WORLD JOURNAL OF PHARMACY AND PHARMACEUTICAL RESEARCH

Review Article

Coden USA: WJPPCL

2026
Volume: 03
Issue: 05
Page: 102-127

NANOEMULSION-BASED TOPICAL DRUG DELIVERY SYSTEMS FOR ACNE VULGARIS: FORMULATION DESIGN AND CHARACTERIZATION STRATEGIES

Amir Chauhan, Shabnam Ain*, Babita Kumar, Qurratul Ain

Sanskar College of Pharmacy and Research, Ghaziabad-201001, Uttar Pradesh, India.

Received: 18 March 2026 **Revised: 10 April 2026** **Accepted: 30 April 2026**

Corresponding Author: Shabnam Ain

Address: Sanskar College of Pharmacy and Research, Ghaziabad-201001, Uttar Pradesh, India.

DOI: https://doi.org/10.5281/zenodo.19940855,

ABSTRACT:

Follicular hyperkeratinisation, bacterial colonization, and excessive sebum production are the hallmarks of acne vulgaris, a chronic inflammatory skin condition that frequently results in papules, pustules, and scarring. Anti-acne medications like benzoyl peroxide, retinoids, and antibiotics are frequently administered via traditional topical formulations like creams, gels, and lotions. However, poor skin penetration, instability, and frequent dose requirements restrict their therapeutic efficacy and lower patient compliance. Topical drug delivery methods based on nanoemulsions have shown promise in addressing these issues by improving drug solubility, stability, and bioavailability. Oil, water, and surfactant dispersions that are thermodynamically or kinetically stable and have droplet sizes that are usually between 20 and 200 nm are known as nanoemulsions. Improved drug penetration through the stratum corneum and targeted delivery to pilosebaceous units, the main location of acne pathology, are made possible by their enormous surface area and small droplet size. The formulation design and characterization techniques of nanoemulsion-based acne treatment systems are the main topics of this review. The choice of oils, surfactants, and co-surfactants, optimization of droplet size, zeta potential, viscosity, and stability, and drug loading methods appropriate for hydrophilic and lipophilic drugs are important factors to take into account. Particle size analysis, entrapment efficiency, in vitro drug release, ex vivo skin penetration, and deposition investigations are examples of characterization techniques that are emphasized. Additionally, current developments involving combination treatments and herbal

actives are covered. In comparison to traditional formulations, nanoemulsion-based topical systems offer increased penetration, controlled release, less irritation, and better patient adherence, making them a suitable platform for enhancing anti-acne therapy.

KEYWORDS: Nanoemulsions**,** Topical drug delivery**,** Acne vulgaris**,** Skin penetration**,** Anti-acne agents**,** Controlled release**,** Pilosebaceous targeting.

1. INTRODUCTION

The pilosebaceous units, which are made up of sebaceous glands, hair follicles, and related epithelial structures, are the main target of acne vulgaris, a chronic inflammatory condition. It presents as a variety of lesions, including as inflammatory papules, pustules, nodules, non-inflammatory comedones, and, in extreme situations, cystic lesions that may cause hyperpigmentation and permanent scarring. Recent epidemiological studies have revealed an increasing frequency of adult-onset acne, especially among women aged 25 to 40, despite the condition's predominance in teenagers and young adults.[1] This condition is frequently associated with hormonal changes, stress, and lifestyle variables. Hyperseborrhea, aberrant keratinocyte desquamation resulting in follicular plugging, colonization by Cutibacterium acnes (formerly Propionibacterium acnes), and activation by regional inflammatory mechanisms mediated by cytokines, chemokines, and free radicals are all part of the complex pathophysiology of acne. Acne lesions grow and worsen as a result of these processes taken together.[2] Acne is one of the most common dermatological conditions in the world, affecting 9–10% of the population. Acne can have a significant negative influence on psychological health in addition to its physical symptoms, leading to low self-esteem, social anxiety, depression, and a lower quality of life. Numerous studies show that people with moderate to severe acne frequently suffer from severe social disengagement and poor interpersonal relationships, underscoring the necessity of efficient and patient-friendly treatment approaches.[3]

1.1. Limitations of Conventional Topical Therapies

For mild-to-moderate acne, traditional topical treatments continue to be the primary line of treatment. Active ingredients like benzoyl peroxide, topical retinoids (tretinoin, adapalene, tazarotene), antibiotics (clindamycin, erythromycin), azelaic acid, and salicylic acid are commonly administered through creams, gels, ointments, and lotions. These substances are intended to lower sebum production, calm local inflammation, stop bacterial development, and restore follicular keratinization. Conventional formulations are widely used, although

they have serious drawbacks.[4] The skin's outermost layer, the stratum corneum, prevents active substances from penetrating deeper follicular and sebaceous structures, which frequently leads to subtherapeutic medication concentrations at the target region. Many anti-acne medications are chemically unstable; retinoids, for instance, break down when exposed to light, and benzoyl peroxide can quickly oxidize, decreasing its effectiveness. Common side effects that frequently result in poor patient adherence include erythema, irritation, peeling, dryness, and burning sensations. Low compliance and treatment cessation are also caused by the need for numerous administrations over long periods of time to sustain therapeutic benefits. When taken as a whole, these drawbacks highlight the need for sophisticated, more efficient, and patient-friendly drug delivery methods that can minimize side effects while circumventing skin barrier obstacles.[5]

1.2. Advantages of Nanotechnology in Acne Management

Delivery techniques centered around nanotechnology provide creative answers to the problems with traditional topical formulations. Regarding these, nanoemulsions have drawn a lot of interest because of their special physicochemical characteristics and capacity to improve topical medication administration. Nanoemulsions, which usually have droplet diameters between 20 and 200 nm, are submicron-sized dispersions of water and oil stabilized by surfactants. Because of their small size, they have more surface area and can penetrate deeper into the pilosebaceous structures, which are the main locations of acne pathology through the stratum corneum.[6] Additionally, nanoemulsions offer continuous and regulated drug release, lowering the frequency of application while preserving therapeutic concentrations at the intended site. Both hydrophilic and lipophilic anti-acne drugs, among them as retinoids, benzoyl peroxide, antibiotics, and natural anti-inflammatory or antioxidant substances like curcumin, green tea polyphenols, and aloe vera extracts, can be included into nanoemulsions due to their high solubilization capacity.[7]

Furthermore, systems based on nanoemulsions provide better stability against oxidation and chemical deterioration, extending their shelf life and effectiveness. Targeted distribution reduces local irritation and side effects that are frequently seen with traditional creams and gels by limiting drug exposure to nearby healthy skin. Co-delivery of multiple therapeutic agents is made possible by the flexibility of formulation design. This allows for combination treatment strategies, such as the concurrent administration of an antibiotic and an anti-inflammatory agent, which can work in concert to reduce inflammation and control bacterial

colonization.[8] Recent studies further show that nanoemulsions can be designed to be stimuli-responsive carriers, improving site-specific medication activity by releasing their payload in accordance with oxidative stress or pH changes in inflammatory acne lesions. When compared to traditional topical formulations, nanoemulsion-based topical systems offer better efficacy, fewer side effects, and more patient compliance, making them a promising and adaptable platform for contemporary acne care.[9,80,88]

