Review article / Artykuł przeglądowy

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Nanocosmetics in skin and hair care. Potential applications and development prospects

Nanokosmetyki w pielęgnacji skóry i włosów. Możliwości zastosowania i perspektywy rozwoju

ABSTRACT

Nanotechnology has revolutionized the cosmetic sector. Nanocarriers have improved the stability, biological efficacy, and sensory attributes of body care products. Despite this significant potential, issues such as risk assessment, regulatory oversight, long-term safety, and the harmonious integration of innovation with practical functionality remain critical. A key challenge in skin and hair care is the natural protective barrier, which limits the transport and delivery of active substances to deeper tissue layers and the bloodstream. Research confirms that nanocarriers significantly improve nutrient penetration through the epidermal barrier; however, such preparations also require rigorous safety assessment. The high translational potential of nanocosmetics underscores their pivotal role in the development of personalized products. Nevertheless, the current market landscape highlights an urgent need to elucidate the mechanisms and effects of applying nanotechnology in cosmetology.

This review aimed to present the current state of knowledge regarding nanocosmetics, their efficacy, and potential toxicity. It also highlights the translational effectiveness of these preparations.

Keywords: nanocosmetics, liposomes, skin, hair, toxicity, nanocarrier.

STRESZCZENIE

Nanotechnologia zrewolucjonizowała sektor kosmetyczny. Zastosowanie nanonośników zwiększyło stabilność, skuteczność biologiczną oraz walory sensoryczne preparatów do pielęgnacji ciała. Mimo znacznego potencjału, istotną kwestią pozostaje ocena ryzyka, kontrola regulacyjna, długofalowe bezpieczeństwo oraz harmonijne zestawienie innowacji z ich praktyczną funkcjonalnością. Kluczowym wyzwaniem w pielęgnacji skóry i włosów pozostaje naturalna bariera ochronna, która ogranicza transport oraz dostarczanie substancji aktywnych do głębszych warstw tkanek i krwiobiegu. Badania potwierdzają, że zastosowanie nanonośników znacząco zwiększa przenikanie składników odżywczych przez barierę naskórkową, choć równolegle podkreśla się potrzebę krytycznej oceny bezpieczeństwa takich preparatów. Wysoki potencjał translacyjny nanokosmetyków odzwierciedla ich kluczową rolę w rozwoju preparatów spersonalizowanych. Niemniej jednak obecna sytuacja rynkowa wskazuje na pilną potrzebę szczegółowego wyjaśnienia mechanizmów oraz skutków stosowania nanotechnologii w kosmetologii.

Celem przeglądu było przedstawienie aktualnego stanu wiedzy na temat nanokosmetyków, ich skuteczności oraz przewidywanej toksyczności. Podkreślono również efektywność translacyjną tego typu preparatów.

Słowa kluczowe: nanokosmetyki, liposomy, skóra, włosy, toksyczność, nanonośnik.

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INTRODUCTION

Cosmetics are products that enhance skin health and support personal hygiene. The worldwide beauty market is now worth $511 billion and is predicted to grow at a 5.30% annual rate between 2022 and 2026 [1]. A significant rise in brand recognition is driven by factors such as influencer influence and the accessibility of online shopping. During the forecast period, social media usage is anticipated to propel market growth. One of the most well-known sectors to benefit from nanotechnology is the cosmetics industry, which is currently one of the top sectors using it to develop new products [2]. This can be attributed to several trends, such as a growing desire for self-care products with effective skin performance and increased interest in the power of regimens and routines. It is now well known that nanocarriers improve cosmetic performance in several ways, acting as both an active ingredient and/or a carrier. These technologies introduce new features to cosmetic products, emphasizing the need for a clear and comprehensive explanation of the use of nano-carriers in cosmetics [3]. Among the nano-carriers that substantially reduce the shortcomings of conventional cosmetics and add additional beneficial properties to a product, liposomes are a key example. Liposomes have been a promising type of nanocarriers, which are composed of phospholipids and cholesterol and an effective technology to fulfil satisfactory consumer needs; they have received a lot of attention and are extensively explored in a variety of cosmetic formulations. Liposomes can entrap both hydrophilic and lipophilic active ingredients [4]. They are primarily composed of cholesterol along with other excipients, as cholesterol offers several advantages, such as modulating membrane fluidity and permeability. It also enhances the overall stability of the liposomal structure [5]. Liposomes have a high affinity for the stratum corneum (SC), allowing more effective uptake of encapsulated active ingredients or molecules than conventional dosage forms [6]. Moreover, cosmetic liposomes are further modified into a few types, such as transferosomes, niosomes, novasomes, ultrasomes, and ethosomes. Like liposomes, these are sophisticated vesicular delivery systems. Niosomes are made of cholesterol and non-ionic surfactants, whereas transferosomes are modified liposomes with an edge activator. Novasomes are complex vesicles with high payload capacity; in contrast, ultrasomes are liposomal vesicles that encapsulate enzymes [7]. This review mainly emphasizes the emergence of nanocosmetics, their advantages over conventional cosmetics, the skin barriers to cosmetics, and their clinical implications, along with marketed products. This review aimed to provide comprehensive details on nanocosmetics, their efficacy, and expected toxicity. This review also highlights the translational efficacy of nanocosmetics. These epidermal barriers can be further categorised by function (Fig. 1).

