

# Cosmetic Topical Formulations: Design Strategies, Skin Interaction Mechanisms, Clinical–Cosmetic Applications, and Emerging Trends

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## Abstract

*Cosmetic topical products are central to modern skin care, as they deliver active ingredients directly to the skin surface and upper layers to improve appearance, texture, and function. By acting locally on the epidermis and adnexal structures, these preparations help manage dryness, photoaging, pigmentation, acne, and sensitive-skin conditions while minimizing systemic exposure. A wide range of dosage forms – creams, lotions, gels, ointments, serums, sprays, and transdermal-inspired cosmetic patches – are engineered to modulate skin hydration, barrier function, and penetration of cosmetic or cosmeceutical actives. Recent advances in formulation science have introduced nanocarriers, vesicular systems, smart hydrogels, and bioactive dressings adapted for cosmetic use, improving stability, targeted delivery, sensorial properties, and consumer adherence. Nonetheless, cosmetic topical delivery faces challenges, including the strong barrier function of the stratum corneum, irritation risk, variability in skin condition, and the need to comply with cosmetic safety and regulatory standards. This review outlines skin structure relevant to cosmetic delivery, classification of cosmetic dosage forms, key formulation components, mechanisms of skin interaction and absorption, clinical–cosmetic applications, advantages, limitations, and recent innovations in cosmetic and cosmeceutical topical systems, highlighting their growing role in contemporary cosmetic science and practice.*

**Keywords:** cosmeceuticals, cosmetic formulation, dermatological aesthetics, nanocosmetics, skin delivery, topical cosmetics

## INTRODUCTION

The skin is the largest organ of the body and a primary target for cosmetic intervention, as it defines visible appearance, texture, and perception of health and age. Environmental stressors such as ultraviolet radiation, pollution, low humidity, as well as intrinsic factors like aging and hormonal changes impair barrier function and contribute to dryness, wrinkles, dyschromia, and sensitivity [1]. Cosmetic topical products have evolved from simple beautifying preparations to scientifically designed formulations that enhance hydration, protect against environmental damage, and support barrier repair and overall skin well-being.

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Conventional cosmetic formulations – creams, lotions, gels, and ointments – are developed to maintain appropriate hydration, improve sensorial attributes, and deliver active cosmetic ingredients such as emollients, humectants, antioxidants, exfoliants, and whitening agents. Cosmeceutical concepts further bridge cosmetics and dermatology by incorporating bioactive agents like vitamins, peptides, botanical extracts, and low-dose anti-inflammatory molecules aimed at modulating biological pathways associated with photoaging, pigmentation, or acne, while remaining within cosmetic regulatory boundaries [2].

Globally, there is a growing demand for evidence-based cosmetic products tailored to specific skin types (oily, dry, sensitive, mature) and conditions (acne-prone, hyperpigmented, photoaged), which has stimulated intense research into skin biology, carrier systems, and safety assessment. At the same time, consumers increasingly seek multifunctional products that combine hydration, UV protection, antioxidant defense, and aesthetic benefits in a single formulation, placing additional demands on formulation design and stability [3].

Within this context, topical cosmetic medicines and cosmeceutical products must balance efficacy, pleasant sensory profile, and regulatory compliance, while ensuring long-term safety and tolerability. This review focuses on cosmetic topical systems, emphasizing their formulation strategies, mechanisms of interaction with the skin, clinical–cosmetic applications, and recent advances relevant to the scope of Recent Trends in Cosmetics [4].

### **SKIN ANATOMY AND PHYSIOLOGY RELEVANT TO COSMETIC TOPICAL DELIVERY**

The skin forms a complex interface between the body and the environment and plays a decisive role in the behavior of cosmetic topical products. It is organized into three main layers: epidermis, dermis, and hypodermis, each contributing differently to barrier function, hydration, and mechanical support.

The epidermis, particularly the stratum corneum, is the principal barrier to penetration of cosmetic actives. The stratum corneum consists of flattened, anucleate corneocytes embedded in an ordered lipid matrix of ceramides, cholesterol, and fatty acids, forming the characteristic “brick-and-mortar” structure. This arrangement restricts passage of hydrophilic and high-molecular-weight molecules and, at the same time, maintains water balance and protects against irritants and microbes. Many cosmetic strategies – such as use of humectants, occlusives, lipid-replenishing agents, and mild penetration enhancers – aim to modulate this layer without damaging its integrity [5].

