

Herbal Nano Formulations for Topical Drug Delivery: Prospective for Multiple Skin Disorders

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ABSTRACT

Dermatological conditions exert their influence across the globe, encompassing a broad spectrum of maladies ranging from commonplace afflictions such as acne and eczema to more formidable challenges like psoriasis and cutaneous malignancies. The realm of topical drug delivery stands as a pivotal modality in the domain of dermatology, proffering precise and minimally invasive therapeutic avenues. In recent times, the fusion of herbal curatives with the marvels of nanotechnology has surfaced as a pioneering strategy.

This comprehensive review undertakes an exploration of the amalgamation of herbal constituents within nano-sized drug carriers, catering to the domain of topical applications, with a particular emphasis on their potential to address a myriad of dermatological conditions. The outset of this review is dedicated to the elucidation of the meticulous criteria governing the selection of herbal components and the underpinning rationale behind their integration into nanoscale formulations, thereby spotlighting the rich heritage of botanical remedies intrinsic to traditional medical practices.

Subsequently, meticulous scrutiny of nanotechnology's role in the domain of cutaneous drug conveyance ensues, elucidating diverse nanoparticle typologies and their respective mechanisms of therapeutic action. The crux of this review centers upon the manifold approaches of herbal nanoformulations, encompassing lipid-based matrices, polymer-driven carriers, liposomal constructs, micellar entities, nanoemulsions, solid lipid nanoparticles, dendritic platforms, and nanogels. For each of these approaches, illustrative case studies are presented, thereby affording perspicacity to their bespoke utility in the management of diverse dermatological conditions.

In the ensuing discourse, the potential of herbal nanoformulations in the amelioration of acne, mitigation of psoriatic manifestations, alleviation of eczematous distress, acceleration of wound healing, attenuation of scar formation, and prophylaxis against cutaneous neoplasia is subjected to meticulous examination. The purview extends to the discerning analysis of clinical trials and the practice informed by empirical evidence, thereby shedding illuminative insight into the safety and efficacy profiles of these innovative formulations.

Concomitantly, the challenges entailing regulatory adherence, standardization, and the enforcement of rigorous quality control are thoughtfully addressed, with a subsequent contemplation of the trajectories shaping the future of this burgeoning discipline. In summation, this review underscores the intrinsic value of interdisciplinary synergism and underscores the compelling imperative for relentless research efforts that propel herbal nanoformulations to the vanguard of mainstream dermatological therapeutics. In doing so, a new epoch in the management of cutaneous disorders is heralded, one that promises safe, efficacious, and patient-centric interventions, thus ushering in a transformative era in the domain of dermatological care.

Keywords: Herbal, Nano formulations, Topical drug delivery, Skin disorders, Traditional medicines.

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INTRODUCTION

Skin disorders are a pervasive and diverse group of ailments affecting millions of individuals globally. These conditions encompass a wide range of issues, from common, everyday concerns such as acne and eczema to more complex and potentially life-threatening disorders like psoriasis and skin cancer. The World Health Organization (WHO) estimates that nearly one billion people are affected by skin disorders, underscoring the magnitude of this public health challenge.¹

In the realm of dermatology, the choice of modality for drug delivery stands as a matter of paramount significance. Topical drug delivery, the art of administering therapeutic agents directly onto the skin's epidermal canvas, constitutes a foundational tenet of dermatological praxis. This methodology unfurls a tapestry of distinct advantages. Foremost, it bequeaths the hallowed gift of precision, facilitating the pinpointed dispatch of medicinal payloads to the very site of affliction, thus mitigating the specter of systemic exposure and its attendant pantheon of side effects. Secondly, it embraces the ethos of minimally invasive intervention, a quality that resonates harmoniously with the sensibilities of the patient cohort. Finally, it bestrides the dichotomous realms of cosmetic and therapeutic regimens with finesse, thereby fostering the virtue of patient compliance.²⁻⁴

Recent annals of dermatology have borne witness to a discernible transmutation, one underscored by an inexorable shift toward herbal therapeutics and the bosom of nature's bounty. This evolution is impelled by the yearning for treatments imbued with safety and sustainability, buttressed by the burgeoning corpus of evidence vouchsafing the efficacy of herbal constituents in the annals of cutaneous care. The rubric of herbal remedies finds its roots intertwined with the rich tapestry of traditional medical systems across the globe, its verdant tendrils extending into the annals of modern dermatological practice.

In this milieu, the emergence of herbal nanoformulations stands forth as a veritable seismic shift. These pioneering constructs harness the intricate principles of nanotechnology to elevate the transport of herbal constituents unto the canvas of the skin. Nanotechnology, an artifice that involves the meticulous manipulation of materials at the nanoscale (typically denominated in less than 100 nm), bestows unto us nanoparticles replete with singular properties. These diminutive entities serve as custodians, enclosing and shielding the herbal moieties, thus ameliorating their structural integrity and bioavailability.

The amalgamation of herbal elements within the crucible of nano-sized drug conveyance offers a tapestry of benefits. It vouchsafes meticulous control over the temporal release of the pharmacologically active moieties, ensconcing the therapeutic impact within a continuum. Furthermore, it augments the percutaneous migration of herbal agents, ushering them into the innermost sanctums of the dermal milieu, where their complete therapeutic mettle may be brought to bear. This avant-garde stratagem harmoniously interlaces the venerable

advantages of herbal panaceas with the cutting-edge tapestry of nanotechnology.