TYPES OF NANO COSMETIC SYSTEMS

As nanotechnology has successfully solved numerous bioactive agent delivery problems, it is widely used in the pharmaceutical and cosmeceutical fields. Various nanocosmetic systems are used in formulations to improve product stability, solubility, safety, and effectiveness while minimising toxic side effects. The different types of nanocosmetic systems available include liposomes, nanocrystals, nanoemulsions, dendrimers, solid lipid nanoparticles, nanocapsules, niosomes, nanostructure lipid carriers, and mineral nanoparticles, etc.

Liposomes

Liposomes are spherical vesicles with a central aqueous volume enclosed within phospholipid bilayers known as a lamel-

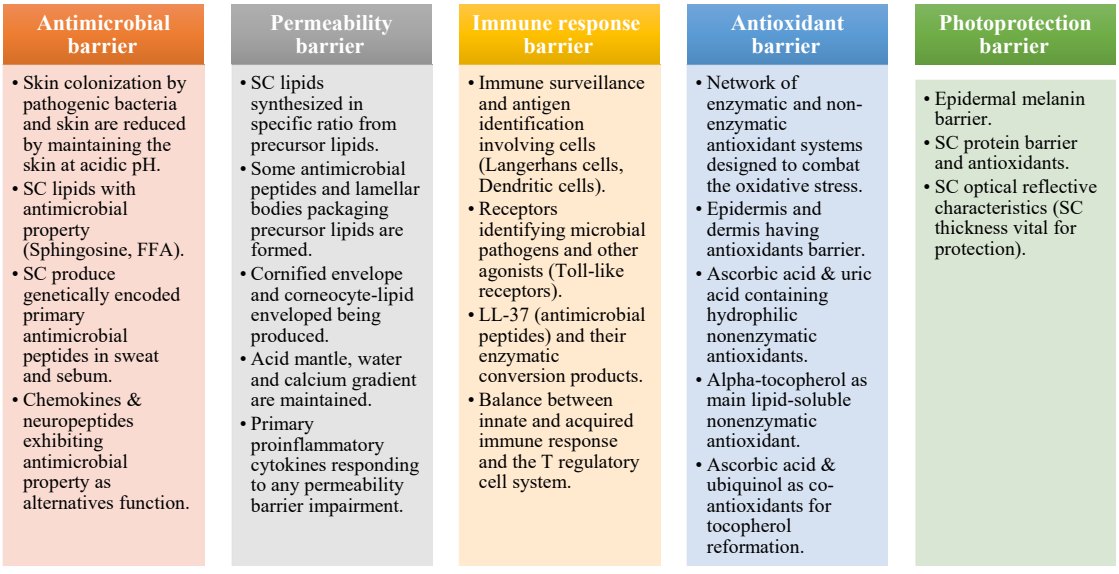


Fig. 1. Epidermal barriers based on their function. **Source:** [8].

la [9]. Nano-liposomes are nano-sized liposomes with diameters ranging from 15 nm to several microns [9]. Their nano size makes them capable of being good dermal carriers by protecting skin from external stressors through the formation of an occlusive layer on skin and moisturizing it via liposome rupture [10]. Hence, with outstanding biocompatibility and biodegradability characteristics, nano-liposome technology continues to lead market development [11, 12]. Cosmetic liposomes are further classified into transferosomes, ultrasomes, marinosomes, noisomes, etc. [9]. Commercially available nanoliposome products include moisturisers (Dermosome - Microfluidics) and anti-wrinkle creams (Capture Totale - Dior) [13-15]. Cholesterol and phospholipids are the main components of liposomes, which determine the rigidity or fluidity of liposomes [16, 17]. Various liposomal cosmetics have been developed and classified according to their characteristics. For example, niosomes, which are vesicles of 100-500 nm, and transferosomes of 200-300 nm [17]. Liposome formulations offer significant benefits in treating a wide range of dermatological problems (Tab. 1).