2. PATHOPHYSIOLOGY OF ACNE VULGARIS

Sebum production, microbial colonization, and inflammation interact to cause lesions in acne vulgaris, a multifactorial inflammatory condition of the pilosebaceous unit. Designing successful treatment interventions requires an understanding of these systems.[10]

2.1. Sebum Overproduction

Sebum, a lipid-rich fluid that lubricates and shields the skin, is produced by sebaceous glands. Androgen-mediated hyperseborrhea causes excessive sebum production in acne, which fosters bacterial development and follicular obstruction. Increased synthesis of inflammatory mediators including free fatty acids and squalene oxidation products, which exacerbate local inflammation and aid in the formation of comedones, is another effect of elevated sebum levels.[11]

2.2. Bacterial Colonization

Sebaceous follicles are naturally home to the gram-positive, anaerobic bacterium *Cutibacterium acnes*. Sebum excessive production and follicular obstruction contribute to the proliferation of acne in skin that is prone to it. Lipases, which convert triglycerides into pro-inflammatory free fatty acids, are among the chemotactic agents and enzymes that C. acnes generates. The bacterial metabolites increase local inflammatory responses and aid in the development of papules and pustules by activating Toll-like receptors and inflammasomes in keratinocytes and immune cells.[12]

2.3. Inflammatory Responses

A key factor in the pathophysiology of acne is inflammation. Cytokines such interleukin-1 (IL-1), IL-6, TNF-α, and prostaglandins are released when innate immune pathways are activated. These cytokines draw immune cells to the follicle and surrounding dermis. Redness, swelling, and the development of inflammatory lesions are the outcomes of this

process. Additionally, hyperkeratinization can be triggered by chronic inflammation, which prolongs follicular obstruction and lesion recurrence.[13,89]

2.4. Key Targets for Anti-Acne Therapy

Efficient anti-acne treatment tackles several processes based on the pathophysiology:

- **Sebum suppression:** Retinoids or anti-androgenic drugs lessen the production of sebum.
- **Antimicrobial activity:** Systemic or topical antibiotics prevent the growth of C. acnes.[14]
- **Keratolysis and normalization of follicular turnover:** Salicylic acid and retinoids stop the production of comedones.
- **Anti-inflammatory effects:** Natural antioxidants, benzoyl peroxide, and niacinamide all lessen inflammation caused by cytokines.[15]
- **Combination therapy:** It has been shown to be more successful in lowering the number of lesions and recurrence when it targets several pathogenic variables at once.

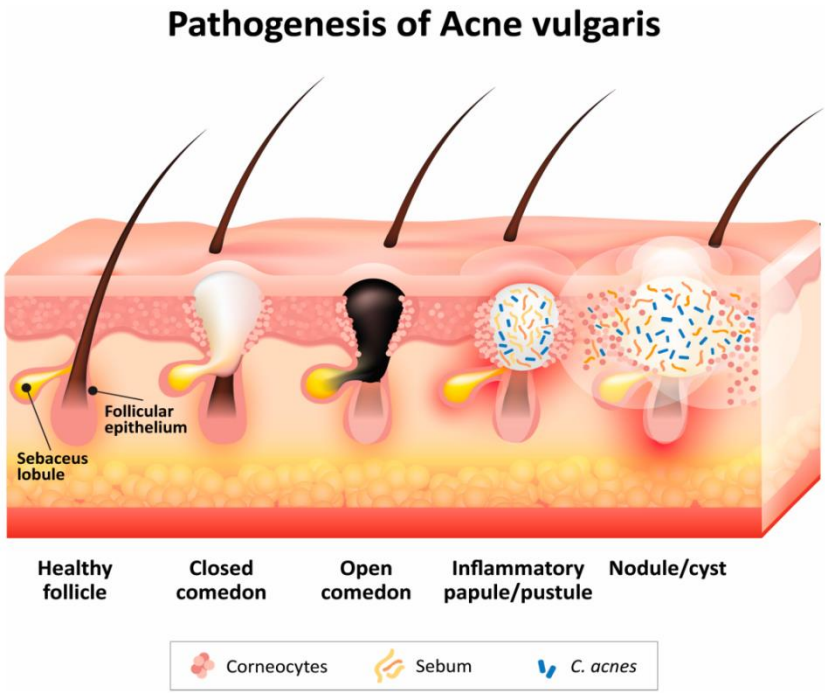

Fig. 1: Pathophysiology of Acne Vulgaris[16]

3. RATIONALE FOR NANOEMULSION-BASED THERAPY

Considering they overcome many of the drawbacks of traditional formulations, nanoemulsions have become cutting-edge topical drug delivery solutions for the treatment of acne. They are particularly well suited for targeting the pilosebaceous unit because of their distinctive physicochemical characteristics, which include small droplet size, large surface area, and thermodynamic stability.[17,88]

3.1. Enhanced Drug Solubilization and Stability

Retinoids, benzoyl peroxide, and certain antibiotics are among the many anti-acne medications that exhibit poor water solubility and instability in traditional creams and gels. Depending on the type of medicine, nanoemulsions can dissolve both hydrophilic and lipophilic substances by adding them to the aqueous or oil phase. Surfactants and co-surfactants form a persistent interfacial coating surrounding droplets that shields the medication from hydrolysis, oxidation, and light-induced destruction. Longer shelf life and increased drug availability at the site of action are two benefits of this enhanced solubilization and stability.[18,81,82]

3.2. Improved Skin Penetration and Follicular Targeting

Nanoemulsions' microscopic droplet size typically less than 200 nm allows for improved diffusion into deeper skin layers and closer interaction with the stratum corneum. In addition to preferentially accumulating in hair follicles and sebaceous glands the main locations implicated in acne nanoemulsions can pass through intercellular lipid channels. By fluidizing skin lipids, some surfactants and oils employed in nanoemulsions improve penetration and make it easier for drugs to reach the pilosebaceous unit.[19]

3.3. Controlled and Sustained Drug Release

By maintaining medications inside the internal phase and releasing them gradually as droplets dissolve in skin lipids, nanoemulsions can allow controlled and sustained release of drugs. By maintaining therapeutic drug levels for extended periods of time, this sustained administration lessens the necessity for frequent application. Recurrence rates are reduced and lesion resolution is enhanced by ongoing medication availability at the target site.[20,83,84]

3.4. Reduced Irritation and Side Effects

Dryness, burning, and irritation are frequently caused by high concentrations of anti-acne medications on the skin's surface. By distributing the medication more evenly and delivering it progressively into the skin, nanoemulsions reduce the epidermis's abrupt exposure to high drug concentrations. Additionally, encapsulation lessens the immediate interaction of irritating medications with the skin's surface, improving patient compliance, tolerability, and reducing local side effects.[21]