Beneath the epidermis, the dermis is a vascularized connective tissue rich in collagen, elastin, glycosaminoglycans, blood vessels, and nerves. From a cosmetic perspective, the dermis underlies key features such as firmness, elasticity, and wrinkle formation, and is a target for bioactive molecules like peptides, retinoids, and antioxidants that influence collagen synthesis and matrix remodeling. The hypodermis, largely composed of adipose tissue, contributes to cushioning and contour, and is increasingly recognized as relevant in discussions of cellulite and body-contour cosmetics [6].

Skin permeability is affected by multiple factors: physicochemical properties of actives (molecular size, log P, ionization), formulation attributes (vehicle type, emulsifier system, occlusiveness, presence of enhancers), and physiological conditions (hydration, age, anatomical site, ethnicity, and pre-existing dermatological conditions). Understanding these factors is essential for designing cosmetic formulations that achieve the desired local effect – hydration, smoothing, brightening – while maintaining safety and consumer comfort [7].

### **CLASSIFICATION OF COSMETIC TOPICAL DOSAGE FORMS**

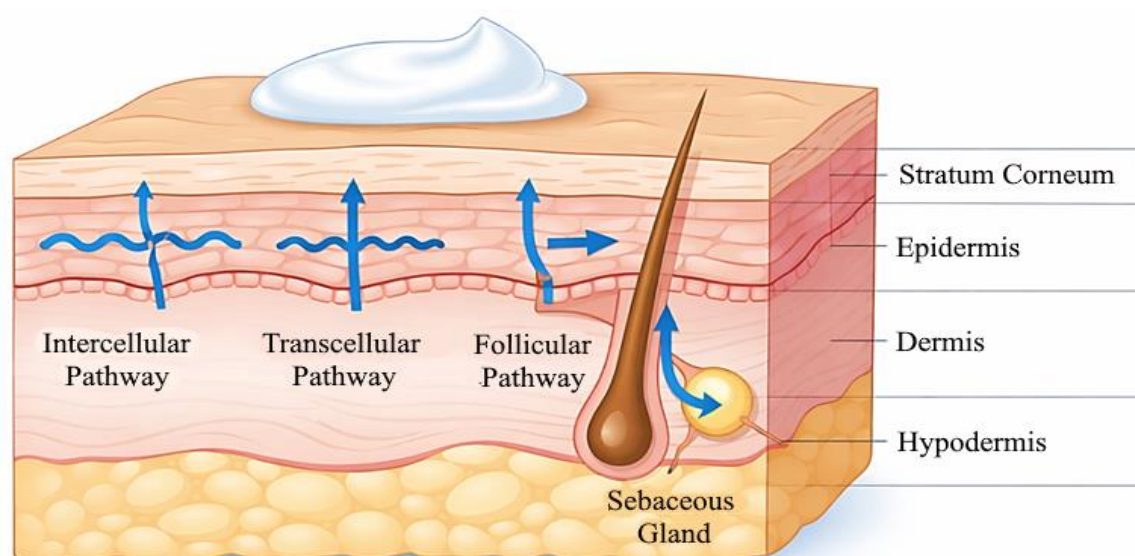
Topical cosmetics can be classified by dosage form and by cosmetic purpose or application area. Such classification aids in aligning formulation design with consumer expectations, skin type, and targeted cosmetic benefits.

#### **Classification Based on Dosage Form**

- *Ointments and Balms*: Semi-solid systems with a high proportion of oleaginous bases (hydrocarbons, waxes, butters) that create occlusive films, enhance hydration, and protect severely dry or chapped areas such as lips, heels, or hands. They are useful in barrier-repair cosmetics and overnight treatments for xerosis and sensitive skin [8].
- *Creams*: Oil-in-water or water-in-oil emulsions that combine spreadability with good cosmetic elegance and are widely used in moisturizers, anti-aging products, fairness/brightening creams, and

medicated cosmetics for acne or pigmentation. They allow incorporation of both hydrophilic and lipophilic actives and are generally well accepted by consumers due to their non-greasy feel.

