation is essential. As nanomedicine matures and regulatory pathways become clearer, these systems may soon redefine how scalp conditions are managed in dermatology.

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