STM JOURNALS

Nano Trends:
A Journal of Nanotechnology and Its Applications

ISSN: 0973-418X
Volume 27, Issue 1, 2025
January–April
DOI (Journal): 10.37591/NTs

https://journals.stmjournals.com/nts

Review NTs

Advanced Ointment Formulation: An Insightful Review of Innovation and Efficacy

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Abstract

This review provides an in-depth exploration of the evolution of ointment formulations, particularly considering the increasing prevalence of fungal infections and the growing demand for effective antifungal treatments. Traditional ointment formulations, while useful, often face significant challenges, such as inadequate penetration into the skin, poor bioavailability, and undesirable textures that limit their efficacy. As a result, there has been a shift toward more advanced, innovative formulations that aim to address these shortcomings. Nanomedicine and nanotechnology have played a pivotal role in this transition, leading to the development of novel drug delivery systems, such as nanoemulsions, liposomes, solid lipid nanoparticles, and nanostructured lipid carriers. These systems enhance stability, bioavailability, and targeted delivery of antifungal agents, thereby improving treatment outcomes. The review also highlights the use of both natural and synthetic polymers in the development of wound and burn dressings, underscoring their biocompatibility, biodegradability, and potential for tissue regeneration. Hydrogels are noted for their promising applications in transdermal drug delivery systems due to their ability to provide sustained release and enhance skin permeability. Furthermore, the review discusses the importance of safety and efficacy evaluations through various methods, including in vitro and in vivo studies, clinical trials, and regulatory standards like good manufacturing practices and pharmacovigilance, ensuring that these formulations meet safety and performance criteria

Keywords: Nanoemulsion, solid lipid nanoparticles, hydrogels, In-Vivo, liposomes

INTRODUCTION

Background

An ointment is a thick, semisolid substance with a greasy or oily base, typically 80% oil and 20% water. It is applied externally to the skin or mucous membranes, often used as moisturizers or active ingredients for protective, healing, or preventive purposes. Ointments can be applied to various parts of the body, including the skin, eye lining, chest, genital areas, anus, and nose. They are highly moisturizing, effective for treating dry skin, and have a low risk of allergic reactions and irritation due to their minimal ingredients. The modern environment has led to increased exposure to various fungal strains, resulting in numerous fungi-related issues. The severity of these problems depends on the degree of interaction between the infecting fungus and the organism it affects [1].

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Received Date: December 14, 2024
Accepted Date: December 30, 2024
Published Date: January 03, 2025

Citation: Mohd. Wasiullah, Piyush Yadav, Ajay Kumar Yadav. Advanced Ointment Formulation: An Insightful Review of Innovation and Efficacy. Nano Trends: A Journal of Nanotechnology and Its Applications. 2025; 27(1): 14–23p. DOI: https://doi.org/.v27i01.192117

Antifungal agents are developed and utilized to prevent and treat infections, but ongoing research aims to discover more effective and convenient treatment options to improve the performance of antifungal ointments. The effectiveness of antifungal treatments depends on several factors, such as solubility, tissue penetration, and drug stability. Researchers continue to seek faster-absorbing ointments and other drug delivery methods. Nanomedicine and nanotechnology have gained attention for addressing the limitations of traditional drug delivery systems in fighting microbial infections and healing injuries. The primary focus areas in the application of nanoparticles (NPs) and nanomedicine are in biological, pharmaceutical, and medical fields. NPs are suitable for biological labelling due to their size, which is comparable to proteins. NPs are widely used in various areas, such as tissue engineering scaffolds, targeted drug delivery, and disease diagnosis. For pharmaceutical use, they must exhibit biocompatibility and biodegradability, as well as ease of production, optimal mechanical properties, a proper release time Figure 1 [2].

Figure 1. Ointment.

Types of Ointment

Ointments can be classified as medicated or non-medicated.

a. *Medicated ointment:* Medicated ointments contain active pharmaceutical ingredients (API) and are used for protective, therapeutic, or preventative purposes.
b. *Non-medicated ointment:* Non-medicated ointments serve as physical effects like protectants, moisturizers, or lubricants.