Nanocrystals

Nanocrystals (NC) are defined as nanoscale particles with sizes below 1000 nm [24], composed of drug particles and stabilised by certain stabilisers, and kept dispersed to prevent aggregation. Common stabilisers include polymeric, ionic, and non-ionic agents [25]. NC-based formulations can significantly increase dissolution rate, surface adhesion, and

Tab. 1. Summary of liposomal formulation for various cosmeceutical applications. **Source:** [11, 14, 15, 18, 19-23].

No	Application	Concentration	Study type	Description	Method	Duration of application	Reference
1	Acne	Not specific	*in vitro, in vivo* and *ex vivo*	Adapalene and benzoyl peroxide in liposomal gel	Incorporation	Not specific	[11]
		Not specific, but compares with 1% of adapalene gel	*In vitro* and *ex vivo*	The experiment was carried out on excised pig ear skin to model human skin conditions and assess permeation and follicular targeting of the liposomal adapalene formulation	Encapsulation	24-hour	[11]
2	Psoriasis	0.05%, 0.1%, 0.25% and 0.5%	*In vivo* and *in vitro*	BALB/c mice with imiquimod-induced psoriasis treated with topical deformable liposome-loaded methotrexate	Methotrexate was entrapped in deformable liposomes formed of phosphatidylcholine and oleic acid	Not specified	[14]
		Not specified	*In vivo* and *in vitro*	Mice treated with hydrogels containing different tretinoin-loaded nanocarriers	Tretinoin was incorporated into several nanocarriers	Not specified	[19]
3	Melasma and Hyperpigmentation	Not specified	Clinical trial	21 female patients with melasma were treated with the cream for 4 weeks and assessed at weeks 2 and 4	Liposome-encapsulated cream	4 weeks	[15]
		0.1%	Randomized controlled split-face trial	23 patients with melasma applied 0.1% cream 0.1% or vehicle to each side of the face twice	Liposome-encapsulated cream	8 weeks	[15]
4	Hypopigmentation and vitiligo	Not specified	Clinical study	19 patients were recruited with recalcitrant vitiligo patches that were treated with blister roof transplantation and followed by khellin liposomes, with evaluation done by UV light and repigmentation	Liposome-encapsulated khellin with UV light and blister roof transplantation	Not specified	[20]
		Not specified	*In vitro* study	Evaluation of melanin and tyrosinase activity stimulation and assessment of antioxidant activity	Co-loaded ultradeformable liposomes	Not applicable	[21]
5	Antiaging	Not specified	*In vitro* study	Rosmarinic acid-loaded liposomes. Evaluation of transdermal permeation, antioxidant activity and inhibition of collagenase and elastase enzymes	Ethosomes and liposomes	Not specified	[22]
		Not specified	Not specified	Vitamin D3 in liposomes	Liposomal formulation		[23]

dermal bioavailability of the drug. In dermal drug delivery systems, the drug's physicochemical properties play an important role in skin permeation. The smaller the size of NCs, the greater the drug delivery through the skin barriers [18]. Additionally, NCs are used in dermal medication delivery to formulate poorly soluble antioxidants, including hesperidin, apigenin, and rutin, as nanosuspensions for skin-protective and anti-ageing products [26]. The first product with rutin was launched in March 2007: Juvedical products, i.e., age-decoder face fluid and face cream. Thereafter, Platinum Rare products were also available in 2009 and contained hesperidin [26].

Nanoemulsions

The emulsions of uniform and extremely small droplets with a composite size of 20-200 nm are known as nanoemulsions. In contrast, classical emulsions are characterised by coarse droplet sizes up to 1 µm [27]. Nanoemulsions are kinetically stable dispersions of two immiscible liquids, water and oil, that form a single phase with the addition of an emulsifier [28]. This leads to higher stability and skin absorption, better retention time, and 10-15% less emulsifying agent required [28, 29]. As nanoemulsions have a smaller droplet size, i.e, 1-100 nm, they offer better skin permeation and are more effective in delivering through the skin barrier [29]. In nano size, they further reduce the gravity force and prevent flocculation and coalescence [30]. Furthermore, these emulsions can penetrate tough skin with strong penetration, eliminating the need for an extra penetration booster [28]. Hence, they are widely useful in lotion, cream, and moisturiser applications. Besides skin products, cationic nanoemulsion shampoo also significantly improves dry hair problems by making hair shinier and less greasy [28].