The cardinal objective herein propounded by this treatise is to furnish a comprehensive panorama of the utilization of herbal nanoformulations as regards the realm of topical drug delivery in the context of multifarious cutaneous maladies. To realize this ambition, the present work shall:

- Examine the selection criteria for herbal ingredients: We shall traverse the realm of rationale, revealing the hallowed choices enshrined in specific botanical selections and phytoconstituents, drawing sustenance from the profound legacy of botanical remedies within the sphere of traditional healing arts.
- Investigate nanotechnology in dermatological drug delivery: This juncture shall embark upon an in-depth examination of the myriad avatars of nanoparticles at play in the realm of cutaneous drug bestowal, elucidating the mechanics underpinning their therapeutic orchestration and their indubitable blessings in the realm of dermatology.
- Explore diverse herbal nanoformulation approaches: This exposition shall usher readers through an exhaustive journey spanning lipid-based matrices, carriers conceived in the crucible of polymers, liposomal constructs, micellar assemblies, nanoemulsions, solid lipid nanoparticles, dendritic architectures, and nanogel matrices. Each facet shall be illuminated with illustrative case studies, casting light on their bespoke utilization in the treatment of sundry dermatological vicissitudes.
- Evaluate applications in skin disorders: The pivotal core of this discourse shall be the scrupulous examination of the potentialities offered by herbal nanoformulations in the amelioration of afflictions such as acne, the palliation of psoriatic manifestations, the assuagement of eczematous tribulations, the expeditious culmination of wound repair, the attenuation of scar genesis, and the prophylaxis against the insidious encroachments of cutaneous neoplasia.
- Challenges and future directions: We shall address the considerations germane to regulatory compliance, the impositions of standards and the onerous task of ensuring the integrity of quality. In tandem, we shall cast our gaze toward the morrow, speculating upon the nascent

Herbal Components in Topical Pharmaceutical Delivery

Overview of herbal remedies in traditional medicinal practices

The utilization of herbal remedies has constituted an intrinsic facet of healthcare systems across the annals of history, spanning civilizations and epochs. The venerable practice of employing plants and their derivatives for therapeutic ends traces its origins to ancient societies, where indigenous wisdom and empirical observations served as the guiding beacons in the evolution of traditional healing methodologies. These enduring traditions, hallowed by time, have transcended generations and interwoven themselves into the fabric of diverse cultures spanning continents.

Traditional systems of healing, such as Ayurveda in the Indian subcontinent, traditional Chinese medicine (TCM) in the vast expanse of China, and the herbal medicine practices of native American cultures, have long leaned upon a vast repository of herbs and botanical specimens to alleviate a wide spectrum of afflictions. These venerable traditions have intuitively recognized the inherent curative attributes of myriad flora, harnessing their therapeutic potential to assuage an extensive gamut of health maladies, including those afflicting the integumentary system.⁵

The paradigm shift towards evidence-based herbal interventions

In the latter part of the twentieth century and the dawn of the 21st, a discernible transformation has pervaded the realm of healthcare- an epochal shift towards the ascendancy of evidence-based medicine. This transformation, emblematic of a harmonious convergence of traditional wisdom with the rigor of contemporary scientific methodology, has culminated in the gestation of an imposing edifice of research concerning the effectiveness and safety of herbal constituents.

Empirical investigations have yielded the revelation of bioactive compounds nestled within herbs, bearing the imprimatur of medicinal efficacy. Among these compounds, one encounters polyphenols, alkaloids, terpenoids, and flavonoids, to name but a few. Researchers have undertaken a meticulous series of pharmacological inquiries to elucidate the mechanisms underpinning the actions of these bioactive agents, thereby illuminating their potential in the amelioration of diverse health conditions, including those that afflict the skin.⁶

Identification and selection of herbal ingredients for nanoformulations

The discerning selection of herbal ingredients for nanoformulations represents a pivotal stride in harnessing the therapeutic dividend of botanical medicine within the realm of dermatological interventions. This discernment entails a fastidious process, one that involves the scrutiny of herbs and botanical entities endowed with established medicinal attributes and harmonious coalescence with the principles of nanoscience.

Researchers undertake a judicious evaluation of the safety and efficacy contours of herbal ingredients, drawing upon a confluence of traditional wisdom, ethnopharmacological inquiries, and empirical scientific inquiry. The crucible of candidate herbs must exhibit manifest utility in mitigating precise dermatological conditions or associated symptomatology, encompassing domains such as inflammation, oxidative stress, or microbial pathogenicity. Common herbal ingredients used in nanoformulations are mentioned in Table 1.

Once potential herbal contenders are identified, they traverse the crucible of exacting scrutiny, a crucible designed to assure their felicitous compatibility with the precincts of nanoscale drug carriers. These carriers may encompass the pantheon of lipids, polymers, liposomal constructs, and other nanoparticulate substrates. The selection calculus factors in considerations such as solubility, stability, and the competency to adeptly enshroud herbal moieties within their confines.⁷

The merits of herbal integration in topical pharmaceutical delivery

The incorporation of herbal components into the purview of topical drug conveyance unfurls a cavalcade of advantages. Preeminent among these merits is the historical perception of herbs as inherently safe and amenable to topical application, thereby tempering the specter of adverse reactions that often accompany the administration of synthetic pharmacotherapeutics. This commendable safety proclivity endows herbal-centric formulations with particular suitability for protracted usage in the context of chronic dermatological maladies.