Characteristics of an Ideal Ointment

1. An ideal ointment should be stable, evenly dispersed with finely divided active ingredients and have no therapeutic effects.
2. It should have a smooth texture and be free from graininess, ensuring its stability and effectiveness [3].

Advantages of an Ointment

1. Ointments offer targeted drug application to affected areas, minimizing exposure and reducing side effects.
2. They bypass first-pass metabolism, making them convenient for patients unconscious or having difficulty orally taking medications.
3. Ointments are chemically stable and easier to handle than liquid dosage forms, making them ideal for administering drugs with a bitter taste.

Disadvantages of an Ointment

1. Ointments are oily, semisolid preparations that can leave stains and be less cosmetically appealing.
2. They can be contaminated or cause irritation when applied with fingertips, are bulkier and less convenient to handle than solid dosage forms.
3. Accurate dosing depends on the consistency of the amount applied, and they are less physically and chemically stable compared to solid dosage forms.

Need for Innovative Formulations

Traditional ointments face several challenges in terms of drug delivery and efficacy, patient compliance, targeted release, chronic and hard-to-treat conditions, multifunctionality, stability,

environmental considerations, and personalized medicine. One of the main challenges is the difficulty in delivering APIs efficiently to the target site due to the skin's barrier function [4].

Nanotechnology, such as NPs, nanoemulsions, and liposomes, is increasingly used to improve drug penetration into deeper layers of the skin. Vesicular carriers (Liposomes and Niosomes) encapsulate APIs in lipid bilayers, allowing for better skin penetration and controlled release over time. Microeedles and Iontophoresis are techniques that temporarily disrupt the stratum corneum, enabling more effective drug absorption. To improve patient compliance and convenience, many conventional ointments have an oily, sticky texture that can be uncomfortable and cosmetically unappealing for patients. Innovative solutions include non-greasy and fast-absorbing ointments, quick-drying formulations, transdermal patches, sustained or controlled-release ointments, and thermosensitive or pH- responsive ointments [5].

For chronic and hard-to-treat conditions, advanced formulations are needed to manage symptoms and promote healing over time. Innovative solutions include hydrocolloid-based ointments, biocompatible polymers, and antimicrobial peptides (AMPs), which can target resistant strains of bacteria and offer a new way to treat drug-resistant infections like MRSA. Multi-functional ointments aim to combine multiple therapeutic actions into a single product, simplifying the regimen for patients. Natural and herbal ingredients like aloe vera, turmeric, and tea tree oil are also being explored for their anti-inflammatory, soothing, and antimicrobial benefits [6].

Stability and self-life are also important aspects of traditional ointments. Advances in formulation technology, such as using anhydrous formulations or advanced packaging, can extend the shelf life of ointments without the need for preservatives, which are often linked to skin irritation. Lipid-based nano-carriers enhance drug stability by protecting them from environmental factors like air or moisture. As environmental concerns grow, there is increasing pressure to develop formulations that are environmentally friendly and meet stringent regulatory requirements. Innovative solutions include biodegradable ointments, clean label formulations, and regulatory innovations. Personalized ointments allow for personalized formulations tailored to individual patient needs, enabling precision medicine in dermatology. Smart ointments, which adjust drug release based on the skin's condition, are also being researched for optimized treatment [7].