Dendrimers

Dendrimers are three-dimensional nanomolecules that are unimolecular and highly branched from their central multimeric core [31]. Dendrimers have a very small diameter, ranging from 2 nm to 20 nm [32]. They are further categorised into generations G0.5, G1, G2, G3, G4, and G5 based on the total number of branches sprouting from their core [33-34]. Thus, various dendrimers are available for manufacturing cosmetic products for better solubility, polyvalence, and lower cytotoxicity [32]. However, their intrinsic viscosity is most important for cosmetic formulations such as shampoos, hair-styling gels, and sunscreen [35]. Cosmetic companies such as L'Oréal and Revlon have widely introduced dendrimers into their skin and hair products to improve product intensity [31].

Solid lipid nanoparticles (SLN) & nanostructured lipid carriers (NLC)

SLN and NLC are lipoidal centres enclosed within shells, which are alternative carrier systems to liposomes, emulsions, and polymeric nanoparticles [10, 36]. SLNs have an average particle size of 50-500 nm, whereas NLCs range from 10 to 500 nm and have the advantage of improving drug-loading capacity; however, they have a shorter shelf life and reduced drug encapsulation [37]. Both transporter systems enhance skin infiltration due to their solid-state lipid matrix and small size in the nano range, thus improving the product's biocompatibility and safety as a carrier [37]. Moreover, SLNs provide better stability and sunscreen effects, whereas NLCs provide better encapsulation and stability, making them suitable for anti-ageing and moisturising products. Chanel Allure and Dr. Rimpler Ctanova are examples of commercially available SLN and NLC products in the market [14, 38, 39].

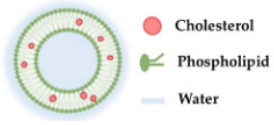
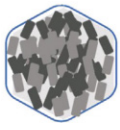
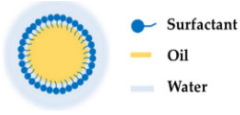
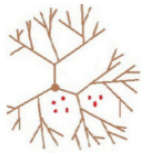
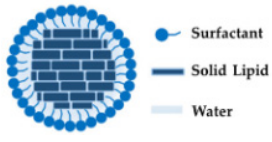
Nanosilver & nanogold

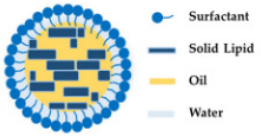
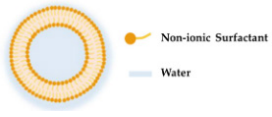
Because of their antibacterial properties, mineral nanoparticles - such as nanosilver and nanogold - are frequently utilized in cosmetic formulations. Different cosmetic products can benefit from various metallic nanoparticles. Because of their antibacterial properties, which cause silver ions to attach to respiratory chains and alter the permeability of bacterial cell walls to increase the production of reactive oxygen species (ROS) and render the environment unsuitable for bacterial growth, silver nanoparticles, which range in size from 1 to 100 nm, are frequently used in cosmetics [38]. Lancome and Natural Korea are examples of manufacturer formulating their whitening and anti-wrinkle products through nanosilver as a carrier system [39]. On the other hand, Egyptians have widely used gold nanoparticles in beauty and care products for many years because they believed gold can maintain skin complexity and flexibility. They range from 5 nm to 400 nm and come in various colours, from red to purple, depending on their size, shape, and total surface area [40-41]. Manufacturers formulating anti-ageing and anti-wrinkle products with gold nanoparticles as carriers include Chantecaille, LR Zeitgard, and Orogold [10].

Nanocapsules and niosomes

They have a size range of 100-500 nm and consist of a solid and liquid core that is composed of active pharmaceutical ingredients (API) that are embedded in the natural/synthetic polymer membrane. Examples of nanocapsules include anti-wrinkle cream, Primordiale Intense (L'Oréal), Hair Care and Nano Collagen (Braziliss) [34, 36, 42-44]. Niosomes range from 100 nm to 2 µm and consist of vesicles with a phospholipid bilayer formed from non-ionic surfactants with hydrophilic & lipophilic terminals. Formed in conjugate with PEG & cholesterol. Examples include the anti-ageing cream Lancome® (L'Oréal, Paris) [42-43, 45-46]. The particular types of nanocosmetic systems are summarized in the tab. 2.