- *Gels and Hydrogel-Based Products*: Three-dimensional polymer networks entrapping aqueous or hydroalcoholic phases, often transparent, fast drying, and cooling. These are particularly suitable for oily or acne-prone skin, scalp, and hairy areas, enabling delivery of anti-acne actives, soothing agents, or hair-cosmetic ingredients without heavy residues.
- *Lotions and Fluid Emulsions*: Low-viscosity products intended for large surface areas, including body lotions, after-sun lotions, and light facial moisturizers. They are favored in warm climates and for normal to oily skin types due to quick absorption and low greasiness.
- *Pastes and High-Solid Preparations*: Stiff semi-solids with high content of insoluble powders, used in protective cosmetics such as baby diaper-area products, anti-chafing pastes, and certain sunblock formulations with physical UV filters.
- *Sprays, Foams, and Mists*: Aerosol and non-aerosol systems used for deodorants, hair styling, body sprays, and facial mists, designed for rapid application, even distribution, and pleasant sensory effects.
- *Transdermal-Inspired Cosmetic Patches and Masks*: Patches, sheet masks, and under-eye pads deliver concentrated doses of humectants, peptides, and botanical extracts to localized areas, often using occlusion to enhance penetration and immediate visible effects such as plumping or brightening (Figure 1) [9, 10].