NANOTECHNOLOGY-BASED OINTMENTS

Nanoemulsion

Nanoemulsions are systems where an oil phase is dispersed within an aqueous phase, often distributed through an oil network, containing nanometer-sized particles or other lipid components. These formulations create a uniform mix of two immiscible liquids, enhancing the properties of drugs, such as solubility, stability, permeability, and bioavailability. They are widely used in dermatology to enhance drug distribution to and from the stratum corneum, and have been applied to various drug types, including pharmaceutical, cosmeceutical, phytopharmaceutical, nutritional, and nutraceutical products, all aimed at improving human health. A study explored the topical delivery of the anticancer agent piperine using a nanoemulsion made from alginate and chitosan, improving drug absorption. The results showed that the nanoemulsion's effectiveness was concentration-dependent, leading to the destruction of epidermal cancer cells at 1%. Another example is a nanoemulsion containing oleoresins designed to treat cutaneous leishmaniasis, which exhibited improved skin penetration, reduced inflammation, and eliminated protozoan amastigotes in mice models.

Farooq and colleagues developed a nanoemulsion for the antifungal drug miconazole, which significantly enhanced skin permeation and therapeutic activity against fungal infections caused by Candida albicans. A nanoemulsion composed of virgin nutmeg and coconut oils, loaded with cyclosporine, was designed to treat psoriasis, demonstrating enhanced biological activity, reduced systemic toxicity, and improved skin hydration [8–12].

Liposomes

Liposomes are lipid bilayer structures that can encapsulate hydrophilic substances and lipophilic drugs, making them a promising approach for medical use due to their nontoxic properties. For example, melatonin (MLT) was incorporated into elastic liposomes using the thin-film dispersion method to address skin aging. These liposomes were designed to overcome the challenges of poor solubility and low bioavailability associated with oral melatonin. In vivo testing on a UV-induced photoaged skin model in female Kunming mice showed that elastic liposomes penetrated skin layers more effectively than conventional liposomes, improving skin hydration and elasticity while preserving dermal collagen and fibers. Nanoliposomes, smaller, nanoscale lipid bilayer vesicles, are smaller, nanoscale vesicles. In a study, clove essential oil (CEO) and tea tree oil (TTO) were combined in different concentrations to evaluate the antifungal potential of multicomponent nanoliposomes loaded with essential oils. The CEO-loaded nanoliposomes exhibited the highest entrapment efficiency and the strongest mycelial growth inhibition (MGI) against T. rubrum strains, making them the most effective formulation in the study [13–17].

LIPID BASED OINTMENT FORMULATION

Solid Lipid NPs

Solid lipid nanoparticles (SLNs) are emulsion-based carriers known for their ability to deliver lipophilic bioactive compounds, offering biocompatibility and serving as effective carriers for antimicrobial agents. Ramzan and colleagues developed and optimized SLNs loaded with ketoconazole (KTZ) to improve skin penetration for treating skin infections. Their optimized formulation was found to be photostable and capable of deeper penetration into the human stratum corneum. These SLNs demonstrated controlled and sustained drug release, with superior skin permeation compared to the commercial 2% KTZ formulation in both ex vivo and vivo studies on rat skin. Similarly, Singh and his team formulated miconazole (MCN)- loaded SLNs for topical application to treat fungal skin infections. These SLNs were incorporated into a hydrogel using Carbopol, which enhanced the retention of MCN in rat skin, provided localized and controlled drug release at the fungal site, and exhibited strong antifungal activity against *Candida albicans*. In ex vivo, in vivo, and skin irritation tests, the hydrogel formulation showed superior antifungal efficacy compared to the commercially available product, making it a promising candidate for future MCN delivery through topical routes. In another study, SLNs were used in a hydrogel formulation with chitosan as a gelling agent for treating allergic contact dermatitis (ACD). This formulation enabled sustained drug release, improved skin penetration, and demonstrated increased therapeutic effectiveness in a BALB/c mice model of ACD, significantly alleviating symptoms. Despite the promising results, challenges remain in applying these systems clinically. Issues, such as complex regulatory requirements and limited in vivo data on the ability of these nanosystems to permeate biological membranes, distribute drugs within skin layers, and deposit in body tissues still need to be addressed [18, 19].