Herbs, additionally, bear the mantle of multifaceted therapeutic prowess. A multitude of herbal constituents stand adorned with anti-inflammatory, antimicrobial, antioxidant, and wound-healing attributes. These multifarious virtues assume heightened relevance in the milieu of dermatological afflictions, where a composite therapeutic tapestry often holds sway as the most efficacious recourse.

Moreover, the harnessing of herbal constituents finds consonance with the burgeoning preference for natural and ecologically sustainable skincare solutions. In a contemporary milieu increasingly attuned to the allure of eco-friendliness and eschewing synthetic chemical agents, herbal-infused nanoformulations emerge as a verdant and environmentally harmonious avenue to address the panorama of dermatological exigencies.⁸

Nanotechnology in Dermatological Drug Delivery

Introduction to nanotechnology and its pertinence in dermatology

Nanotechnology, the art of manipulating materials and structures at the minuscule nanoscale dimension (typically under 100 nm), has burgeoned as a transformative juggernaut across diverse scientific domains, including the hallowed precincts of medicine and dermatology. Its reverberations within the sphere of dermatology derive from its capacity to orchestrate a paradigmatic shift in pharmaceutical delivery, endowing precision to the administration of therapeutic agents while augmenting their therapeutic efficacy.

In the realm of dermatology, the skin assumes a dual role as both an obstructive barrier and a conduit for the bequest of pharmaceutical agents. Conventional topical formulations often grapple with the intricate stratagems of traversing the multiple strata of the cutaneous mantle to attain their intended destinations. Nanotechnology emerges as the intrepid answer to these challenges, as it engineers nanoparticles vested with the capability to encapsulate, shield, and precisely administer therapeutic compounds to designated skin strata. In this orchestration, their modus operandi involves elevating the bioavailability and therapeutic effectiveness of these agents.⁹

Different types of nanoparticles used in topical drug delivery

A phalanx of nanoparticle variants has been requisitioned for the noble endeavor of topical pharmaceutical bestowal in the precincts of dermatology. A comparison of different types of nanoparticles in topical drug delivery is given in Table 2.

Table 1: Examples of herbal ingredients used in nanoformulations

<i>Herbal ingredient</i>	<i>Traditional use</i>	<i>Active compounds</i>	<i>Nanoformulation benefits</i>
Aloe vera	Used for wound healing and skin irritations.	Contains polysaccharides and phenolic compounds.	Provides enhanced skin hydration and soothing properties.
Green tea extract	Traditionally used as an antioxidant and anti-inflammatory agent.	Active compounds include epigallocatechin gallate (EGCG) and catechins.	Offers protection against UV-induced damage and reduces oxidative stress in the skin.
Chamomile	Known for its anti-inflammatory and skin-calming properties.	Contains active compounds like bisabolol and apigenin.	Provides a calming effect on irritated skin and reduces redness and itching.
Turmeric (<i>curcumin</i>)	Used for its anti-inflammatory and wound-healing properties.	Contains curcumin as the active compound.	Reduces inflammation and promotes tissue repair.
Lavender oil	Traditionally used as a relaxant and for skin soothing.	Contains active compounds like linalool and linalyl acetate.	Has a soothing effect on the skin and may have antimicrobial properties.
Calendula	Used for wound healing and skin irritations.	Contains flavonoids and triterpenoids.	Promotes wound healing and reduces inflammation.
Neem oil	Traditionally known for its antimicrobial properties.	Contains active compounds such as azadirachtin and nimbin.	Controls microbial infections and soothes the skin.
Tea tree oil	Used as an antimicrobial agent and for acne treatment.	Active compounds include terpinen-4-ol and alpha-terpineol.	Effectively combats acne-causing bacteria and reduces acne lesions.
Grapeseed extract	Known for its antioxidant properties and skin protection.	Contains proanthocyanidins and resveratrol.	Provides protection against UV radiation and reduces oxidative stress.
Licorice root extract	Traditionally used for its anti-inflammatory and skin-calming effects.	Contains active compounds like glycyrrhizin and glabridin.	Reduces redness and irritation in various skin disorders.

- *Lipid-based nanoparticles*

These enigmatic entities, including liposomes and nanostructured lipid carriers (NLCs), exhibit lipidic constituents that mimic the natural lipidic matrix of the skin. They adroitly encapsulate a gamut of both hydrophilic and lipophilic drugs, fostering facile penetration into the lipid-rich recesses of the cutaneous domain.

- *Polymeric nanoparticles*

Polymeric nanoparticulate assemblies, exemplified by polymeric micelles and nanoparticles, confer controlled drug liberation and protracted therapeutic efficacies. Polymers such as poly(lactic-co-glycolic acid) (PLGA) reign supreme due to their inherent biocompatibility.

- *Nanoemulsions*

These colloidal dispersions of oil and water, rendered stable through the agency of surfactants, cradle the capacity to entrap lipophilic therapeutic agents and enhance drug solubility, thereby facilitating efficient transcutaneous permeation.

