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Review

Nanosponges for the Management of Psoriasis: Characterization and Limitations

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Abstract:
growth, immunological dysregulation, and the formation of scaly, erythematous plaques. Poor skin penetration, short retention times, and possible side effects are common limitations of conventional topical treatments, such as corticosteroids and retinoids. A cutting-edge drug delivery method that can improve the therapeutic effectiveness of anti-psoriatic medications is nanosponges. Effective drug encapsulation, increased solubility, improved skin retention, and controlled drug release are all made possible by their porous three-dimensional structure. Nanosponge-based formulations decrease systemic absorption, increase patient compliance, and enable targeted delivery to inflammatory skin. Preclinical research has demonstrated notable decreases in epidermal hyperproliferation, scaling, and inflammation. Nanosponges are a promising approach for safer and more efficient psoriasis treatment, despite ongoing difficulties with large-scale production, stability, and regulatory approval.

Keywords: Topical drug delivery, controlled drug release, targeted drug delivery, anti-psoriatic therapy, skin inflammation, psoriasis, nanosponges, and nanotechnology.

INTRODUCTION

Millions of people worldwide suffer from psoriasis, a chronic inflammatory skin condition that significantly affects both physical health and quality of life. Red, scaly patches that appear on the skin as a result of aberrant immune responses and excessive skin cell growth are the disease's hallmark. Psoriasis is difficult to manage because, in addition to its skin symptoms, it is frequently linked to other medical conditions like psoriatic arthritis, diabetes, metabolic syndrome, and cardiovascular disorders. [1]

The most popular method of treating mild-to-moderate psoriasis is still topical therapy. However, traditional formulations like creams, ointments, and gels frequently have drawbacks like poor skin penetration, the need for frequent application, a brief duration of action, and the potential for systemic or local side effects. These disadvantages could lower patient adherence and treatment efficacy. [1]

New possibilities for enhancing topical medication delivery in psoriasis have been made possible by recent developments in nanotechnology. Because of their porous structure, high drug-loading capacity, and capacity to deliver controlled and sustained drug release, nanosponges have emerged as a promising system among various nanocarriers. Nanosponge-based formulations provide a new and efficient method for treating psoriasis and have enormous potential for future therapeutic uses by improving drug stability, skin retention, and targeted delivery while lowering systemic exposure. [4]

Nanosponges of different kinds:

1. Nanosponges made of polymers

These are created by creating a three-dimensional porous network by crosslinking synthetic or natural polymers.

These consist of polymers like ethyl cellulose, PVA, PVP, and chitosan that have been crosslinked with substances like carbonyl diimidazole or diphenyl carbonate. They provide good drug loading capacity, adjustable porosity, and high stability. Both hydrophilic and hydrophobic drugs can be used with these systems, which offer regulated drug release. They are primarily used for corticosteroid delivery in psoriasis, which improves sustained action and lessens irritation.

2. Nanosponges Based on Lipids

These are lipid-derived colloidal carriers made of both liquid and solid lipids that are stabilized by surfactants like poloxamers or Tween 80.

They are biocompatible, soft systems with improved dermal penetration and a strong affinity for the skin. Their occlusive properties enhance drug absorption and skin hydration. They are used to improve penetration into thickened plaques and deliver anti-inflammatory drugs like curcumin in psoriasis.[2]

3. Nanosponges Based on Cyclodextrin

By crosslinking cyclodextrins (α, β, or γ) with substances like diphenyl carbonate, these stiff porous networks are created.

They have excellent solubilization of poorly soluble drugs, high porosity, and the capacity to form host-guest inclusion complexes. They offer controlled release and improved stability. They enhance the topical delivery and bioavailability of immunomodulators and poorly soluble anti-psoriatic medications used in psoriasis treatment.[2]

Nanosponges Drug Delivery Mechanism

1. Encapsulation of Drugs in Porous Matrix

Drugs are trapped or incorporated into the porous three-dimensional network of nanosponges, which prevents degradation and increases stability for both hydrophilic and lipophilic drugs.