Drug Absorption Pathways

~~~~~ Intercellular Pathway    → Transcellular Pathway    → Follicular Pathway

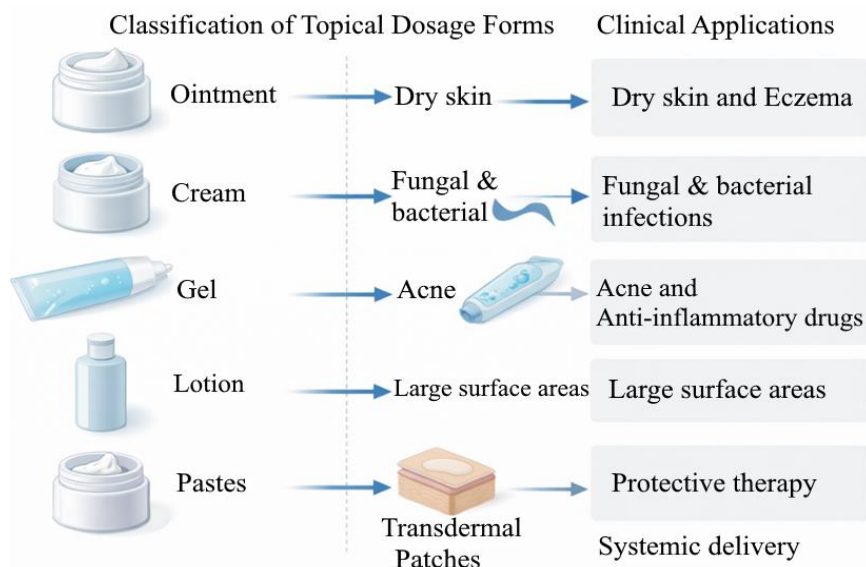
**Figure 1.** Schematic representation of skin layers and principal pathways for cosmetic active penetration (intercellular, transcellular, and appendageal).

### Classification Based on Cosmetic Use

Cosmetic topical products may also be grouped according to their intended cosmetic function: [2].

- Skin hydration and barrier repair (moisturizers, emollient creams, barrier creams).
- Anti-aging and anti-wrinkle care (retinoid-containing products, peptides, antioxidants).
- Skin brightening and tone-evening (depigmenting agents, exfoliating acids, vitamin C products).
- Acne and oily-skin care (sebum-regulating gels, exfoliating lotions, non-comedogenic moisturizers).

- Sun protection (sunscreens combining organic and inorganic filters).
- Sensitive-skin and anti-redness care (soothing, anti-inflammatory cosmetics).
- Hair and scalp cosmetics (shampoos, conditioners, serums, anti-dandruff and anti-hair-fall products) (Figure 2 and Table 1).



**Figure 2.** Classification of cosmetic topical dosage forms and their common cosmetic applications.

**Table 1.** Common cosmetic topical dosage forms and applications.

| Dosage form     | Key characteristics                           | Typical cosmetic applications                                   |
|-----------------|-----------------------------------------------|-----------------------------------------------------------------|
| Ointments/balms | Greasy, occlusive, high lipid content         | Severely dry skin, lip care, barrier-repair overnight products. |
| Creams          | Semi-solid, elegant, easily spreadable        | Moisturizers, anti-aging, brightening, medicated cosmetics.     |
| Gels            | Water-based, fast drying, cooling             | Acne care, oily-skin care, scalp and hair serums.               |
| Lotions         | Low viscosity, suitable for large areas       | Body moisturizers, after-sun products, light facial care.       |
| Patches/masks   | Localized, often occlusive, concentrated dose | Under-eye care, intensive hydration, spot brightening.          |

## FORMULATION COMPONENTS OF COSMETIC TOPICAL PRODUCTS

The performance and consumer acceptance of cosmetic topical products depend strongly on the choice and synergy of their components. Key elements include cosmetic active ingredients, bases/vehicles, penetration-modulating agents, and stabilizing and sensorial excipients [11, 12].

### Cosmetic Active Ingredients

Cosmetic actives are selected to provide specific benefits such as moisturization, anti-aging, brightening, sebum control, or soothing effects. Examples include.

- Humectants (glycerin, hyaluronic acid) to attract water and improve hydration.
- Emollients and barrier lipids (plant oils, ceramides, fatty alcohols) to reduce transepidermal water loss.
- Antioxidants (vitamins C and E, coenzyme Q10, polyphenols) mitigate oxidative stress and photoaging.
- Exfoliants and keratolytics (alpha- and beta-hydroxy acids) to promote desquamation and even tone.
- Depigmenting agents (niacinamide, kojic acid, certain botanical extracts) for hyperpigmentation and uneven skin tone.

- Peptides and retinoid derivatives for collagen support and wrinkle reduction.
- Their molecular size, lipophilicity, solubility, and ionization are crucial for determining skin uptake and are considered when selecting vehicles and delivery systems [13, 14].

### **Bases and Vehicles**

Bases and vehicles determine texture, spreadability, and the ability of the active to reach its target site. Common cosmetic vehicle types include.

- Oleaginous bases (hydrocarbon and wax blends) for occlusive, protective balms and ointments.
- Emulsion bases (oil-in-water or water-in-oil systems) for day and night creams with balanced feel.
- Hydrogel or hydroalcoholic bases for refreshing gels suitable for oily skin and scalp-care products [1].

For cosmetic barrier-support formulations, vehicles are selected to maintain moisture, mimic physiological lipids, and promote skin comfort. The choice of emulsifiers, consistency agents, and rheology modifiers greatly influences sensory attributes, which are critical for consumer adherence [15, 16].

### **Penetration Modulators and Enhancers**

Cosmetic formulations often incorporate mild penetration modulators to optimize delivery of actives to the epidermis and superficial dermis without compromising safety. These include short-chain alcohols in limited concentrations, glycols, fatty acids, certain surfactants, and natural terpenes. They may alter lipid packing, increase hydration, or modify partitioning into the stratum corneum, enhancing efficacy of actives such as vitamins, depigmenting agents, or anti-acne molecules [17].

### **Preservatives, Antioxidants, and Stabilizers**

Preservation and stability are key regulatory and safety requirements in cosmetics. Multi-use formulations, particularly emulsions and aqueous gels, require effective preservative systems (e.g., parabens where allowed, organic acids, benzyl alcohol, phenoxyethanol, or preservative blends) to prevent microbial contamination over shelf life and consumer use. Antioxidants and UV stabilizers protect sensitive actives and lipids from degradation, while buffering agents and chelators help maintain optimal pH and limit metal-catalyzed reactions. These measures ensure product safety, efficacy, and consistent performance until the end of shelf life [18].