4. ACTIVE PHARMACEUTICAL INGREDIENTS (APIS) FOR ACNE

Abnormal keratinization, excessive sebum production, bacterial colonization, and inflammation are all components of acne vulgaris. Therefore, using medications that may have an impact on many stages of acne etiology is necessary for efficient therapy. Topical anti-acne medications contain a range of active pharmaceutical ingredients (APIs), either alone or in sensible combinations.[22]

4.1. Retinoids

Retinoids are essential medications for treating acne, especially inflammatory and comedonal acne. The control of keratinization and epithelial cell differentiation is their primary mode of action. They reduce aberrant keratinocyte proliferation and avoid hair follicle obstruction by binding to retinoic acid receptors (RARs) in skin cells. This aids in comedone resolution and prevention.[23]

For mild to moderate acne, tretinoin is frequently found in creams and gels. It has modest anti-inflammatory properties, encourages epidermal turnover, and breaks up existing comedones. Nevertheless, it frequently results in irritation, peeling, and erythema and is chemically unstable when exposed to light and oxygen. Adapalene is less irritating while still having comparable effectiveness since it is more long-lasting and selective for specific retinoid receptors. For long-term acne control, for instance, adapalene 0.1% or 0.3% gel is frequently given. Retinoids are more stable, less irritating, and more effectively delivered into pilosebaceous units when they are encapsulated in lipid-based systems or Nanoemulsions.[24]

4.2. Antibiotics

The main purposes of topical antibiotics are to lessen inflammation and manage Cutibacterium acnes. By attaching to ribosomal subunits, they suppress the synthesis of proteins in bacteria. Comparable to clindamycin, erythromycin inhibits bacterial growth and lowers inflammatory mediators via binding to the 50S ribosomal subunit.[25]

For mild to moderate inflammatory acne, clindamycin 1% gel or lotion is frequently utilized. Due to broad resistance, erythromycin is no longer as popular. Antibiotic monotherapy over an extended period of time raises the chance of bacterial resistance. As a result, they are frequently mixed with benzoyl peroxide, which has bactericidal properties and slows the emergence of resistance. For instance, a typical fixed-dose combination is clindamycin 1% +

benzoyl peroxide 5% gel. By improving follicular targeting, delivery via nanoemulsion devices reduces the chance of resistance and permits lower antibiotic dosages.[26]

4.3. Anti-Inflammatory and Keratolytic Agents

Beta-hydroxy acids like salicylic acid have anti-inflammatory and keratolytic properties. It breaks down keratin plugs, enters follicles, and lessens the development of comedones. Additionally, it reduces edema and redness by blocking inflammatory mediators. Cleansers, gels, and lotions frequently include 0.5–2% salicylic acid.[27]

Azelaic acid possesses anti-keratinizing, anti-inflammatory, and antibacterial properties. It lessens aberrant keratinocyte development and inhibits bacterial mitochondrial enzymes.Azelaic acid 15–20% cream or gel works well for comedonal and inflammatory acne and is safe to use over an extended period of time, including while pregnant.[28]

By preventing the release of cytokines, niacinamide (vitamin B3) lowers inflammation and enhances the function of the skin barrier. Additionally, it lessens redness and sebum production, which makes it beneficial for sensitive skin. By modifying immunological responses, zinc salts lower sebum production, stop bacterial development, and lessen inflammation.[29]

4.4. Herbal and Natural Agents

Herbal and natural remedies are becoming more popular due to worries about irritation and long-term effectiveness of synthetic medications. By causing damage to bacterial cell membranes, tea tree oil demonstrates antibacterial activity against C. acnes. Redness and irritation are lessened by the calming and anti-inflammatory qualities of aloe vera. Polyphenols included in green tea lessen oxidative stress and sebum production. Licorice extract and curcumin have antibacterial and anti-inflammatory properties. For instance, people who are sensitive to synthetic medications can use tea tree oil 5% gel as a substitute for mild acne. These natural chemicals' solubility, stability, and skin penetration are enhanced by nanoemulsion-based administration.[30]

4.5. Combination Therapies

Combination therapy is thought to be the most successful strategy since acne involves several pathogenic processes. For instance, adapalene + benzoyl peroxide gel simultaneously addresses inflammation, bacterial development, and follicular clogging. Benzoyl peroxide

plus clindamycin lowers bacterial resistance while reducing inflammation. Comedonal and inflammatory lesions are both improved by tretinoin + antibiotic combos.[31]

Lipophilic and hydrophilic medications can be co-delivered in a single system using nanoemulsion-based combination formulations, guaranteeing consistent distribution, regulated release, improved follicular targeting, and decreased irritation. As a result, long-term acne treatment is more effective, has fewer adverse effects, and increases patient compliance.[32]

Table 1: Summary of APIs used in Acne Therapy.

Class of API	Examples	Main Mechanism of Action (MOA)	Indications	Common Strengths	Limitations	Benefit in Nanoemulsion Systems
Retinoids	Tretinoin, Adapalene, Isotretinoin (topical)	Normalize keratinization, reduce follicular plugging, increase cell turnover by activating retinoic acid receptors	Comedonal and inflammatory acne	Tretinoin 0.025–0.1%, Adapalene 0.1–0.3%	Irritation, erythema, peeling, photosensitivity, instability	Improved stability, reduced irritation, better follicular penetration[33]
Antibiotics	Clindamycin, Erythromycin, Nadifloxacin	Inhibit bacterial protein synthesis by binding to 50S ribosome; reduce inflammatory mediators	Mild–moderate inflammatory acne	Clindamycin 1%, Erythromycin 2%	Bacterial resistance, irritation	Enhanced follicular targeting, lower dose required, reduced resistance risk[34]
Antibacterial agent	Benzoyl Peroxide	Releases free radicals that kill bacteria; mildly keratolytic	Inflammatory acne, resistance prevention	2.5–10%	Strong irritation, dryness, bleaching of clothes	Controlled release, reduced irritation[35]
Keratolytic agents	Salicylic Acid	Breaks keratin plugs, exfoliates, reduces comedones	Comedonal acne	0.5–2%	Dryness, peeling	Better solubility, improved follicular penetration[36]
Anti-inflammatory agents	Niacinamide, Zinc salts	Reduce cytokine release, regulate sebum, improve barrier function	Inflammatory and sensitive-skin acne	Niacinamide 2–5%, Zinc 1–2%	Mild irritation in some users	Sustained release, better skin tolerance[37]
Dicarboxylic acid	Azelaic Acid	Antibacterial, anti-keratinizing, anti-inflammatory	Comedonal + inflammatory acne, pregnancy-safe	15–20%	Burning, stinging	Improved penetration, reduced irritation[38]
Herbal agents	Tea tree oil, Aloe vera, Neem, Green tea, Curcumin, Licorice	Antibacterial, anti-inflammatory, antioxidant actions	Mild acne, sensitive skin	Tea tree oil ~5%	Allergic reactions in some users	Increased stability, better skin delivery[39]

Combination APIs	Adapalene + BPO, Clindamycin + BPO, Tretinoin + Antibiotic	Act on multiple acne pathways: bacteria, keratinization, inflammation	Moderate–severe acne	Various fixed-dose combos	Higher irritation risk	Controlled co-release, reduced side effects, better compliance[40]
Nanoemulsion-loaded APIs	Retinoids, antibiotics, herbal extracts, combinations	Target follicles, sustained drug release, reduced peak irritation	All acne types	Drug dependent	Formulation complexity	Enhanced stability, penetration, safety, efficacy[41]

5. FORMULATION DESIGN OF NANOEMULSIONS

Nanoemulsions are colloidal systems with droplet sizes usually smaller than 200 nm that are either thermodynamically or kinetically stable. Careful component selection, appropriate preparation techniques, and physicochemical property optimization are necessary for their successful design in order to guarantee stability, effectiveness, and acceptance among patients.