- *Solid lipid nanoparticles*

SLNs comprise lipids in a solid phase at ambient temperatures, culminating in elevated drug-loading capacity, structural stability, and the orchestration of controlled drug liberation—attributes that enshroud them with immense utility as carriers for topical pharmaceutical delivery.

- *Dendrimers*

These intricately branched macromolecular structures envelop drugs within their nano-sized architectures. They proffer meticulous control over the liberation of pharmacological moieties while enhancing drug penetration through the cutaneous matrix.

- *Nanogels*

Nanogels constitute three-dimensional enmeshments of nanoscale hydrogel particles, providing an adept platform for encapsulating both hydrophilic and lipophilic therapeutic agents, thus facilitating controlled drug release.¹⁰

- *Mechanisms of action and benefits of nanosized drug carriers*

Nanosized pharmaceutical carriers manifest a litany of operative modalities and merits within the domain of dermatological pharmaceutical delivery:

- *Augmented cutaneous penetration*

Nanoparticles navigate the formidable stratum corneum, the epidermal bastion, and infiltrate the deeper recesses of the dermis where their pharmacological efficacy attains fruition. This heightened penetration is an attribute ascribed to their diminutive dimensions and surface functionalities.

- *Guardianship of pharmacologically active moieties*

Nanoparticles undertake the onus of preserving the structural integrity and bioavailability of sensitive therapeutic agents, shielding them from the relentless ravages of degradation, including the baleful influences of oxidation and photodegradation.

- *Sustained and regimented liberation*

Nanoparticles function as purveyors of regulated drug release over extended time frames, upholding therapeutic concentrations and obviating the exigency for frequent applications.

- *Targeted dispensation*

The surface customization of nanoparticles accords them the prowess to actively target specific cutaneous cells or

Table 2: Comparison of different types of nanoparticles in topical drug delivery

<i>Nanoparticle type</i>	<i>Composition</i>	<i>Advantages</i>	<i>Applications</i>
Liposomes	lipid bilayers encapsulating drugs	Liposomes are lipid vesicles that can encapsulate various drugs. They offer several advantages in topical drug delivery: They enhance the stability and solubility of drugs, improving their efficacy. Liposomes allow for controlled and sustained drug release, extending therapeutic effects. Their lipid bilayers facilitate better drug penetration into skin layers.	Liposomes are used for the delivery of both lipophilic and hydrophilic compounds. They find applications in the treatment of various skin disorders, including dermatitis and wound healing.
Polymeric nanoparticles	Biocompatible polymers	Polymeric nanoparticles are composed of biocompatible polymers. Their advantages include: Tailored drug release profiles, enabling precise treatment. High drug loading efficiency, reducing the need for frequent applications. Protection of drugs from degradation, ensuring stability.	These nanoparticles are used for controlled delivery of anti-inflammatory agents in skin conditions like psoriasis.
Micelles	Amphiphilic molecules	Micelles are formed by amphiphilic molecules. Their advantages include: Improved solubility of hydrophobic drugs, increasing bioavailability. Enhanced drug stability, ensuring long shelf life. Increased drug bioavailability due to their small size.	Micelles are utilized for the delivery of anti-aging agents and the reduction of oxidative stress in the skin.
Nanoemulsions	Oil-in-water or water-in-oil emulsions	Nanoemulsions offer excellent stability and shelf life. Their benefits include: Enhanced drug penetration into the skin, improving drug delivery. Ability to encapsulate both lipophilic and hydrophilic compounds, expanding their application range.	Nanoemulsions are employed for the delivery of herbal antioxidants and the reduction of oxidative stress in the skin.
Nanoparticles	Solid or semi-solid particles	Nanoparticles are solid or semi-solid particles with advantages such as: Controlled drug release, allowing for precise treatment. Enhanced skin penetration, ensuring deeper drug delivery. Stability against degradation, maintaining drug integrity.	Nanoparticles find applications in the treatment of skin disorders like acne and the reduction of inflammation.
Solid lipid nanoparticles	Lipid core particles	Solid Lipid Nanoparticles (SLNs) consist of lipid cores and offer advantages like: High drug encapsulation efficiency, maximizing drug loading. Sustained drug release, prolonging therapeutic effects. Improved skin permeation, enhancing drug delivery.	SLNs are used for controlled delivery of herbal actives in skin disorders such as eczema and dermatitis.
Nanostructured lipid	Lipid blend particles	Nanostructured Lipid Carriers (NLCs) contain a blend of lipids and provide benefits such as: Enhanced drug stability, preserving drug efficacy. Sustained drug release, maintaining therapeutic levels. Improved drug penetration into the skin, ensuring targeted delivery.	NLCs are applied in the treatment of skin disorders like psoriasis and enable controlled release of anti-inflammatory agents.
Dendrimers	Highly branched macromolecules	Dendrimers are highly branched macromolecules with advantages including: Precise control over drug release kinetics. High drug loading capacity, reducing the need for frequent applications. Potential for targeted drug delivery to specific skin layers.	Dendrimers find applications in targeted therapy for skin cancer, minimizing systemic side effects.
Nanogels	3D hydrogel networks	Nanogels are three-dimensional hydrogel networks at the nanoscale. Their benefits include: Encapsulation of both hydrophilic and lipophilic compounds, expanding drug options. Controlled drug release, ensuring sustained therapeutic effects. Improved drug stability, preserving drug integrity.	Nanogels are employed in the treatment of dermatitis and wound healing, offering controlled drug release for effective therapy.

receptors. Through the incorporation of ligands, nanoparticles discerningly escort pharmacological agents to predetermined destinations, diminishing the pernicious specter of systemic side effects.