2. Diffusion-Based Release Under Control

Depending on pore size and crosslinking, the drug is released gradually through diffusion, offering prolonged action and lowering dosage frequency and adverse effects.

3. Localized Delivery and Skin Retention

Nanosponges stay in skin layers after topical application and release medication locally, increasing psoriasis efficacy while reducing systemic absorption.[5]

Justification for Nanosponges in the Treatment of Psoriasis

Addressing Inflammation of the Epidermis

Psoriasis is a long-term inflammatory skin condition characterized by an overabundance of keratinocytes and cytokines such as TNF-α, IL-17, and IL-23. Because of their small size and ability to penetrate superficial skin layers, nanosponges aid in the targeting of this inflammation. Their porous structure allows for sustained drug release at the site of action, enhancing therapeutic efficacy and lowering inflammation while delivering anti-inflammatory medications directly to the epidermis and upper dermis.

Systemic Exposure Is Reduced by Localized Drug Delivery

Topical medications frequently exhibit poor retention and partial absorption, whereas conventional psoriasis treatments like methotrexate and cyclosporine cause systemic side effects due to their widespread drug distribution. By keeping the medication in skin layers for a longer period of time and lowering systemic absorption through controlled release, nanosponges get around this. In addition to improving patient compliance, lowering dosage frequency, and lowering the risk of organ damage and systemic toxicity, they offer site-specific delivery to afflicted skin.[3]

Techniques for Nanosponges Preparation

1. Diffusion Method of Emulsion Solvent

This process involves dissolving the drug and polymer in an organic solvent and emulsifying the mixture into an aqueous phase that contains stabilizer (such as PVA). Nanosponges are created when the solvent diffuses into the external phase.

Crucial Steps: Drug + polymer dissolved in an organic solvent; emulsified in an aqueous surfactant solution; stirred; solvent diffusion; formation of nanoparticles; collection and drying.

Benefits: has a high encapsulation efficiency, produces uniform particle sizes, and is appropriate for hydrophobic medications.[6]

2. Method of Solvent Evaporation

This process emulsifies the drug and polymer in an aqueous phase after dissolving them in a volatile organic solvent. After that, the solvent evaporates, forming solid nanosponge.

Crucial Steps: Organic phase preparation (drug + polymer) → Emulsification in water → Solvent evaporation under stirring → Formation of nanosponge particles.

Benefits: It is easy to use, has good control over particle size, and can be produced on a large scale.[6]

3. Synthesis Assisted by Ultrasound

This technique enhances particle dispersion and encourages the creation of nanoscale porous structures using ultrasonic energy.

Crucial Steps: Combining drugs and polymers → using ultrasonic waves → creating nanosponges.

Benefits: minimizes particle size, improves drug distribution, and takes little time to prepare.[6]

4. Melt Method (Nanosponges Based on Cyclodextrin)

This process creates a molten polymer network that solidifies when cooled by heating cyclodextrin with a crosslinker at a high temperature without the use of a solvent.

Crucial Steps: Cyclodextrin + crosslinker heating → formation of a molten network → cooling and solidification → grinding into powdered nanosponge.

Benefits: Eco-friendly and solvent-free, it yields a high-purity product that can be used in pharmaceutical applications.[6]

Nanosponge Formulation Characterization

Size Distribution and Particle Size:

Important factors influencing the stability, drug-loading capability, and efficacy of nanosponges are particle size and size distribution. Dynamic Light Scattering (DLS) is frequently used to measure them. In general, smaller particles with a low polydispersity index (PDI) offer better drug delivery and stability. [4]

Zeta Potential:

Zeta potential indicates the colloidal stability of nanosponges by measuring their surface charge. A zeta potential analyzer is used to determine it. Increased positive or negative zeta potential values improve formulation stability and aid in preventing particle aggregation. [5]

Drug Loading and Effectiveness of Entrapment:

The amount of drug successfully integrated into the nanosponge system is indicated by drug loading and entrapment efficiency. Better drug encapsulation and enhanced formulation performance are reflected in higher entrapment efficiency. [4]

Entrapment Efficiency (%) is calculated as follows: (Amount of Drug Entrapped/Total Amount of Drug Added) × 100.