Nanostructured Lipid Carriers (NLC)

Lipid NPs have been used to improve the effectiveness of topical anti-inflammatory drugs. For example, developed fluocinolone acetonide-loaded SLNs for psoriasis treatment, demonstrating prolonged drug release and improved half-life compared to plain drug suspension. It developed Carbopol® 934 hydrogels containing SLN and NLC loaded with cyclosporine and calcipotriol for psoriasis treatment, showing better drug penetration and retention in the epidermis. reported that naproxen-loaded SLN improved skin permeation and retention, while reducing systemic absorption. It created a meloxicam-loaded SLN in a Carbopol® 940 nanoemulgel for dermal delivery, showing good skin tolerability and significant anti-inflammatory effects in a rat paw edema test. developed a sodium carboxymethyl cellulose hydrogel containing chloroquine-loaded SLN for treating rheumatoid arthritis, showing significant improvement in bone erosion and joint health compared to control and standard chloroquine gel groups. It developed an amphotericin B-loaded SLN to enhance its antifungal activity, showing higher drug uptake and retention in ex vivo rat skin tests with minimal

skin irritation. They proposed two approaches to treat mild and moderate atopic dermatitis: restoring the skin barrier with NLC containing silver ions and incorporating anti-inflammatory drugs in NLC to enhance their effectiveness. It conducted a clinical evaluation of progesterone-loaded SLN and NLC hydrogels, showing slightly better drug penetration into the stratum corneum six hours post-application [20, 21].

ADVANCED EXCIPIENT AND MATERIAL

Natural Polymer

Natural polymers are widely used in regenerative medicine, particularly for wound and burn dressings due to their biocompatibility, biodegradability, and similarity to the extracellular matrix. These polymers promote and stimulate wound healing, aiding in tissue repair and skin regeneration. Hydrogels made from biomaterials are particularly useful in pharmaceutical and biomedical applications like wound care, tissue engineering, drug delivery, and organ transplants. Polysaccharides in hydrogel form are widely used for treating wounds and burns, including neutral polysaccharides like βglucans, dextrans, and cellulose, acidic polysaccharides like alginic acid and hyaluronic acid, basic polysaccharides like chitin and chitosan, and sulfated polysaccharides like heparin, chondroitin, dermatan sulfate, and keratan sulfate. Homoglycans, naturally occurring, biocompatible materials that act as local modulators of cellular responses, play an active role in the wound healing process. Electrospun materials like dextran, starch, or cellulose are promising for creating nanofiber matrices in regenerative medicine. αglucans, such as α(1→4), α(1→6)-d-glucan produced from starch by the fungus Aureobasidium pullulans, have been studied for their immune-modulating and pharmacological properties due to their ability to form resilient gel structures. Various types of β(1→3)-d-glucans from yeast, grains, and fungi have been studied for their immune-modulating and pharmacological properties due to their ability to form resilient gel structures. Dextrans, such as carboxymethyl benzylamide sulfonate dextran, is used in medical applications, such as wound and burn dressings, promoting wound healing, controlling the growth of Staphylococcus aureus biofilm, and affecting tumor, smooth muscle, and endothelial cell growth. Cyclodextrins, due to their unique bucket-shaped structure, are employed in modern odor-control dressings. Bioengineered cellulose is primarily used as a scaffold or matrix in dressings for chronic wounds, reducing pain and speeding up healing. Modified cellulose wound dressings can incorporate various active molecules through co- immobilization [22].