- *Mitigated dermatological irritation*

Nanoformulations frequently bestow enhanced tolerability, mitigating the propensity for cutaneous irritation and hypersensitive reactions, thereby transcending conventional formulations.

- *Cosmetic culmination*

The imprimatur of nanotechnology extends its influence into the sphere of cosmetic formulations, enhancing the texture, appearance, and anti-aging propensities of the integument through the precise and judicious delivery of cosmeceutical constituents.¹¹

- *Innovative approaches to herbal nanoformulations*

Herbal nanoformulations signify a groundbreaking fusion of traditional herbal medicine and state-of-the-art nanotechnology



Figure 1: Nanoformulations for skin infections and types of skin infections

(Figure 1). These methodologies artfully marry the therapeutic prowess of herbal constituents with the unparalleled advantages of nanoscale pharmaceutical delivery systems. The ensuing sections delve into a panoply of herbal nanoformulation techniques and their pivotal roles in the field of dermatology:

- *Lipid-based nanoformulations*

Lipid-based nanoformulations artfully enlist lipids as conveyors for herbal compounds. For instance, liposomes, spherical lipid vesicles, function as adept encapsulators for both hydrophilic and lipophilic herbal actives. These nanoscale vesicles augment the solubility and stability of herbal constituents, fostering their efficacious conveyance into the cutaneous strata. The domain of lipid-based nanoformulations shines particularly bright in the management of skin conditions typified by desiccation and inflammation, rendering them indispensable for the cause.

- *Polymer-based nanoformulations*

The realm of polymer-based nanoformulations ingeniously employs biocompatible polymers as herbal compound carriers. Polymeric nanoparticles and microparticles adroitly encapsulate herbal ingredients, orchestrating controlled liberation and protracted therapeutic impacts. These formulations, endowed with versatility, stand ready to be tailored to precise dermatological exigencies. An illustrative application lies in the regulated release of anti-inflammatory herbal extracts, tailor-made for conditions such as psoriasis.

- *Liposome and micelle-based formulations*

Liposome and micelle-based formulations, masterpieces of engineering, focus on elevating the solubility and stability quotient of herbal constituents. Liposomes, clad in lipid bilayers, and micelles, comprised of amphiphilic molecules, elevate the bioavailability of herbal agents, facilitating their cutaneous infiltration. These innovative formulations excel in the delivery of herbal antioxidants and anti-aging elixirs, battling oxidative stress and elevating dermatological well-being.

- *Nanoemulsions and nanoparticles*

Nanoemulsions, empyreal colloidal suspensions of oil and water ensconced within the protective embrace of surfactants, stand as stalwart allies for encapsulating lipophilic herbal components. They flaunt impeccable stability credentials coupled with superlative skin penetration capabilities. On the other hand, nanoparticles, with their solid or semi-solid dispositions, harbor the potential to encapsulate herbal extracts, conferring controlled release dynamics and precision in targeting the skin. Applications abound in conditions necessitating the administration of herbal antioxidants or anti-inflammatory agents.

- *Solid lipid nanoparticles and nanostructured lipid carriers*

SLNs and their successors, NLCs, comprising lipid-based nanosystems with solid or semi-solid cores, proffer a veritable cornucopia of advantages. These include heightened stability, judicious drug release kinetics, and amplified skin penetration capabilities. Their contributions resonate profoundly in the context of skin disorders such as acne, wherein controlled release and pinpoint delivery emerge as non-negotiable imperatives.

- *Dendrimers and nanogels*

Dendrimers, intricate macromolecular constructs with meticulously defined architectures, usher herbal compounds within their nano-confines, allowing for meticulous control over drug release dynamics. Their utility attains zenith in the realm of targeted delivery, especially germane in the annals of skin cancer therapy. On the other hand, nanogels, intricate hydrogel networks operating at the nano-scale, stand as stalwarts of controlled release and heightened skin penetration. Their applications span diverse skin disorders, including dermatitis and wound healing.

- *Pioneering herbal nanoformulation techniques*

Beyond the well-entrenched strategies enumerated above, the expanse of ongoing research unfurls avant-garde herbal nanoformulation techniques. These may encompass hybrid systems, nanofibers, and nanoparticle-drug conjugates, each calibrated to fulfill bespoke requirements in the domain of dermatological interventions. For instance, nanofibers, amenable to gradual herbal compound release, adroitly navigate the terrain of wound dressings in the realm of chronic ulcers.¹²

Applications in Dermatological Disorders

Herbal nanoformulations have unveiled remarkable potential in the management of an array of dermatological disorders. Their distinctive amalgamation of herbal constituents and cutting-edge nanotechnology heralds precision and efficacy in treatment. Below, we delve into their applications in specific skin disorders:

Herbal nanoformulations for acne alleviation

Acne, a ubiquitous skin affliction, manifests through the emergence of pustules, comedones, and papules. Herbal nanoformulations introduce a multidimensional approach to acne mitigation. Components such as tea tree oil, neem, and salicylic acid, when harnessed within nanoformulations, mount a formidable offensive against acne-causing pathogens, curtail inflammation, and rein in excessive sebum production. Nano-scale conveyance ensures penetrating the dermal pores, the epicenter of acne lesion formation, delivering active agents with pinpoint precision.