Yield of Production:

The effectiveness of the nanosponge preparation procedure is assessed using production yield. An effective manufacturing process with little material loss is indicated by a higher production yield. [4]

Production Yield (%) = (Theoretical Mass/Practical Mass of Nanosponges) × 100.

Analysis of Surface Area and Porosity:

The pore properties of nanosponges are assessed using porosity and surface area analysis. Drug loading capacity and drug release behavior are influenced by surface area, pore volume, and pore size, all of which are measured by BET analysis. [5]

Research on Crystallinity:

The crystalline or amorphous nature of a drug in nanosponges is ascertained by X-ray diffraction (XRD) analysis. Successful drug encapsulation is indicated by reduced crystallinity, which may also enhance drug solubility and dissolution. [4]

FTIR, or Fourier Transform Infrared Spectroscopy:

Drug–polymer interactions in nanosponges are assessed, and functional groups are identified using FTIR. It guarantees the absence of unwanted chemical interactions and aids in verifying the compatibility of formulation components. [6]

Limitation:

Scale-Up Difficulties:

Because tiny adjustments to process parameters can have an impact on particle size, drug entrapment, porosity, and drug release, producing nanosponges on a large scale is difficult. One of the biggest challenges in industrial manufacturing is maintaining uniform size distribution, porous structure, and consistent quality. [6]

Long-Term Stability Problems:

Particle aggregation, drug leakage, structural alterations, and drug crystallization can all have an impact on the long-term stability of nanosponges. Environmental elements like light, humidity, and temperature can further diminish stability, and hydrogel-based systems may also experience problems like microbial contamination and viscosity changes. [7]

Safety Issues:

Because there aren't many long-term human studies, the safety evaluation of nanosponges is still limited.

The need for thorough clinical safety evaluations is highlighted by potential hazards such as nanoparticle accumulation, persistent inflammation, changes in the skin microbiome, and toxicity from leftover crosslinking agents. [8]

Regulatory Obstacles:

The absence of clear product classification, quality control procedures, and standardized regulatory guidelines can impede the clinical translation of nanosponge-based drug delivery systems and cause regulatory authorities to take longer to approve them. [9]

Absence of Clinical Support

Preclinical and animal studies provide the majority of the evidence supporting nanosponge-based treatments. More extensive clinical trials are required to confirm their safety and efficacy in human patients, despite the encouraging results. [6]

Regulatory Structure:

Because standardized guidelines for nanomedicines are still developing, the regulatory approval of nanosponge-based drug delivery systems is complicated. Regulatory bodies frequently classify and evaluate them on an individual basis, which can make the approval process more difficult and time-consuming. [9]

Absence of Standardized Guidelines

The lack of precise and uniform guidelines for nanosponge formulations causes regulatory requirements to differ, which delays the creation and approval of clinically useful products. [9]

Characterization and Quality Control:

Regulatory approval requires thorough quality control and characterization. To guarantee product quality, stability, and batch-to-batch consistency, factors like particle size, zeta potential, drug loading, entrapment efficiency, and drug release behavior must be assessed. [6]

Conclusion and Prospects for the Future:

By enhancing drug solubility, stability, skin penetration, and controlled release, nanosponge-based drug delivery systems present a promising treatment option for psoriasis. Preclinical research has demonstrated their capacity to improve patient compliance and safety while reducing skin lesions, scaling, and inflammation. Because of these benefits, nanosponges could be a topical psoriasis treatment of the future. [6]

Difficulties and Prospects: Despite encouraging outcomes, problems with large-scale production, formulation reproducibility, long-term stability, regulatory concerns, and a lack of clinical safety data continue to restrict the clinical use of nanosponge-based formulations. To ensure their successful commercialization and widespread clinical use, more research and standardized evaluation techniques are required.

Prospective Views: Standardized regulatory guidelines, efficient quality control, and cooperation between researchers, industry, and regulatory bodies are essential for the future development of nanosponge-based treatments. Nanosponge technology has the potential to develop into a safe, targeted, and successful next-generation psoriasis treatment with further research and clinical validation. [6,9]

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