5.1. Components of Nanoemulsions

The oil phase, surfactant, co-surfactant, and aqueous phase are the four primary constituents of a nanoemulsion. Lipophilic medications utilized in acne treatment, such as retinoids, essential oils, and herbal extracts, are transported by the oil phase. Medium-chain triglycerides, isopropyl myristate, olive oil, coconut oil, and essential oils like neem or tea tree oil are frequently utilized oils. The oil should be safe to apply topically and have a strong ability to dissolve the medication. Surfactants are necessary to stabilize the droplets and lower the interfacial tension between water and oil. For topical nanoemulsions, non-ionic surfactants like Tween 20, Tween 80, Span 20, and Span 80 are used because of their low toxicity and favorable skin compatibility. Co-surfactants contribute to the interfacial film's increased flexibility and further reduction of interfacial tension. The most frequently encountered glycols and alcohols include ethanol, propylene glycol, polyethylene glycol, and Transcutol. Additionally, they improve the drug's skin penetration. In order to increase stability and skin feel, the aqueous phase which is usually composed of buffer solutions or purified water may also include humectants, preservatives, or viscosity enhancers.[42]

5.2. Types of Nanoemulsions

The combination of the water and oil phases determines the classification of nanoemulsions.

- Oil droplets are distributed across a continuous aqueous phase in **oil-in-water (O/W)** nanoemulsions. Because they are easily washable, non-greasy, and aesthetically pleasing,

they are best suited for topical application. This category includes the majority of anti-acne Nanoemulsions.[43]

- Water droplets are scattered throughout oil in **water-in-oil (W/O)** nanoemulsions. They are less favored in acne because of their oily character, but they are more occlusive and appropriate for dry skin conditions.
- **Bicontinuous nanoemulsions** offer a strong solubilization capacity for both hydrophilic and lipophilic medicines due to their interpenetrating oil and water domains.[44]

5.3. Preparation Methods

Both high-energy and low-energy techniques can be used to create nanoemulsions.

High-energy techniques split droplets into nanosized using mechanical devices. Ultrasonication is a lab-scale preparation technique that uses sound energy to reduce droplet size. High-pressure homogenization, which is appropriate for large-scale production, creates extremely thin droplets by forcing the emulsion through tiny gaps under high pressure.

Low-energy techniques depend on the system's physicochemical characteristics. In order to invert phases and create nano-sized droplets, the phase inversion process entails altering composition or temperature. When combinations of oil, surfactant, and co-surfactant are incorporated to water, spontaneous emulsification takes place, creating nanoemulsions without the need for outside energy. These techniques are easy, affordable, and appropriate for medications that are sensitive to heat.[45,86]

5.4. Optimization of Nanoemulsion Properties

Skin penetration, stability, and attractiveness are all directly impacted by droplet size. Drug absorption and follicular targeting are improved by smaller droplets (less than 200 nm). Size homogeneity is indicated by the polydispersity index (PDI). A system is uniform and stable if the PDI is less than 0.3. Droplet aggregation and instability are indicated by high PDI values. Temperature, storage conditions, oil-to-water ratio, and surfactant content all affect stability. Physical stability, phase separation, creaming, cracking, and drug content homogeneity must all be assessed over time for nanoemulsions. To guarantee successful and patient-friendly topical acne treatment, optimized nanoemulsions should have tiny droplet sizes, low PDI, appropriate viscosity, pleasant skin feel, and long-term physical and chemical stability.[46,90]

6. INCORPORATION INTO TOPICAL VEHICLES

Following preparation, nanoemulsions are typically added to appropriate topical bases, such as gels, creams, or lotions, to enhance patient acceptance, ease of application, and skin residence time. Drug release, skin retention, and overall therapeutic efficacy are all significantly impacted by the vehicle selection.

The most popular nanoemulsion carriers for treating acne and inflammatory skin conditions are gels. The process of creating nanoemulsion-based gels, also known as nanoemulgels, involves dispersing the nanoemulsion into a gelling agent like sodium alginate, carbopol, hydroxypropyl methylcellulose (HPMC), or xanthan gum. They provide a cooling effect, are readily spreadable, and are non-greasy, all of which are beneficial for skin that is prone to acne or inflammation. For instance, compared to traditional gels, adapalene or tea tree oil nanoemulsions added to carbopol gel exhibit improved skin retention and less irritation.[47,83,84,85]

Creams are semi-solid emulsions that can be either water-in-oil or oil-in-water. The stability of delicate medications is enhanced and the moisturizing effect is improved by adding nanoemulsions to cream bases. Although O/W creams are lighter and less greasy, they are recommended for acne. For example, O/W creams containing clindamycin or benzoyl peroxide nanoemulsions exhibit better patient acceptance and medication distribution.[48]

Low-viscosity lotions are ideal for big or hairy areas like the chest or back. Lotions based on nanoemulsions spread readily and leave very little residue. They work well for applying herbal anti-acne remedies, such as extracts of neem or turmeric, to larger skin areas.[49]

Table 2: Factors Affecting Skin Retention and Release.

Factor	Description	Effect on Skin Retention	Effect on Drug Release
Type of topical base	Gels, creams, lotions differ in structure and water/oil content	Creams and emulgels increase residence time; lotions show lower retention	Gels give faster release; creams provide sustained release[50]
Viscosity of vehicle	Thickness of formulation	High viscosity increases retention on skin	High viscosity may slow drug release; low viscosity gives faster release[51]
Penetration enhancers	Ethanol, propylene glycol, Transcutol	Improve drug entry into skin layers	Increase rate and extent of drug release into skin[52]
Humectants	Glycerin, sorbitol	Increase skin hydration and retention	Hydrated skin allows better drug diffusion[53]
Occlusive agents	Dimethicone, petrolatum	Reduce water loss and prolong formulation contact	Indirectly improve drug absorption[54]
Drug–vehicle	Compatibility between	Good compatibility improves	Strong binding reduces release; weak

interaction	drug and base	retention	binding enhances release[55]
Application conditions	Sweating, washing, rubbing	Decrease retention if formulation is removed	Reduce available drug for release[56]
Skin type	Oily, dry, sensitive skin	Oily skin may reduce adhesion; dry skin increases retention	Hydration level affects drug diffusion rate[57]