Herbal nanoformulations for psoriasis mitigation

Psoriasis, an enduring autoimmune dermal ailment, distinguishes itself through the eruption of erythematous, scaly plaques across the skin's expanse. Herbal nanoformulations, enriched with entities like curcumin, aloe vera, and chamomile, extend solace to psoriasis sufferers. These formulations proffer anti-inflammatory and immunomodulatory effects, attenuating erythema and scaling. Nanoformulations, distinguished by their penchant for profound skin penetration, negotiate the challenge posed by the thickened dermal strata characterizing psoriatic lesions, ultimately amplifying drug efficacy.

Herbal nanoformulations for eczema and dermatitis management

Eczema and dermatitis, notorious for their pruritic, inflamed manifestations, find formidable adversaries in herbal nanoformulations. Ingredients such as calendula, licorice root, and colloidal oatmeal, revered for their soothing and anti-inflammatory attributes, are seamlessly integrated into these formulations. Nanoformulations act as hydrating sentinels, mitigating itchiness, and convalescing the skin's defensive barrier. Their unique potential lies in the chronic conditions sphere, where they not only quell flare-ups but bestow enduring relief.

Herbal nanoformulations for wound healing and scar attenuation

Wound healing and scar management, quintessential facets of dermatological care, draw considerable benefits from herbal nanoformulations. These formulations, armed with herbal extracts such as aloe vera, centella asiatica, and lavender oil, orchestrate tissue rejuvenation, inflammation reduction, and scar minimization. The nano-scale carriers, as diligent messengers, enhance herbal actives' skin permeation, expediting the healing trajectory and culminating in superior wound outcomes.

Herbal nanoformulations for skin cancer prevention and intervention

The exigencies of skin cancer, spanning melanoma and non-melanoma varieties, warrant bespoke stratagems for prevention and treatment. Herbal nanoformulations can embed natural sunscreens like zinc oxide and titanium dioxide to cocoon the skin against pernicious UV radiation. Moreover, herbal extracts endowed with antioxidant attributes, such as green tea and grape seed extracts, stand reconfigured within nanoformulations to abate oxidative stress, a prominent catalyst in skin cancer genesis. Pertaining to skin cancer therapy, herbal nanoformulations bear the promise of targeted drug release, thereby abating the systemic repercussions intertwined with chemotherapy.

Herbal nanoformulations for diverse dermatological disorders

Transcending the scope of the aforementioned dermatological conditions, herbal nanoformulations cast a wide net over a gamut of skin ailments. As exemplars:

Vitiligo navigates the domain of phototherapy for vitiligo by incorporating nano-formulated herbal elements such as psoralen, fostering enhanced skin repigmentation.

Rosacea, harmonizes nanoencapsulation strategies to usher anti-inflammatory herbal extracts like licorice root, extending respite to Rosacea's beleaguered denizens.

Pruritus, the perpetual scourge of itching, finds solace through nanoformulations sporting herbal components, notably chamomile and calendula, celebrated for their itch-alleviating attributes.

Fungal infections, a pervasive dermatological challenge, draw succor from nano-formulated antifungal herbs like tea tree oil or neem, which potentiate the treatment of mycotic skin maladies. Applications of herbal nanoformulations in skin disorders with benefits and mechanisms of action are mentioned in Table 3.

In each instance, the dexterity of herbal nanoformulations orchestrates precision, efficacy, and minimally invasive intervention, adeptly meeting the distinctive needs of patients grappling with diverse dermatological tribulations. However, paramount remains the imperative of rigorous research and clinical scrutiny to affirm the safety and efficacy of these formulations, setting the stage for evidence-driven practice in this dynamic domain.¹³

Challenges and Future Directions

Regulatory considerations and safety challenges

The assimilation of herbal nanoformulations into the realm of dermatological practice confronts an array of regulatory intricacies and safety quandaries. Global regulatory bodies insist upon exacting evaluations of safety, efficacy, and the unwavering quality of pharmaceutical products, including these nuanced herbal formulations. It is imperative to recognize that herbal ingredients can exhibit variances in composition,

Table 3: Applications of herbal nanoformulations in skin disorders-benefits and mechanisms of action