Tab. 2. Several types of commercial nanocosmetic systems with their benefits and limitations. **Source:** [6, 15, 17, 21, 36, 41-43, 46-52].

Nanocosmetic system	Specialty	Benefit	Limitation	Commercial Product	Reference
Liposomes  • 20 nm – 2 µm • Vesicular structure with aqueous core surrounded by phospholipids • Composed of cholesterol	Solubilize hydrophobic and hydrophilic substances	Enhance skin penetration Biodegradable Biocompatible Amphiphilic	Reduce reproducibility Decrease medication stacking & physicochemical flimsiness Immune response being triggered	Antiwrinkle Capture Totale (Dior) Moisturizer Dermosome (Microfluidics)	[21, 41]
Nanocrystals  • 10-400 nm • A cluster with a combination of atoms aggregates (Chavda)	Load 100% drug	Improve particle distribution, adhesiveness, dissolution rate, drug solubility Enhance the penetration of poorly water-soluble drugs through the skin	Unsuitable for aqueous API Stable only to a specific extent Aggregation may occur	Toothpaste Nano Whitening Tooth paste (Whitewash) Moisturizer Nano-In Hand & Nail Moisturizing Serum & Foot Moisturizing Serum (Nano-Infinity Nanotech)	[21]
Nanoemulsions  • 50-200 nm • Nanodroplets made up of oil, surfactant, and water cosurfactant	No risk of inherent creaming, coalescence, sedimentation, or flocculation problems	Stable Amphiphilic Transparent	Sensitive to acidic pH Reduction action duration Difficult to prepare	Moisturizer Nano Emulsion Multi-Peptide Moisturizer (Hanacure) Skin creams, Body lotions & Gels Cosmeceutical Vitamin A, D, E & K (Vitalipid)	[15, 36, 41]
Dendrimers  • 2-200 nm • 3D synthetic polymers • Globular, micellar, monodisperse & radially symmetric	Lengthen shelf life of cosmetic products	Improve hydrophobic drug solubility Formulate controlled-release drug Maintain drug stability	Unsuitable for water-loving drugs Risk of cellular toxicity Increase cost of manufacture	Sunscreen Topical Resveratrol Formulation	[17, 41]
Solid lipid nanoparticles  • 50-500 nm • Lipoic core enclosed by a single lipid layer • Stabilized by surfactants/ polymers	Improved drug-loading matrix Crystallinity	Suitable for mass-scale production Better bioavailability & biodegradability Lengthen action duration	Shorter shelf life Reduce drug encapsulation	Perfume & cream Chanel Allure	[15, 48, 49]

Nanocosmetic system	Specialty	Benefit	Limitation	Commercial Product	Reference
Nanostructured Lipid Carriers  • 10-500 nm	Matrix composed of both aqueous & lipid phases	Lengthen shelf duration Suitable for large-scale manufacture	Shorten action duration More drug encapsulated	Face spa cream Dr. Rimpler (Cutanova)	[15, 42]
Nanosilver  • 1-100 nm	Antibacterial property	Excellent biocompatibility	Off-target effect risk Tuning of particle size due to size-dependent cytotoxicity	Whitening & antiwrinkle Lancome Natural Korea	[6, 47, 50]
Nanogold  • 5-400 nm	Antibacterial property	Drug delivery platforms Excellent biocompatibility	Contamination during synthesis leading to toxicity problems	Anti-ageing & anti-wrinkle Chantecaille LR Zeitgard Orogold	[6, 51, 47]
Nanocapsules  • 100-500 nm • Composed of solid & liquid core • APIs enclosed within natural/synthetic polymeric membrane	Produce micelles Amphiphilic	Provide protection to APIs Unwanted odours mask No incompatibility problems Formulate sustained-release products	After formulation, additional purification is needed	Anti-wrinkle cream Primordiale Intense (L'Oréal) Hair Care Nano Collagen (Braziliss)	[15, 36, 52]
Niosomes  • 100 nm - 2 µm • Vesicles with phospholipid bilayer • Produced from non-ionic surfactants with hydrophilic & lipophilic terminals • Conjugate with PEG & cholesterol	Simple surface development and modification (due to functional groups present on the hydrophilic head)	Better drug efficiency Improve bioavailability by improving the drug penetration Increase drug stability	Higher production cost & duration Drug leakage Physical & chemical instability	Anti-aging cream Lancome® (L'Oréal, Paris)	[41, 43, 46]

