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Research Article

Designing Skin-Interactive Nanoformulations in Cosmetics: A Structure–Delivery–Dermatological Impact Framework for Next-Generation Cosmeceuticals

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Abstract

The application of nanotechnology in cosmetic science has led to the development of advanced cosmeceutical systems capable of overcoming the limitations of conventional topical formulations. Skin-interactive nanoformulations, including liposomes, nanoemulsions, solid lipid nanoparticles, and nanostructured lipid carriers, enhance the stability, bioavailability, controlled release, and targeted delivery of active cosmetic ingredients. This paper presents a comprehensive Structure–Delivery–Dermatological Impact (SDDI) framework linking nanocarrier physicochemical design to skin penetration pathways and dermatological outcomes. Dermatological applications in anti-aging, photoprotection, pigmentation control, acne management, and barrier repair are critically discussed, along with safety and regulatory considerations.

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KEYWORDS: Nanocosmetics; Cosmeceuticals; Nanoformulations; Skin penetration; Lipid nanoparticles; Dermatological efficacy

1. INTRODUCTION

The cosmetic industry has evolved from products focused solely on aesthetic appeal to cosmeceuticals that provide functional dermatological benefits. Despite advances, conventional topical formulations often exhibit limited efficacy due to poor penetration across the stratum corneum. Nanotechnology offers innovative carrier systems capable of enhancing skin interaction, stability, and controlled delivery of cosmetic actives. However, rational formulation strategies remain fragmented. This research introduces a Structure–Delivery–Dermatological Impact (SDDI) framework to guide next-generation nano-cosmeceutical development.

2. STRUCTURE–DELIVERY–DERMATOLOGICAL IMPACT (SDDI) FRAMEWORK

2.1 Structural Design of Nanoformulations

Nanocarrier structure plays a decisive role in determining stability, skin interaction, and delivery performance. Particle size, surface charge, morphology, and composition govern skin adhesion and penetration efficiency.

2.1.1 Particle Size and Distribution

Particles below 300 nm demonstrate enhanced follicular localization and prolonged skin residence time, improving delivery efficiency while minimizing systemic absorption.

2.1.2 Surface Charge and Chemistry

Surface charge influences electrostatic interaction with the skin barrier. Positively charged nanoparticles enhance penetration but may increase irritation, requiring surface modification.

2.1.3 Composition and Morphology

Lipid-based nanoparticles mimic the skin lipid matrix, improving biocompatibility and barrier integration compared to polymeric systems.

3. DELIVERY: Skin Interaction And Penetration Mechanisms

Nanoformulations interact dynamically with the skin barrier, exploiting intercellular, transcellular, and follicular penetration pathways for effective delivery.

3.1 Penetration Pathways

The intercellular route is dominant for lipid nanoparticles, while follicular pathways enable targeted and sustained delivery for acne and hair-related conditions.

4. DERMATOLOGICAL IMPACT OF NANO-ENABLED COSMECEUTICALS

Nanoformulations enhance the dermatological performance of cosmetic actives by improving stability, penetration, and controlled release.

4.1 Anti-Aging and Skin Rejuvenation

Nano-encapsulation of retinoids and antioxidants improves collagen synthesis and reduces wrinkle formation with reduced irritation.

4.2 Photoprotection

Nanoparticulate UV filters offer enhanced photostability and uniform skin coverage while reducing sensitization risks.

4.3 Pigmentation Control

Targeted delivery of depigmenting agents regulates melanogenesis more effectively than conventional formulations.

4.4 Acne Management

Follicular targeting of antimicrobial agents improves acne treatment efficacy while minimizing systemic exposure.

4.5 Barrier Repair and Hydration

Lipid nanoparticles restore essential skin lipids, reducing transepidermal water loss and enhancing hydration.

5. FINDINGS

The findings indicate that nanoformulation structure strongly influences skin penetration, retention, and dermatological outcomes. Lipid-based systems demonstrate superior biocompatibility.

6. DISCUSSION

The SDDI framework highlights the importance of aligning formulation design with skin biology. Despite advantages, safety and regulatory considerations remain critical for long-term adoption.

7. CONCLUSION

Skin-interactive nanoformulations represent a transformative advancement in cosmeceutical science. The proposed SDDI framework provides a rational basis for designing safe and effective next-generation cosmetic products.

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