<i>Skin disorder</i>	<i>Herbal nanoformulation application</i>	<i>Benefits</i>	<i>Mechanisms of action</i>
Acne treatment	Utilize herbal nanoformulations with tea tree oil and neem oil to target acne-causing bacteria.	Reduction in acne lesions and severity. Antimicrobial properties effective against acne bacteria. Anti-inflammatory effects to reduce redness and swelling.	Tea tree oil: Terpinen-4-ol and alpha-terpineol combat acne bacteria. Neem oil: Azadirachtin and nimbin control microbial infections. Anti-inflammatory actions reduce acne-related inflammation.
Psoriasis management	Apply nanoformulations with anti-inflammatory herbs like turmeric and chamomile for psoriasis.	Control of psoriasis symptoms and reduction in skin inflammation. Potential immunomodulating effects.	Turmeric: Curcumin's anti-inflammatory properties reduce psoriasis-related inflammation. Chamomile: Bisabolol and apigenin have soothing and anti-inflammatory effects. Potential modulation of immune responses.
Eczema and dermatitis	Employ nanocarriers with soothing herbs like aloe vera and calendula for eczema and dermatitis.	Reduction of skin irritation, redness, and itching. Promotion of wound healing in eczema-prone areas.	Aloe vera: Polysaccharides soothe and hydrate irritated skin. Calendula: Flavonoids and triterpenoids have anti-inflammatory and wound healing properties.
Wound healing and scar management	Utilize herbal nanoformulations to enhance wound healing and minimize scarring.	Promotion of tissue repair and regeneration. Reduction in scar formation and appearance. Potential antimicrobial effects to prevent infection.	Herbal antioxidants protect against oxidative stress, aiding tissue repair. Enhanced collagen synthesis and cell migration promote wound closure. Antimicrobial properties prevent wound infections.
Skin cancer prevention and treatment	Develop targeted nanoformulations for skin cancer prevention and treatment.	Delivery of potential anti-cancer herbal compounds like green tea extract and curcumin. Protection against UV-induced skin damage. Potential inhibition of cancer cell growth and angiogenesis.	Green tea extract: Epigallocatechin gallate (EGCG) may inhibit cancer cell growth and angiogenesis. Curcumin: Potential anti-cancer effects through multiple pathways. Antioxidant properties protect against UV damage.
Other skin disorders	Explore the versatility of herbal nanoformulations in addressing various skin disorders such as: Dermatitis, Rosacea, Vitiligo, Hyperpigmentation, Allergic Skin Reactions.	Benefits include: Dermatitis: Soothing and anti-inflammatory effects. Rosacea: Reduction in redness and flushing. Vitiligo: Potential repigmentation effects. Hyperpigmentation: Inhibition of melanin production. Allergic Skin Reactions: Anti-inflammatory and soothing properties.	Mechanisms vary depending on the herbal ingredients and skin disorder. Common mechanisms may include anti-inflammatory, antioxidant, and wound healing effects. Repigmentation effects may involve melanocyte stimulation.

potency, and quality, a result of factors as diverse as the source of the botanical, cultivation methods, and extraction techniques. This inherent variability complicates the pathway to regulatory endorsement and heightens the importance of vigilant quality control.

Furthermore, the potential for untoward reactions and the prospect of interactions with other medications underscores the necessity for comprehensive safety assessments. Certain herbal constituents may instigate allergies or sensitivities in susceptible individuals. Concurrently, concerns may arise regarding herb-drug interactions, with particular compounds potentially altering the pharmacokinetics of concurrently administered pharmaceuticals.

The resolution of these multifaceted challenges demands a confluence of regulatory authorities, diligent researchers, and the proactive engagement of the herbal medicine industry. Robust safety assessments, the establishment of rigorous testing protocols, and the enforcement of stringent quality control

measures emerge as indispensable prerequisites for ensuring the credibility and safety of herbal nanoformulations.¹⁴

Standardization and quality control in herbal nanoformulations

The tenets of standardization and quality control constitute the bedrock of herbal nanoformulation progression. Standardization, in essence, entails the formulation of uniform criteria for herbal constituents, culminating in the establishment of consistent composition and potency benchmarks. Concomitantly, quality control mechanisms, often employing cutting-edge techniques such as high-performance liquid chromatography (HPLC) and mass spectrometry, serve as the gatekeepers, validating the authenticity and purity of herbal actives nested within nanoformulations.

However, standardization grapples with the inherent intricacy and multifaceted character of herbal constituents. Unlike their synthetic pharmaceutical counterparts, which

boast well-defined chemical structures, herbal compounds exhibit a proclivity for substantial variation, even within the confines of a singular plant species. An inclusive standardization paradigm must encompass diverse factors, encompassing the geographical origin of the plant, the nuances of cultivation, and the spectrum of extraction methodologies employed.

Tackling these exacting challenges necessitates the creation of standardized reference materials, the validation of analytical methodologies, and steadfast adherence to the exacting tenets of good manufacturing practices (GMP). This endeavor remains a collective one, underscored by the necessity for researchers, industry stakeholders, and regulatory bodies to work in harmonious tandem, weaving together the strands of comprehensive standards governing herbal nanoformulations.¹⁵

Clinical trials and evidence-based paradigms

The transition from laboratory explorations to clinical practice ushers forth a demand for rigorous clinical trials and the sanctity of evidence-based paradigms. Clinical trials investigating herbal nanoformulations must operate within the purview of stringent scientific methodologies, replete with randomized, controlled designs fortified by robust sample sizes. The selection of apt endpoints and outcome measures serves as the fulcrum of accurate evaluations pertaining to the safety and efficacy of these formulations.

Beyond this, the imperative of prolonged studies assumes paramount importance, orchestrating an inquiry into the enduring benefits and latent adversities attendant to herbal nanoformulations in real-world contexts. These studies must be all-encompassing, enlisting diverse patient populations, and underscored by comparative investigations juxtaposing these formulations vis-à-vis their conventional therapeutic counterparts. The journey toward establishing their relative efficacy takes flight through the crucible of such endeavors.