Synthetic Polymer

Synthetic polymers, such as composite nanobiomaterials with small pores and high surface area, are commonly used in wound and burn dressings. These materials are typically produced through techniques like electrospinning and include antibacterial wound-dressing materials made from electrospun polyurethane-dextran nanofiber mats containing ciprofloxacin hydrochloride and water-soluble polymer–carrageenan hydrogels. Other materials, like cellulose acetate, poly-l-lactide, and poly(lactide-coglycolide), are often combined with shikonin for wound healing due to their antimicrobial, anti-inflammatory, antioxidant, and antitumor properties. New developments in wound dressings include chitosan–poly(N,N- diethylacrylamide) interactive and thermoresponsive polymer networks, bactericidal films made from chitin derivatives, polyethylene glycol functionalized with low molecular weight heparin, and poly(ethylene glycol)–protein conjugates as occlusive wound dressings. Other examples include polyvinyl alcohol–gelatin based semi-interpenetrating networks, gelatin sponges with different cross-linking agents, polyvinyl alcohol–sodium carboxymethylcellulose membranes with fucidic acid, novel porous cryo-foams made from polyvinyl alcohol and polyacrylic acid, curcumin-loaded polylactic acid nanofibers, and collagen–poly-l-lactic acid composite materials. Polylactic acid-based polymers and copolymers are emerging as biodegradable material options, while polyurethane membranes with antibacterial properties and polyurethane foams combined with pH-sensitive alginate/bentonite hydrogels show promise in wound care. Polyvinylpyrrolidone–alginate hydrogels with nanosilver, resveratrol-immobilized polyvinylpyrrolidone hydrogels, and electrospun emodin-polyvinylpyrrolidone nanofibers are also notable examples. Fatty acid-based polyurethane films, poly-3- hydroxybutyrate–polyε-caprolactone biodegradable membranes, and non-

woven matrices from polyε-caprolactone homopolymers and polyl-lactide–ε-caprolactone have also been explored [23].

Hydrogels

Hydrogels are polymer networks made from a single species of monomer, with a crosslinked structure that varies depending on the monomer and polymerization technique used. These hydrogels are useful for transdermal drug delivery systems and ophthalmic applications. Homopolymers can be either crosslinked or non-crosslinked, depending on the nature of the monomer and the polymerization method. Crosslinked homopolymers like poly(3-hydroxypropyl methacrylate) (PHPMA) and poly(glycerol methacrylate) (PGMA) are commonly used for slow drug delivery and in contact lenses. Non-crosslinked homopolymers include poly(N-vinylpyrrolidone) (PNVP) and polyvinyl alcohol (PVA), which are particularly beneficial in medicine due to their high-water solubility. Poly(2-hydroxyethyl methacrylate) is a commonly used monomer in hydrogels, along with polyethylene glycol dimethacrylate as a crosslinker and benzoin isobutyl ether as an initiator. Co-polymeric hydrogels consist of two types of monomers, with at least one being hydrophilic. Examples include poly(NVP-co- HEMA) and poly(HEMA-coMMA). Semi-interpenetrating networks (semi-IPN) involve one polymer penetrating a crosslinked network without forming chemical bonds, offering benefits like pore size modification and slow drug release. Examples include semi-IPNs of alginate and amineterminated poly(N-isopropyl acrylamide) (PNIPAAm) created using calcium chloride as a crosslinking agent, gum Arabic loaded with silver nitrate, and acrylic or acrylamide co-polymer hydrogels. Interpenetrating networks (IPNs) consist of two polymers, with one being synthesized or crosslinked in the presence of the other. This technique produces hydrogels with enhanced mechanical properties, stiffness, and drug-loading efficiency compared to conventional hydrogel preparation methods. IPN hydrogels exhibit faster shrinking and swelling behavior, making them suitable for biomedical applications. Hydrogels in drug delivery are highly valued for their controlled and sustained drug release capabilities, effective at releasing drugs at targeted sites and having various applications [24].

EFFICACY AND SAFETY EVALUATIONS

In Vitro Studies

Drug Release Studies evaluate the release of the API from the ointment base over time using Franz diffusion cells. These studies help formulators adjust the base composition or drug concentration to optimize release. Permeation Studies assess the ointment's ability to deliver the active ingredient across the skin barrier using excised human or animal skin. These studies ensure the ointment is effective in delivering the API to the target site, aiding in selecting the appropriate base and optimizing skin absorption. Skin Irritation and Sensitization (In Vitro Models) evaluate the potential for the ointment to cause irritation or allergic reactions without using animal models. Reconstructed human epidermis models are used to assess cell viability using assays like the MTT assay. Early screening for skin compatibility helps in refining the formulation to minimize irritants or allergens, reducing the risk of adverse reactions when tested in vivo or clinically. Rheological Studies examine the physical properties of the ointment, such as viscosity, spreadability, and flow behavior. These studies measure how the ointment behaves under stress and over time using instruments like rheometers. A well-formulated ointment should be easy to apply, spread evenly, and remain stable during storage, as rheological properties directly impact patient compliance and overall product stability [25].