KEY DRIVERS OF NANOTECHNOLOGY-BASED COSMETICS

Nanotechnology is viewed as the most important technology of the 21st century and is expected to have a significantly positive impact on the cosmetics sector [10]. The role of cosmetics is rapidly changing due to globalization, and using them is now more important than ever for one's well-being. The development of novel and redesigned goods and technologies is predicted to contribute significantly to the global beauty and personal care market's expected $716 billion valuation by 2025 [4]. The development of nanotechnology-based cosmetics is primarily driven by rising demand for innovative, individualised products based on increasingly detailed scientific knowledge [4]. The introduction of nanotechnology has driven a major advance in high-quality products, as nanoparticles enhance cosmetic performance in several ways,

acting as both transporters and active components. For anti-ageing creams, moisturising creams, hair-repair shampoos, serums, and conditioners, nanomaterials are frequently used [53]. Beyond the growing demand for high-quality products, a variety of socio-psychological factors may also affect how society responds to advances in nanotechnology-based cosmetics [13]. This is because nanotechnology has often faced general scepticism due to questions about the actual advantages of nanoparticles in product performance, as well as concerns about possible long-term toxicity [54].

SAFETY CONCERNS OF NANOCOSMETICS

Nanocarriers are widely used in many fields, including cosmetics, because of their exceptional properties. The unique characteristics of nano-carriers serve as a double-edged sword [55]. The rare properties of given nano-carriers provide enticing advantages or desired functions (UVB and UVA filters in sunscreens). At the same time, they may also pose potential negative effects (toxicity) on consumers [13]. This raises safety concerns and health risks, especially because particles are reduced to nano sizes, and their properties can change quickly. It is widely recommended that nanosized titanium dioxide (TDN) may be more toxic than microsized titanium dioxide (TDM) [36]. Unfortunately, safety evaluation has not kept pace with the rise of new nanoparticles, as TDM is widely used in a variety of products, including industrial materials and cosmetics. This article aimed to assess the genotoxic potential of TDM (anatase and rutile) on bottlenose dolphin leukocytes. Blood samples were obtained from four male and one female specimens reared at the Adriatic SeaWorld "Oltremare" (Riccione, Italy) [33]. According to Jinyuan et al., inhalation of micro-sized TDM causes inflammation at a dose of 10mg/m^3 for 13 weeks in three *in vivo* animal experiments [33]. Nano cosmeceuticals are not subject to clinical trials, raising concerns about their potential toxicity [10]. Hence, the FDA Nanotechnology Task Force provided recommendations for regulatory consideration regarding safety. With an emphasis on the safety and non-adulteration of cosmetic products, the need for nanomaterial safety came to the fore in the USA [35, 48].

Potential toxicity of nanocarriers used in cosmetics

Nanoparticle toxicity is strongly influenced by several parameters that can be adjusted during manufacturing, including surface characteristics, coating, size, shape, and aggregation capability. Poorly soluble nanoparticles have been shown to be carcinogenic and can increase toxicity [10]. Poorly soluble particles, for example, titanium dioxide and carbon black, are linked to carcinogenicity through inhalation exposure. Chronic inflammation and oxidative stress in the lungs, which cause DNA damage and tumour formation, are further causes for concern. According to the International Agency for Research on Cancer (IARC), a few poorly soluble particles are also classified as carcinogenic to humans based on animal studies [49]. Gold nanoparticles are generally considered safe, but they can show cytotoxicity depending on several factors, including particle size, shape, and the type of cells they interact with. For example, smaller nanoparticles are more easily taken up, which can lead to cytotoxic effects [56]. The toxicity of nanoparticles absorbed through the skin is also influenced by their chemical composition [10]. Because of their antibacterial properties, silver nanoparticles are frequently used in cosmetic products. However, the exact nanosilver concentration that kills bacteria can also kill body cells, including keratinocytes and fibroblasts [57]. Studies have shown that sunscreen lotions containing zinc oxide and titanium dioxide nanoparticles with diameters ranging from 10 to 200 nm can penetrate healthy skin and cause unintentional biological harm [36]. A recent study showed that titanium dioxide nanoparticles can cause Sertoli cell autophagy and necrosis, which can detrimentally affect spermatogenic cells and testicular morphology in zebrafish [36].