7. CHARACTERIZATION STRATEGIES

7.1. Physicochemical Characterization

Droplet size, polydispersity index (PDI), zeta potential, pH, and viscosity are the main metrics used to assess nanoemulsion formulations. Dynamic light scattering is used to quantify droplet size and PDI because smaller, evenly distributed droplets provide improved stability and skin penetration. Higher absolute values of zeta potential, which predicts physical stability and implies surface charge, lessen droplet aggregation because of electrostatic repulsion. To prevent irritation, topical nanoemulsions should have a pH between 5.0 and 6.5, which is compatible with skin. A Brookfield or rotating viscometer is typically used to evaluate viscosity, which is crucial for spreadability, skin retention, and patient acceptability.[58]

7.2. Stability Studies

In order to make certain nanoemulsions retain their characteristics while being stored, stability testing is crucial. In thermal stability studies, formulations are subjected to various temperatures (such as room temperature, refrigeration, and accelerated settings) in order to track phase separation, creaming, or droplet size changes. By using a strong gravitational force to identify early indicators of instability like coalescence or fracture, centrifugation tests are used to forecast long-term stability. In long-term stability tests, the formulation is kept for several months and its physical appearance, droplet size, pH, and drug content are frequently assessed.[59,88,89]

7.3. In Vitro Drug Release and Skin Permeation Studies

To ascertain the pace and degree of drug release from the nanoemulsion, Franz diffusion cells with synthetic or dialysis membranes are frequently used in in vitro drug release research. To assess medication penetration via various skin layers, skin penetration experiments are conducted using removed human or animal skin. When comparing nanoemulsion formulations with traditional formulations, metrics like cumulative drug permeated, flux, and permeability coefficient are useful.[60,85]

7.4. In Vitro Anti-Acne Activity and Antimicrobial Testing

Using techniques like agar diffusion or broth dilution, in vitro antimicrobial investigations against Cutibacterium acnes and other skin pathogens are used to assess the biological efficacy of nanoemulsion-based anti-acne formulations. By assessing the decrease in inflammatory markers, anti-inflammatory activity can be evaluated using cell culture models. These results verify that nanoemulsions retain or improve the therapeutic effectiveness of the integrated anti-acne medicines in addition to improving delivery.[61]

8. RECENT ADVANCES AND RESEARCH TRENDS

8.1. Novel APIs in Nanoemulsions

In an effort to enhance acne treatment, recent studies have investigated a number of novel and repurposed medications in nanoemulsion systems. To address the low skin penetration of traditional dapsone gel, for example, dapsone nanoemulsion gels were created; research revealed a greater reduction in inflammatory lesions with less irritation. Azelaic acid nanoemulsions have been shown to increase the drug's solubility and skin distribution of this weakly water-soluble medication, resulting in improved depigmenting and anti-acne benefits with less dryness.[62] In order to prevent the systemic adverse effects of oral medication while retaining a potent anti-seborrheic and comedolytic activity, isotretinoin nanoemulsions for topical use have also been investigated. Nadifloxacin nanoemulsions, which demonstrated better antibacterial efficacy against Cutibacterium acnes than commercial creams, are another example. Additionally, scientists have created benzoyl peroxide nanoemulsions to lessen its potent oxidizing and irritating effects while maintaining its antibacterial efficacy.[63]

8.2. Herbal Nanoemulsions for Acne

In recognition of improved patient acceptability and safety, herbal nanoemulsions are becoming more and more popular. Among the most extensively studied are tea tree oil nanoemulsions, which have potent activity against C. acnes and Staphylococcus epidermidis while causing less skin irritation than pure oil or traditional gels. Neem oil nanoemulsions are useful in lowering both inflammatory and non-inflammatory acne lesions and have shown strong antibacterial and anti-inflammatory properties. In acne models, curcumin nanoemulsions demonstrate increased anti-inflammatory and antioxidant action while also improving curcumin's poor solubility and stability. Aloe vera extract nanoemulsions are used to promote the healing of acne lesions and soothe irritated skin. Additionally, green tea

polyphenol nanoemulsions have been created to lower oxidative stress and sebum production, two major factors in the development of acne.[64]

8.3. Combination Nanoemulsions

One important area of research is combination therapy, which targets several acne-causing variables simultaneously. For instance, by combining keratolytic and antibacterial properties, adapalene and clindamycin co-loaded nanoemulsions have demonstrated improved management of comedones and inflammatory lesions. Erythromycin and benzoyl peroxide nanoemulsions have potent antibacterial properties with less irritation while lowering bacterial resistance. Tea tree oil and salicylic acid nanoemulsions are examples of herbal-synthetic mixtures that have both comedolytic and antibacterial properties.[65] In nanoemulsions, curcumin and clindamycin have demonstrated increased antibacterial and anti-inflammatory activity. Additionally, some research has shown that adding vitamin E or vitamin C to retinoid nanoemulsions can lessen inflammation and oxidative stress. These practical research instances demonstrate that, when compared to traditional single-drug topical formulations, nanoemulsion-based combination therapy offers greater efficacy, enhanced tolerability, and increased patient compliance.[66]

9. CHALLENGES AND LIMITATIONS

9.1. Physical and Chemical Stability Issues

Sustaining long-term chemical and physical stability is one of the fundamental issues with topical systems based on nanoemulsions. Nanoemulsions are vulnerable to instability processes such coalescence, flocculation, creaming, and Ostwald ripening during preservation because of their extremely small droplet size and high surface energy [67]. These processes can be accelerated by variations in humidity, light exposure, and temperature. Furthermore, a lot of anti-acne medications, such retinoids, benzoyl peroxide, and herbal components, are chemically unstable and can break down when exposed to light, moisture, or air. Drugs may interact with surfactants and co-surfactants employed in nanoemulsions, eventually losing their efficacy. To increase shelf life, oils, surfactants, antioxidants, and packaging components must all be carefully chosen.[68]

9.2. Skin Irritation Potential

Nanoemulsions can continue to occur in skin reactions even if their controlled release is intended to lessen irritation. The stratum corneum lipids can be disrupted by high concentrations of surfactants and co-surfactants, which are necessary to stabilize

nanoemulsions. This might result in dryness, burning, or erythema. Additionally, increased penetration may raise the possibility of administering irritating medications excessively deeply into the skin. This may exacerbate redness and discomfort in sensitive and acne-prone skin. Some people may experience allergic reactions to herbal nanoemulsions. Therefore, prior to clinical use, appropriate safety assessment, irritant testing, and excipient level adjustment are required.[69]

9.3. Scalability and Commercial Translation

Another significant challenge is scaling up nanoemulsion formulations from lab to industrial production. Production costs are increased by high-energy techniques like ultrasonication and high-pressure homogenization, which call for costly equipment and considerable energy input.[70] It is theoretically difficult to maintain constant droplet size and quality throughout large-scale manufacturing. Because nano-based goods require additional safety and toxicity data, regulatory approval is especially complicated. Additionally, the commercial translation of nanoemulsion-based anti-acne therapies may be delayed or restricted due to increased production costs, stability issues, and unclear regulatory standards for nanomedicines.[71]

9.4. Regulatory and Approval Barriers

Considering precise and consistent rules for nanomedicines are still developing, products based on nanoemulsions are subject to regulatory uncertainty. For nano-sized systems, regulatory bodies frequently require more toxicity, safety, and environmental effect assessments. Development time and cost are increased as a result. Approval is made more difficult by the absence of defined evaluation techniques for nanocarriers.[72]