## **MECHANISMS OF COSMETIC ACTION AND SKIN ABSORPTION**

Cosmetic products primarily act on the skin surface and upper layers, modulating barrier function, hydration, pigmentation, and dermal matrix integrity. Their mechanisms are closely linked to skin structure and the physicochemical design of the formulations [19].

### **Percutaneous Absorption in Cosmetics**

Percutaneous absorption describes the movement of a cosmetic ingredient from the skin surface into deeper layers. For most cosmetic actives, the target is the stratum corneum and viable epidermis, with limited or no systemic exposure. Diffusion is driven by concentration gradients and governed by lipophilicity, molecular size, vehicle properties, and skin condition. Dermal absorption studies and in vitro models are increasingly used to demonstrate safety and compliance with cosmetic regulations when exposure beyond the skin is possible [20, 21].

### **Routes of Penetration**

Three principal pathways for cosmetic ingredient penetration are recognized.

- Intercellular route through lipid domains between corneocytes, dominant for many lipophilic molecules and cosmetic oils.
- Transcellular route across corneocytes, involving alternating hydrophilic and lipophilic domains, relevant for certain small amphiphilic compounds.

- Appendageal route via hair follicles and sweat glands, which may act as reservoirs for particulate systems such as nanoparticles and for targeted hair/scalp cosmetics.

Modern nanocosmetic systems frequently exploit follicular pathways to enhance local availability of actives while limiting systemic uptake [22].

### Factors Influencing Cosmetic Absorption

Intrinsic factors (molecular weight, log P, ionization), formulation factors (vehicle, concentration, occlusive character, use of enhancers), and skin-related factors (hydration, temperature, site, integrity, and disease state) collectively determine the extent and profile of cosmetic absorption. Age-related changes and photoaging can alter barrier function and lipid composition, influencing how cosmetic products perform in different populations [23].

## CLINICAL–COSMETIC APPLICATIONS OF TOPICAL COSMETICS

Cosmetic topical products support both aesthetic goals and skin comfort, often complementing dermatological treatments in conditions like acne, rosacea, or post-procedure recovery.

### Management of Common Cosmetic Skin Concerns

- *Dry and Sensitive Skin:* Emollient and humectant-rich creams and ointments restore hydration, reinforce the lipid barrier, and reduce sensations of tightness and discomfort.
- *Photoaging and Wrinkles:* Anti-aging cosmetics combine retinoid derivatives, peptides, antioxidants, and sunscreens to smooth fine lines, improve elasticity, and prevent further UV-induced damage [2].
- *Hyperpigmentation and Uneven Tone:* Brightening products include depigmenting agents, exfoliating acids, and UV filters to reduce dark spots, melasma appearance, and post-inflammatory hyperpigmentation [2].
- *Acne-Prone and Oily Skin:* Non-comedogenic gels and lotions containing exfoliating and sebum-regulating ingredients help manage shine, comedones, and blemish marks, often alongside prescription therapy.

### Hair, Scalp, and Periocular Cosmetics

Hair-care cosmetics such as shampoos, conditioners, hair masks, and serums are formulated to cleanse, protect the cuticle, reduce breakage, and deliver active ingredients for dandruff control or hair-fiber strengthening. Scalp serums and leave-on treatments often use light vehicles and targeted actives to support scalp comfort and cosmetic management of hair fall. Periocular cosmetics (eye creams, gels, and patches) aim to improve hydration, fine lines, puffiness, and dark circles using low-irritant vehicles and gentle actives [24].

### Adjunctive Role with Dermatological Therapy

Cosmetic products frequently function as adjuvants to dermatological treatments by maintaining barrier integrity, reducing irritation from active drugs, and improving overall treatment adherence. For example, carefully designed moisturizers and cleansers are integral to routines in acne, atopic dermatitis, or post-procedural care, even though they remain regulated as cosmetics when no therapeutic claims are made.

## ADVANTAGES AND LIMITATIONS OF COSMETIC TOPICAL DELIVERY

### Advantages

Cosmetic topical delivery offers several advantages.

- Direct action on the skin surface and superficial layers, where cosmetic benefits are desired.
- Reduced systemic exposure compared with oral or injectable routes, enhancing safety margins.
- High local concentrations of key actives with tailored sensorial profiles that improve consumer satisfaction and routine adherence.

- Non-invasive, convenient application, compatible with daily self-care and long-term use.

### **Limitations and Consumer-Related Issues**

However, cosmetic topical systems also face limitations.