Safety concern and toxicity testing: Potential toxicity of nanomaterials used in cosmetics

Toxicity testing is often conducted based on the toxicological profile and exposure route. The toxicokinetics of nanoparticles are influenced by both exposure duration and physicochemical properties. This article discusses a few toxicity tests. Genotoxicity results from damage to a cell's genetic structure. The cytotoxic and genotoxic tests performed on nanoparticles used in cosmetics are displayed in the tab. 3 below.

CLINICAL STUDIES ON NANOCOSMETICS

Clinical studies are essential for nanocosmetics to ensure product safety and efficacy before releasing them to the market for consumer use. Nanocosmetics are available in different nanocarriers to improve stability, penetration, and effectiveness.

Clinical studies on liposomes

Liposomes, in their nano size, are widely used in the nanocosmetic industry because of their biocompatibility, sustained-release ability, biodegradability, and enhanced therapeutic effectiveness [59]. According to a clinical investigation, liposomes containing the antioxidant ursolic acid can increase collagen and ceramide levels in cultured healthy human epidermal keratinocytes and fibroblasts, respectively. The outcome demonstrates that the ceramide content rises by over 11. Therefore, liposomes appear to influence keratinocyte differentiation and dermal collagen synthesis in a manner similar to retinoids. In addition, Takashashi et al. showed that aloe gel extract encapsulated in liposomes using the Bangham method shows a considerable

Tab. 3. Summary of genotoxic and cytotoxic tests conducted on cosmetic nanomaterials. **Source:** [41-45, 52, 58].

Ingredient	Activity	Nanotoxicity study	Proposed toxicity mechanism	Reference
Carbon black	Colorant	MTT assay - THP-1 cells (cytotoxic)	Impairment of the phagocytic capacity of monocytes	[52]
		MTT reduction assay - human dermal fibroblast (cytotoxic)	Breached plasma membrane integrity	[41]
Titanium dioxide	UV filter	*In vivo* comet assay - bone marrow and liver (genotoxic)	Oxidative stress and agglomeration inside the cell	[42]
		In vitro comet assay -bottlenose dolphin leukocytes (genotoxic)	DNA damage	[43]
		Human lymphocytes	DNA damage	[44]
Zinc oxide	UV filter	Comet assay - L02 and HEK293 cells (genotoxic)	DNA damage	[58]
		MTT assay - cytotoxic to human dermal fibroblast cells	Upregulation of p53and phospho-p38proteins	[45]

increase in proliferation rate compared with the control trial. Collagen synthesis was increased by 23% [46]. Hence, antioxidants encapsulated within liposomes are said to increase their efficiency in decreasing fine lines on the face. Liposomes are also incorporated into anti-wrinkle products. For instance, 5-aminolevulinic acid helps reduce periorbital and nasolabial wrinkles in photoaging [41].

Clinical studies on nanoemulsions

Nanoemulsions are widely used in nanocosmetics and incorporate moisturizing agents such as rice bran oil. It is also commonly used for sun screening, anti-ageing, or treating skin diseases [42]. A study was conducted on 17 Caucasian women with healthy skin (20-29 years old), 5 women with atopic dermatitis (21-30 years old), 1 man and 3 women with psoriasis with no skin lesions on the forearm region [42]. In a moisturizing study, rice bran oil nanoemulsion showed a remarkable increase of 38% moisturizing variance in healthy skin participants and a 30% increment in psoriasis or atopic dermatitis volunteers [42]. This happens as droplets from the nanoemulsion adhere to the skin, forming a dense film that prevents water from evaporating from the skin [43]. According to Clinical Trials Library by the US National Library of Medicine, a study on proof-of-concept regarding topical 3%-Diclofenac-Nano-Emulsion Cream for osteoarthritis knee pain was conducted in 2007 [58]. However, the results have not yet been reported. In short, nanoemulsions as a carrier system for drugs and cosmetics are often under investigation in clinical trials.

Clinical studies on solid lipid nanoparticles

Solid lipid nanoparticles (SLN) are an active nanocarrier system for sunscreen agents, such as oxybenzone. It is desirable as it reduces the release rate of oxybenzone through the SC by 30-60% [45]. This is due to the non-linear diffusion coefficient and SLN drug-enriched core formation [45]. Nonetheless, this nanocarrier is useful because it acts as a physical sunscreen and provides sustained release of sunscreen molecules for prolonged effectiveness [45]. A clinical study compared oxybenzone in an SLN formulation with conventional oil-in-water (o/w) emulsion. 24 healthy Caucasian volunteers between the ages of 23 to 29 participated in this study [45]. The penetration rate of oxybenzone into the SC was assessed by the tape stripping method. 5% oxybenzone SLN obtained a lower penetration rate of 4.40+/-0.14% compared to emulsion with 5.48+/-0.19% penetration rate [45]. Furthermore, as the SLN formulation formed a dense film on SC, sunscreen molecules adhered within the film, prolonging the sun-screening effects [60].