9.5. Cost and Market Acceptance

Compared to traditional topical formulations, nanoemulsion solutions are more costly due to the usage of specialized excipients, sophisticated equipment, and lengthy safety testing. This could restrict acceptance and affordability, particularly in markets with low and moderate incomes. The lack of long-term clinical information may also make patients and physicians reluctant to use nano-based products.[73]

9.6. Formulation Complexity and Compatibility Issues

Carefully choosing the oil, surfactant, co-surfactant, and medication is necessary to create a stable nanoemulsion. Certain medications exhibit poor compatibility with specific excipients, which can cause instability or precipitation. It is also difficult to include nanoemulsions into

gels or creams without changing the size of the droplets. Both the development time and the failure risk are increased by the aforementioned formulation complexity.[74]

10. FUTURE PERSPECTIVES

10.1. Smart and Stimuli-Responsive Nanoemulsions

Future studies will concentrate on creating "smart" nanoemulsions that can react to particular stimuli like pH, temperature, enzymes, or oxidative stress seen in skin that is irritated by acne. For instance, in the slightly acidic environment of inflammatory follicles, pH-responsive nanoemulsions may release medications more quickly.[75] When bacterial enzymes from Cutibacterium acnes are present, enzyme-responsive systems may release antibiotics or anti-inflammatory substances. When skin temperature increases during inflammation, temperature-sensitive nanoemulsions may improve medication release. By enabling on-demand medication release, these devices would increase efficacy while reducing needless exposure and adverse effects.[76]

10.2. Personalized Topical Therapy

Another interesting approach is personalized nanoemulsion-based therapy. Individual differences in acne severity, skin type, hormonal effect, and microbiological profile are significant.[77] In the future, formulations might be tailored according to patient-specific characteristics like inflammatory condition, dominant bacterial strains, oily or dry skin, and sensitivity. For instance, individuals with mostly comedonal acne could be given formulations containing retinoids and keratolytics, whereas those with severely inflammatory acne may receive nanoemulsions rich in anti-inflammatory and antioxidant compounds. Artificial intelligence, biomarkers, and digital skin analysis could be combined to create customized nanoemulsion compositions for the best results.[78]

10.3. Clinical Translation Opportunities

There can be a great deal of potential for clinical translation, even if the majority of nanoemulsion systems currently remain in the laboratory or preclinical stage. In order to demonstrate long-term safety and greater efficacy over traditional formulations, future efforts should concentrate on carrying out carefully planned clinical trials. Researchers, the pharmaceutical industry, and regulatory bodies working together can expedite development and approval. Nanoemulsion-based topical solutions may soon be commercially readily accessible and frequently employed in the treatment of acne thanks to enhanced stability, scalable production techniques, and unambiguous regulatory guidelines.[79]

CONCLUSION

Topical medication delivery methods based on nanoemulsions are a major development in the treatment of acne vulgaris. Nanoemulsions offer superior medication solubilization, improved skin and follicular penetration, and better stability of both synthetic and herbal anti-acne medicines by addressing the drawbacks of traditional creams and gels. They are particularly well suited for delivering medications directly to the primary sites implicated in acne development because of their small droplet size, broad surface area, and capacity to target pilosebaceous units. Consequently, nanoemulsions can lessen local discomfort and the requirement for repeated application while increasing therapeutic efficiency.

Research investigations have demonstrated encouraging effects when a variety of active pharmaceutical compounds, including as retinoids, antibiotics, anti-inflammatory medications, and herbal extracts, are used. When compared to single-drug formulations, combination nanoemulsions that target several pathogenic variables, including excess sebum production, bacterial colonization, inflammation, and follicular hyperkeratinization, have shown better results. Evaluations conducted both in vitro and in vivo consistently show improved skin retention, controlled release, and increased antibacterial and anti-inflammatory activity, underscoring the potential of nanoemulsions as topical carriers for long-term acne treatment.

Despite these benefits, widespread clinical use is still constrained by issues with stability, safety, scalability, and regulatory approval. In addition to carrying out extensive clinical trials to determine long-term safety and efficacy, future research should concentrate on creating more stable, patient-friendly, and economical formulations. Nanoemulsion-based topical solutions are expected to play a significant role in future-oriented acne therapy and customized dermatological care with ongoing technological improvements and increased industry-academia collaboration.

REFERENCES

1. Samancı B, Yener G, Değim İT. Nanoemulsions a new topical drug delivery system for the treatment of acne. Journal of Research in Pharmacy, 2023 Jan 1; 27(1): 1-1.
2. Tanzeem M, Guptha PM, Kanoujia J, Kumar A, Gupta M. Improved Efficacy of Burdock-loaded Nano-emulsion Gel in Acne Vulgaris Treatment by the Quality by Design Approach. Current Drug Therapy, 2025.

3. Salim N, Ahmad N, Musa SH, Hashim R, Tadros TF, Basri M. Nanoemulsion as a topical delivery system of antipsoriatic drugs. RSC advances, 2016; 6(8): 6234-50.
4. Taleb MH, Abdeltawab NF, Shamma RN, Abdelgayed SS, Mohamed SS, Farag MA, Ramadan MA. Origanum vulgare L. essential oil as a potential anti-acne topical nanoemulsion—In vitro and in vivo study. Molecules, 2018 Aug 28; 23(9): 2164.
5. Heroweti J, Mindiono IA, Mahmud N, Pradasari F, Fresiva U, Prihantini M. Formulation of Nanoemulsion Gel Pogostemon cablin Benth. And Anti-acne Activity. Indonesian Journal of Pharmaceutical Science and Technology, 2025 Oct 31; 12(3): 338-48.
6. Dos Santos ZM, Zan FR, Rech VC, Ourique AF. Topical Nanotherapeutics for the Treatment of Acne Vulgaris. InNovel Nanocarriers for Skin Diseases, 2025 Feb 10; 39-97. Apple Academic Press.
7. Talianu MT, Dinu-Pîrvu CE, Ghica MV, Anuţa V, Jinga V, Popa L. Foray into concepts of design and evaluation of microemulsions as a modern approach for topical applications in acne pathology. Nanomaterials, 2020 Nov 19; 10(11): 2292.
8. Garcia CR, Malik MH, Biswas S, Tam VH, Rumbaugh KP, Li W, Liu X. Nanoemulsion delivery systems for enhanced efficacy of antimicrobials and essential oils. Biomaterials Science, 2022; 10(3): 633-53.
9. Najafi-Taher R, Amani A. Nanoemulsions: colloidal topical delivery systems for antiacne agents-A Mini-Review. Nanomedicine Research Journal., 2017 Feb 1; 2(1): 49-56.
10. Souto EB, Cano A, Martins-Gomes C, Coutinho TE, Zielińska A, Silva AM. Microemulsions and nanoemulsions in skin drug delivery. Bioengineering, 2022 Apr 5; 9(4): 158.
11. Jayronia S, Kohli K, Agarwal R. Formulation and in vitro Evaluation of Tea Tree Oil-based Tretinoin Nanoemulsion for Antimicrobial and Anti-inflammatory Activity in Acne Management. Journal of Pharmaceutical Innovation, 2026 Feb; 21(1): 61.
12. Magrode N, Poomanee W, Kiattisin K, Ampasavate C. Microemulsions and nanoemulsions for topical delivery of Tripeptide-3: From design of experiment to anti-sebum efficacy on facial skin. Pharmaceutics, 2024 Apr 19; 16(4): 554.
13. Rahma H, Priani SE, Fakih TM, Suarantika F, Patricia VM, Laksono BT, Subekti PI. Nanoemulsion-based delivery system of tamanu (Calophyllum inophyllum L.) oil: Formulation, characterization, and antibacterial activity. Pharmacia, 2025 Jun 9; 72: 1-1.
14. Mahajan S, Kaur K, Saini N, Chaudhary TK, Nim L, Bedi N. Development and evaluation of topical nanoemulgel formulation of tazarotene for effective treatment of