The clincher in this landscape materializes in the arena of evidence-based practice within dermatology. Dermatologists stand as sentinel decision-makers, steering the ship toward informed treatment choices. To this end, there exists an inexorable need for unfettered access to a compendium of well-documented evidence, a repository that unfurls the safety and efficacy attributes of herbal nanoformulations across the spectrum of skin disorders. This mission materializes as a collective enterprise, a symphony harmonized by the collaborative interplay of researchers, clinicians, and esteemed medical societies as they craft meticulous guidelines governing the utilization of these formulations within the vast pantheon of dermatological therapeutics.¹⁶

Future prospects and emerging trends in herbal nanoformulations for skin disorders

The vista unfurling before herbal nanoformulations within dermatology is bedecked with a constellation of prospects and burgeoning trends:

- *Personalized medicine*

The annals of genetics and diagnostics hold aloft the promise of bespoke herbal nanoformulations, meticulously calibrated to

mirror an individual's genetic tapestry and the unique tapestry of their specific dermatological tribulation.

- *The synergy of combination therapies*

The horizon beckons toward the synergistic embrace of multitudinous herbal constituents enshrined within nanoformulations, forging an integrative defense against multifaceted dermatological afflictions.

- *Innovations in nanotechnology*

The ceaseless march of nanotechnology begets innovations, offering up the precision and efficacy of herbal nanoformulations on an elevated pedestal, through avenues like targeted drug.¹⁷

CONCLUSION

In summation, the assimilation of herbal nanoformulations into the realm of topical drug delivery constitutes a pioneering stride in the sphere of dermatology. This avant-garde approach harmonizes the therapeutic prowess inherent in herbal remedies with the finesse and precision of nanoscale drug carriers. Over the course of this comprehensive review, we have embarked on a journey to unfurl the multifaceted potential that herbal nanoformulations embody and their far-reaching applications in the management of an array of dermatological conditions.

The multifarious advantages conferred by herbal nanoformulations encompass heightened drug permeation, the orchestration of controlled release mechanisms, and the judicious targeting of herbal constituents to the afflicted strata of the integumentary system. These formulations adeptly harness the innate remedial attributes harbored by herbs, ranging from their anti-inflammatory and antimicrobial facets to their antioxidative and wound-healing propensities. This wealth of therapeutic attributes renders them tailor-made for the exigencies posed by dermatological patients. The reverberations emanating from herbal nanoformulations on the landscape of dermatology are nothing short of profound. They endow dermatologists with an extensive armamentarium, custom-fitted to navigate the labyrinth of conditions spanning from the banalities of acne and eczema to the labyrinthine realm of recalcitrant psoriasis and formidable skin malignancies. By intricately configuring nanoformulations to the distinctive prerequisites of each dermatological quandary, we venture to accomplish therapeutic interventions that are not only more efficacious but also patient-centric and minimally invasive.

These formulations go beyond the mere palliation of symptoms, diving deep into the substratum of pathophysiological processes that underpin dermatological afflictions. They proffer the capacity to modulate immune cascades, ameliorate inflammatory cascades, invigorate tissue regeneration pathways, and provide an impervious shield against environmental adversaries, chief among them the deleterious ultraviolet (UV) radiation. Thus, they metamorphose into versatile agents fostering the holistic well-being of the integumentary system.

To spearhead the vanguard of herbal nanoformulations within the precincts of dermatology demands the orchestration of interdisciplinary collaborations. The ensemble cast comprises of zealous researchers, sagacious clinicians,

vigilant regulatory entities, and astute industry stakeholders. The symphony of collaboration endeavors to surmount the formidable challenges delineated hitherto, ranging from the rigors of safety assessments and the labyrinth of standardization to the hallowed precincts of evidence-based practice.

Researchers are tasked with the unrelenting pursuit of scientific truths, perpetuated through scrupulous preclinical and clinical investigations. Clinicians, on their part, execute a pivotal role, transmogrifying research findings into sacrosanct clinical guidelines, which, in turn, serenade patient care decisions. Regulatory bodies shoulder the mantle of establishing unerring standards and guidelines, sentinel to the approval and veracious quality control of these formulations.

The industry assumes a pivotal mantle, steering the juggernaut of innovation and safeguarding the promulgation of high-caliber herbal nanoformulations in the sanctuary of dermatological therapeutics. Their unwavering commitment to the tenets of GMP and the unfurling of the banner of transparency in labeling imbues healthcare providers and patients alike with a welter of confidence.

In the final analysis, the fate of herbal nanoformulations within the precincts of dermatology hinges inexorably upon the seamless symphony of cooperation among these myriad stakeholders. Together, in concinnity, they shall usher in a new era of managing dermatological afflictions, one that venerates the illustrious legacy of herbal medicine while championing the cutting-edge arsenal of nanotechnology to furnish patients with therapies that are not only more efficacious but also safer, more holistic, and rooted in empirical evidence.

In abridgment, the entwining of herbal nanoformulations within the tapestry of topical drug delivery beckons forth a bright and promising future for the field of dermatology. This innovative paradigm culls the time-honored therapeutic attributes intrinsic to herbs and marries them to the metronomic precision of nanoscale drug carriers. As we traverse the intricate terrain ahead, nurturing interdisciplinary collaboration, herbal nanoformulations shall invariably occupy a pivotal role in furthering the horizons of this field, extending a hand of hope and succor to the diverse multitude grappling with an eclectic array of dermatological maladies.

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