- The stratum corneum represents a strong barrier, restricting penetration of hydrophilic or large molecules, which may limit the efficacy of certain high-molecular-weight actives.
- Inter-individual variability in skin type, age, climate exposure, and concurrent dermatological conditions can lead to variable perceived effectiveness [25].
- Local intolerance, irritation, contact allergy, or fragrance sensitivity can occur, necessitating careful selection of excipients and patch testing strategies, especially for sensitive-skin products.
- Consumer acceptance is influenced by greasiness, odor, drying time, residue, and packaging, and poor acceptance can compromise consistent use even for efficacious formulations.

### **RECENT ADVANCES IN COSMETIC TOPICAL DELIVERY SYSTEMS**

Recent years have seen rapid development of advanced delivery systems adapted from pharmaceutical technologies for cosmetic purposes.

- *Nanotechnology-Based Formulations*: Lipid nanoparticles, nanoemulsions, and polymeric nanoparticles enhance solubility, protect unstable actives such as vitamins and botanical compounds, and improve localization within the stratum corneum and hair follicles.
- *Liposomes, Niosomes, and Other Vesicular Carriers*: Vesicular systems can encapsulate both hydrophilic and lipophilic ingredients, improving penetration and sustained release while potentially reducing irritation. They are widely explored in anti-aging, brightening, and hair-care cosmetics.
- *Microneedle-Inspired and Semi-Invasive Cosmetic Devices*: Although strictly regulated and often device-based, microneedle and microchannel technologies are being adapted in professional cosmetic settings to enhance penetration of serums and masks, especially for anti-aging indications.
- *Smart and Stimuli-Responsive Systems*: Hydrogels and films responsive to temperature, pH, or light are under investigation to enable controlled release and improved user experience in next-generation cosmetic masks and patches.
- *Green and Sustainable Formulation Approaches*: There is growing emphasis on biodegradable polymers, plant-derived surfactants, and eco-friendly preservatives, aligning cosmetic innovation with regulatory and consumer expectations for sustainability [26, 27].

### **SAFETY, TOXICITY, AND REGULATORY CONSIDERATIONS IN COSMETICS**

Topical cosmetic products are subject to cosmetic-specific regulations that prioritize consumer safety and restrict therapeutic claims. Safety assessment typically includes toxicological evaluation of ingredients, dermal irritation and sensitization testing, stability studies, and microbiological quality control. Cosmetics must be safe for intended use and under reasonably foreseeable conditions, which includes repeated daily application over long periods.

Common local adverse reactions include stinging, redness, itching, and allergic contact dermatitis, often associated with fragrances, preservatives, or certain actives. While systemic toxicity is uncommon at cosmetic doses, regulatory frameworks in major regions require adherence to positive and negative lists of ingredients, maximum concentration limits, and labeling standards. Proper formulation, compatibility testing, and post-marketing surveillance (consumer feedback, cosmetovigilance) are essential to ensure ongoing safety [28].

### **FUTURE PERSPECTIVES**

Future directions in cosmetic topical delivery focus on personalization, high-performance yet gentle formulations, and deeper integration of dermatological and cosmetic science. Advances in omics technologies and skin microbiome research are expected to support development of personalized cosmetic regimens based on skin type, genetic profile, and lifestyle [29].

Nanocarriers, hybrid vesicular systems, and bioactive dressings adapted for cosmetic use will likely provide more precise targeting of epidermal and dermal structures, combining efficacy with superior sensory properties. Digital tools, including imaging-based skin analysis and AI-supported product selection, may help consumers choose and monitor cosmetic routines more effectively. Continued collaboration between formulators, dermatologists, toxicologists, and regulatory experts will be crucial to maintain safety while expanding the functional scope of topical cosmetic products [30].

## CONCLUSION

Cosmetic topical formulations play a pivotal role in modern skin and hair care, providing localized, non-invasive approaches to improve hydration, texture, pigmentation, and signs of aging. Their effectiveness depends on a detailed understanding of skin structure, the judicious selection of actives, vehicles, and penetration modulators, and careful attention to safety and sensory attributes. Emerging technologies – including nanocarriers, vesicular systems, smart hydrogels, and advanced patches – are expanding the capabilities of cosmetic products while remaining within cosmetic regulatory frameworks. As research in skin biology and formulation science progresses, cosmetic topical delivery systems are expected to become increasingly sophisticated, personalized, and aligned with both consumer expectations and regulatory requirements.

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