excision wounds. Current Nanomedicine (Formerly: Recent Patents on Nanomedicine)., 2022 Jul 1; 12(2): 137-49.

15. Abbasi U, Khan MZ, Fatima M, Gupta G, Molugulu N, Sahebkar A, Abourehab MA, Kesharwani P. Exploring the potential of nanoemulgels for dermatological disorders. Journal of Drug Targeting., 2025 Apr 24: 1-23.
16. Ijaz F, Nasir B, Rashid SA, Naseem F, Jalil A, Riaz A, Latip J, Alzahrani KJ, Alsharif KF, Azad AK. Colistin adorned topical nanoemulsion gel formulation for enhanced anti-microbial activity. Scientific Reports., 2025 Sep 30; 15(1): 1-5.
17. Alamoudi MK, Ahmad N, Ansari K, Aldossari RM, Khalid MS, Ullah Z, Alyami HM, Alqahtani AJ, Merghani A, Ahmad S, Haque A. A comparative dermatokinetic evaluation of thymoquinone-loaded nanoemulsion gel for enhanced wound healing and anti-inflammatory efficacy. Polymer Bulletin., 2025 Sep; 82(14): 9581-621.
18. Romes NB, Abdul Wahab R, Abdul Hamid M. The role of bioactive phytoconstituents-loaded nanoemulsions for skin improvement: a review. Biotechnology & Biotechnological Equipment., 2021 Jan 1; 35(1): 711-30.
19. Le TT, Nguyen TK, Nguyen VM, Dao TC, Nguyen HB, Dang CT, Le TB, Nguyen TK, Nguyen PT, Dang LH, Doan VM. Development and characterization of a hydrogel containing curcumin-loaded nanoemulsion for enhanced in vitro antibacteria and in vivo wound healing. Molecules., 2023 Sep 4; 28(17): 6433.
20. Nguyen D, Kumar M. Formulation and Evaluation of Nanoemulsion-Based Cream Using Green Ingredients Exhibiting Enhanced Performance Characteristics. Colloid Journal., 2025 Apr; 87(2): 302-14.
21. Deniz FS, Oyardı O, Bozkurt Guzel C, Yalcın TE, Yiğitkan S, Kan Y, Ulger Toprak N, Orhan IE. Assessment of the Anti-Acne Properties of Some Medicinal Plants and Development of an Herbal Anti-Acne Formulation. Pharmaceutics., 2025 Mar 1; 17(3): 317.
22. da Silva TL, de Oliveira Capote AC, Beltrame FL, Ferrari PC. Nanoemulsions for Skin Delivery of Essential Oils: A Systematic Review. Phytotherapy Research., 2026 Jan 10.
23. Eid AM, Naseef H, Jaradat N, Ghanim L, Moqadeh R, Yaseen M. Antibacterial and anti-acne activity of benzoyl peroxide nanoparticles incorporated in lemongrass oil nanoemulgel. Gels., 2023 Feb 27; 9(3): 186.
24. Rathee J, Malhotra S, Pandey M, Jain N, Kaul S, Gupta G, Nagaich U. Recent update on nanoemulsion impregnated hydrogel: a gleam into the revolutionary strategy for

diffusion-controlled delivery of therapeutics. AAPS PharmSciTech., 2023 Jul 12; 24(6): 151.

25. Phaugat P, Nishal S, Dutt R, Khansili A. A co-additive nanoemulgel formulation of tretinoin and curcumin: Formulation and optimization. Journal of Applied Pharmaceutical Science., 2022 Sep 4; 12(9): 058-66.
26. Sharma RP, Jerome N, Pradeep S, Yadav S, Saravanakumar R. Recent Advances in Nanoemulsion-Based Therapeutics for Inflammation and Edema Treatment. Regenerative Engineering and Translational Medicine., 2025 Jul 25: 1-22.
27. Salau AK, Shehu MS, Adisa KO, Olarewaju OI, Adeyemo AA. Nanoemulsion drug delivery systems for dermatological disorders: a review of mechanisms, clinical applications and commercial advances. UMYU Scientifica., 2025 Jun 30; 4(2): 175-92.
28. Raina N, Rani R, Thakur VK, Gupta M. New insights in topical drug delivery for skin disorders: from a nanotechnological perspective. ACS omega., 2023 May 19; 8(22): 19145-67.
29. Puspadewi R, Milanda T, Muhaimin M, Chaerunisaa AY. Nanoparticle-encapsulated plant polyphenols and flavonoids as an enhanced delivery system for anti-acne therapy. Pharmaceuticals., 2025 Feb 4; 18(2): 209.
30. Tanuku S, Velisila D, Thatraju D, kumar Vadaga A. Nanoemulsion formulation strategies for enhanced drug delivery. Journal of Pharma Insights and Research., 2024 Aug 4; 2(4): 125-38.
31. Yuniarsih N, Chaerunisaa AY, Elamin KM, Wathoni N. Polymeric nanohydrogel in topical drug delivery system. International Journal of Nanomedicine., 2024 Dec 31: 2733-54.
32. Stefanov SR, Andonova VY. Lipid nanoparticulate drug delivery systems: recent advances in the treatment of skin disorders. Pharmaceuticals., 2021 Oct 26; 14(11): 1083.
33. Patel S, Pandey G, Yadav SK. Review on nanoemulsion based drug delivery system. Asian J Pharmaceutical Educ Res., 2018; 7(2): 17-27.
34. Sivadasan D, Madkhali OA. The design features, quality by design approach, characterization, therapeutic applications, and clinical considerations of transdermal drug delivery systems—a comprehensive review. Pharmaceuticals., 2024 Oct 9; 17(10): 1346.
35. Liu S, Deng T, Cheng H, Lu J, Wu J. Advances in Transdermal Drug Delivery Systems and Clinical Applications in Inflammatory Skin Diseases. Pharmaceutics., 2025 Jun 6; 17(6): 746.