Clinical studies on nanostructured lipid carriers

Nanostructured lipid carriers (NLC) can encapsulate argan oil as a liquid lipid to enhance skin hydration, as it provides a synergistic effect on skin hydration. This is due to the lipid composition of NLC and its occlusive effect characteristics [61]. A study was conducted with 10 Caucasians aged 21 to 30 with healthy skin for a month. This controlled, single-blind clinical trial divided volunteers into two groups: hydrogel-NLC formulation and hydrogel formulation, applied once daily for a month [61]. No formulation was applied to the forearm, serving as the control. After a month, the participants receiving the hydrogel-NLC formulation showed a marked increase in skin hydration ($P<0.05$) [61]. Consequently, argan oil formulated in the NLC carrier system is said to improve skin hydration due to its synergistic hydrating effect.

LEADING BRANDS OF NANO-COSMETICS

Many businesses have begun including nanocarriers in their product formulations because nanotechnology is increasingly

used in cosmetics. The first liposomal cosmetic product to be sold was Christian Dior's Capture anti-ageing cream in 1986. It was made of natural components to enhance skin quality and had particle sizes ranging from nano to micro. Many other products quickly followed. Moreover, the first liposomal face cream for men and the first emulsion with liposome inclusion, by the name Myosphere, were two skin care products that were introduced by Laboratories RoC in 1987 and 1990. This emulsion, with liposomes ranging from 15nm to microns, was designed for male skin care to provide proper nutrition and enhance the penetration efficiency of peptides, antioxidants, and vitamins. Additionally, the first liposomal formulation for body care was developed in 1987, with phosphatidylcholine being one of the key constituents of liposomes, which has been utilised in skin care products such as moisturizer, lotions, creams, and hair care products due to its softening and its ability to maintain the shine and silkiness of hair [8]. Furthermore, various skin protection products such as sunscreens and self-tanning creams were developed after 1988 [7]. Firstly, the liposome can be found as one of the most used nanomaterials in moisturizer preparation due to its prolonged humectant properties. Brands such as Decorté, Lancôme, and Estée Lauder have been found to formulate their products with nanotechnology [34]. Decorte launched Advanced Repair serum, which included liposomes sized 100-200 nm to enhance penetration and provide skin glow. Furthermore, sunscreen is a cosmetic product that has experienced extensive application of nanotechnology. Brands such as Lancôme offer nanotechnology sunscreens containing nano filters with niacinamide, vitamin C, and hyaluronic acid for anti-ageing. L'Oréal is the most well-known brand in nanotechnology anti-wrinkle cosmetics, and it sells an anti-wrinkle cream called Ravtalift that incorporates nanosomes containing proretinol A (a modified form of vitamin A designed to provide nutrients to cells) [62].

CONCLUSIONS

Nanotechnology is widely used in cosmetics and has gained recognition for its promising effects on the skin. In this review, the structure and characterization of nano-cosmetics and how they permeate through the skin or hair barrier have been included. Moreover, this article also focused on incorporating nanotechnology to overcome skin-barrier limitations, enhance solubility, improve stability, and develop more efficient products. Although nanomaterials have shown positive recognition and value in various fields, the biggest worry, which is safety issues, still remains whether nano-sized particles in cosmetics will enter the bloodstream during usage. Moreover, nanoparticle toxicity is strongly influenced by a wide range of parameters, including surface characteristics, coating, structure, size, and aggregation capacity, which require further assessment or testing during development. Additionally, this review includes several clinical studies on the safety and efficacy of certain types of nano-cosmetics. Thus, these findings provide an overview of liposomes in cosmetics and their technology, which offers strong potential for both research platforms and the marketplace.

SUMMARY

Nanocosmetics enhance penetration through skin and hair barriers. The scope of article is to emphasizes the emergence of nano-cosmetics, their advantages over conventional cosmetics, the skin barriers to cosmetics, and their clinical implications, along with marketed products. This review aims to provide comprehensive details on nano-cosmetics, their efficacy, and expected toxicity. This review also highlights the translational efficacy of nano-cosmetics.

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Competing interests

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Authors contributions

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Use of AI tools

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