In Vivo Studies

Pharmacokinetic studies (PK) are crucial in understanding the absorption, distribution, metabolism, and excretion of a drug when applied as an ointment. These studies involve collecting blood samples and skin biopsies to assess drug levels in systemic circulation and determine if any systemic exposure occurs. Efficacy studies (In Vivo) evaluate the therapeutic effect of the ointment in living systems, such as wound healing models or infection models. These tests demonstrate the real-world efficacy of

the ointment, ensuring it delivers desired therapeutic outcomes. Skin irritation and sensitization studies (In Vivo) assess the potential for skin irritation or allergic reactions following topical application. The Draize test is used in animals to monitor signs of erythema, edema, or ulceration, while patch tests are conducted in humans to assess redness, swelling, or other reactions. Toxicology studies evaluate whether the topical application of the ointment could lead to systemic toxicity. Repeated-dose dermal toxicity studies are performed in animal models over a defined period, including weight changes, behavioral differences, and histopathological examination of tissues. These studies are essential for determining the safety of the ointment, especially with prolonged use, ensuring no systemic toxicity occurs. Local tolerance studies examine how well the skin tolerates repeated applications of the ointment. The ointment is applied to the same area of the skin daily in animal models or human volunteers for 2–4 weeks, observing any signs of irritation, sensitization, or damage to the skin. This ensures the ointment is safe for chronic use, particularly for patients requiring long-term treatment [26].

Clinical Trials

Clinical trials are crucial in the development of ointments, as they ensure safety, efficacy, and optimal dosing in human populations. These trials are typically conducted in three phases: Safety and Tolerability, Efficacy and Dose Finding, and Confirmatory Efficacy and Safety.

Phase I

Safety and Tolerability: This phase evaluates the safety, tolerability, and PKs of the ointment in a small group of healthy volunteers or patients. The study design includes single ascending dose and multiple ascending dose designs, with endpoints, such as local skin reactions, systemic absorption, and metabolization [27].

Phase II

Efficacy and Dose Finding: This phase evaluates the preliminary efficacy of the ointment and determines the optimal dose for further testing while continuing to assess safety. The study involves a larger group of participants (100–300) who have the condition the ointment is intended to treat. The study design is usually randomized, double-blind, placebo-controlled trials, with different concentrations tested to identify the optimal dose with maximum efficacy and minimal side effects.

Phase III

Confirmatory Efficacy and Safety: This phase confirms the efficacy and safety of the ointment in a large group of patients, comparing the ointment to standard treatments or placebo. The study design is usually randomized, controlled, and double-blind, with endpoints, such as primary efficacy outcome, safety profile, and quality of life. Phase III is the definitive trial that determines if the ointment is safe and effective for large- scale use. Successful completion of Phase III trials leads to filing a New Drug Application (NDA) or Marketing Authorization Application (MAA) [28].

Phase IV

Post-Marketing Surveillance: This phase monitors the safety and effectiveness of the ointment after it has been approved and is on the market. Key considerations include patient recruitment, application protocol, assessment methods, safety monitoring, and comparison groups. Patient recruitment is essential for selecting appropriate patient populations, standardizing the application of the ointment, using objective and subjective methods to assess outcomes, and frequent monitoring of local skin reactions, systemic effects, and general health. Comparator groups, including a placebo or standard treatment comparator, help determine the true efficacy of the ointment and whether it offers any advantages over existing therapies.

In summary, clinical trials play a crucial role in the development of ointments, ensuring safety, efficacy, and optimal dosing in human populations. The phases of safety, efficacy, confirmation, and

post-marketing surveillance are essential for determining the effectiveness and safety of ointments [29].

Regulatory Considerations

The objective of pre-formulation studies and regulatory guidelines is to gather data on the API and excipients that will guide formulation decisions. Key requirements include API characterization, excipient safety, regulatory guidelines for ointments, pharmacopoeial standards, good manufacturing practices (GMP), and regulatory pathways for ointment approval.

GMP ensure consistency in production and control to meet quality standards. This includes proper facility design, trained personnel, thorough documentation for batch production and quality control testing, stringent quality control procedures, and stability testing.

Regulatory pathways for ointment approval include NDA, Clinical Trial Design and Regulatory Oversight, Clinical Trial Applications, Good Clinical Practice (GCP), PKs and Efficacy, and Special Considerations for Topicals. Clinical trials must be conducted in compliance with GCP guidelines to ensure the integrity of data and the protection of trial participants. Labeling and regulatory compliance are essential for ensuring that the product's labeling complies with regulatory requirements and provides clear, accurate information to both healthcare providers and patients. Key requirements include the name and concentration of the active ingredient(s), instructions for use and application, warnings and contraindications, storage conditions and expiry date, batch number and manufacturing details for traceability, and patient information leaflet (PIL) for prescription ointments. Stability and self-life determination is crucial for ensuring the ointment remains safe and effective throughout its self-life. Regulatory agencies require developers to conduct stability studies in line with ICH Q1A guidelines, testing the ointment under various environmental conditions to assess chemical stability, physical stability, microbiological stability, and expiry date. Post-marketing surveillance and pharmacovigilance are also necessary to monitor the safety and efficacy of the ointment after it has been approved and marketed to the public.

Post-marketing surveillance (Phase IV Trials) involves manufacturers conducting post-marketing studies to collect long-term data on safety, especially for chronic-use ointments. Adverse Event Reporting is required, which can lead to changes in labeling, safety warnings, or even product recalls. If safety concerns arise after the product is marketed, manufacturers must be prepared to issue recalls or update the labeling with new warnings or contraindications.

In summary, preformulation studies and regulatory guidelines are essential for obtaining data on the API and excipients, ensuring consistency in production and quality control, and ensuring the safety and efficacy of ointments. Regulatory pathways for ointment approval, clinical trials, labeling, stability, shelf-life determination, post-marketing surveillance, and pharmacovigilance are all crucial steps in the development and marketing of ointments [30].

CONCLUSIONS

The evolution of ointment formulations has seen significant advancements, particularly with the integration of nanotechnology. Traditional ointments face challenges, such as drug delivery efficiency, patient compliance, and the need for targeted release mechanisms. Innovative formulations, including nanoemulsions, liposomes, SLNs, and NLCs, present promising solutions to these challenges.

Nanoemulsions have demonstrated enhanced drug solubility, stability, and skin penetration, making them suitable for various therapeutic applications, including antifungal and anticancer treatments. Liposomes, particularly elastic liposomes, have shown improved bioavailability and therapeutic outcomes for conditions like skin aging. SLNs and NLCs have proven effective carriers for

antimicrobial agents, offering controlled drug release and improved skin permeation, thereby enhancing the efficacy of treatments for skin infections and inflammatory conditions.

Ongoing research into these advanced formulations highlights the potential for more effective, patient-friendly treatment options in dermatology. Innovations like multifunctional ointments, eco-friendly formulations, and personalized medicine highlight the growing demand for customized solutions that address the specific needs of each patient. As the field progresses, it is crucial to address regulatory hurdles and ensure comprehensive in vivo studies to facilitate the clinical application of these advanced systems. In conclusion, the incorporation of nanotechnology into ointment formulations represents a significant leap forward in addressing the limitations of traditional drug delivery systems, ultimately improving therapeutic outcomes and patient satisfaction in managing various skin conditions.

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