36. Omidi M, Morteza-Semnani K, Saeedi M, Frahmand M, Kamali M, Mohammadian E, Hassan Hashemi SM. Lavender essential oil nanoemulsion gel as skin lightener: green formulation, full characterization, anti-melanogenesis effect, and in-vitro/in-vivo safety profile assessment. Nanomedicine Journal., 2025 Jul 1; 12(3).
37. Cheng T, Tai Z, Shen M, Li Y, Yu J, Wang J, Zhu Q, Chen Z. Advance and challenges in the treatment of skin diseases with the transdermal drug delivery system. Pharmaceutics, 2023 Aug 21; 15(8): 2165.
38. Gupta M, Agrawal U, Vyas SP. Nanocarrier-based topical drug delivery for the treatment of skin diseases. Expert opinion on drug delivery, 2012 Jul 1; 9(7): 783-804.
39. Donthi MR, Munnangi SR, Krishna KV, Saha RN, Singhvi G, Dubey SK. Nanoemulgel: a novel nano carrier as a tool for topical drug delivery. Pharmaceutics., 2023 Jan 3; 15(1): 164.
40. Garg A, Sharma GS, Goyal AK, Ghosh G, Si SC, Rath G. Recent advances in topical carriers of anti-fungal agents. Heliyon., 2020 Aug 1; 6(8).
41. Bhardwaj S, Tiwari A. Nanoemulgel: A promising nanolipoidal-emulsion based drug delivery system in managing psoriasis. Dhaka University Journal of Pharmaceutical Sciences., 2021 Dec 29; 20(2): 235-46.
42. Yan Z, Zhang S, Wu G, Kang Y, Fu C, Wang Z, Wang G, Tang L, Wang W. Advances in Nanotechnology-Based Topical Delivery Systems for Skincare Applications. Pharmaceutics., 2026 Jan 3; 18(1): 63.
43. Gupta N, Gupta GD, Singh D. Localized topical drug delivery systems for skin cancer: Current approaches and future prospects. Frontiers in Nanotechnology., 2022 Oct 21; 4: 1006628.
44. Imam SS. The future of non-invasive ways to treat cancer. Int J Pharm Sci & Res., 2021; 12(8): 4684-96.
45. Imam SS, Agarwal S. A Pragmatic Approach To Treat Lung Cancer Through Loading Theaflavin -3,3'-Digallate And Epigallocatechin Gallate In Spanlastic. Asian J Pharm Clin Res., 2021 Nov 7; 14(11): 1-8.
46. Imam SS, Imam ST, Mdwasifathar, Kumar R, Ammar MY. Interaction Between Ace2 And Sars-Cov2, And Use Of EGCG And Theaflavin To Treat Covid 19 In Initial Phases. International Journal of Current Pharmaceutical Research., 2022 Mar; 14(2): 5-10.
47. Imam SS, Sharma R. Natural compounds promising way to treat Lung Cancer. International Journal of Pharmaceutical Research and Applications., 2023; 8(2): 552- 558.

48. Imam SS, Sharma S, Kumari D, Khan S, Pathak P, Katiyar D. An Expedient Approach to Treat Asthma through Non-Steroidal, Natural Transferosomes Aerosol System. Innovare journal of medical sciences., 2022; 10(6): 7-11.
49. Imam SS, Imam ST, Agarwal S, Kumar R, Ammar MY, Athar MW, Akthar A. Lung Cancer Therapy Using Naturally Occurring Products and Nanotechnology. Innovare journal of medical sciences, 2022; 10(4): 1-5.
50. Imam ST, Imam SS. The Cream which relieves the pain of Menstrual cramps without interfering with the Hormones or Period Cycle. Research Journal of Pharmacy and Technology., 2023; 16(3): 1239-6.
51. Imam SS. Topical Formulation Constituted with Transferosomes for the Treatment Of Non-Melanoma Skin Cancer. Asian J Pharm Clin Res., 2023 May 7; 16 (5): 27-32.
52. Imam SS. Nanoparticles: The Future of Drug Delivery. Int J Curr Pharm Sci., 2023 Nov. 15; 15 (6): 8-15.
53. Imam SS, Mehdi S, Mansuri A. A comprehensive review on the pharmacological potential of red ginseng oil, tea tree oil and hemp seed oil. European Journal of Biomedical., 2024; 11 (4): 167-77.
54. Imam SS. Sublingual Tablets Amalgamated with Nano-particles and natural products to treat Oral Cancer., 2024; 17(5): 2056-62.
55. Imam SS, Mehdi S. Factors Affecting Pharmaceutical Pricing In India. International Journal of Pharmaceutical Sciences., 2024; 2 (4): 1367-1384. DOI: 10.5281/zenodo.11314004.
56. Mehdi S, Tabrez UZ, Imam SS. Management of Green Pharmaceuticals. International Journal of Pharmaceutical Sciences and Research., 2024; 15 (7): 1951-1962. DOI: 10.13040/IJPSR.0975-8232.15 (7).1951-62.
57. Imam SS. Evaluating the Impact of Us Tariffs And Evolving Global Trade Policies On Pharmaceutical Pricing, Market Penetration, and the Supply of Generic Medicines from India to the World. Journal of Pharmacoeconomics and Pharmaceutical Management., 2025 Nov 7; 11(2): 27-34.
58. Imam SS. Pharmaceutical Marketing Management in India. Journal of Pharmacoeconomics and Pharmaceutical Management., 2024 Oct 23; 10(2): 37-48.
59. Mandal S, Vishvakarma P, Mandal S. Future aspects and applications of Nanoemulgel formulation for topical lipophilic drug delivery. European Journal of Molecular & Clinical Medicine, 2023; 10(01): 2023.

60. Jain AK, Jain S, Abourehab MA, Mehta P, Kesharwani P. An insight on topically applied formulations for management of various skin disorders. Journal of Biomaterials Science, Polymer Edition., 2022 Nov 23; 33(18): 2406-32.
61. Hosny KM, Alhakamy NA, Al Nahyah KS. The relevance of nanotechnology, hepato-protective agents in reducing the toxicity and augmenting the bioavailability of isotretinoin. Drug Delivery., 2021 Jan 1; 28(1): 115-25.
62. Nair AB, Chaudhary S, Jacob S, Patel D, Shinu P, Shah H, Chaudhary A, Aldhubiab B, Almuqbil RM, Alnaim AS, Alqattan F. Intranasal administration of dolutegravir-loaded nanoemulsion-based in situ gel for enhanced bioavailability and direct brain targeting. Gels., 2023 Feb 3; 9(2): 130.
63. Malavi S, Kumbhar P, Manjappa A, Chopade S, Patil O, Kataria U, Dwivedi J, Disouza J. Topical Emulgel: Basic Considerations in Development and Advanced Research. Indian Journal of Pharmaceutical Sciences., 2022 Sep 1; 84(5).
64. Ershaid JM, Abudoleh SM, Lafi DN, Dahshan NA. Formulation and Characterization of PLGA Minocycline Microneedles for Enhanced Skin Deposition and Antibacterial Activity in Acne Treatment. Polymers., 2025 Oct 31; 17(21): 2912.
65. Jain V, Kumar H, Chand P, Jain S, S P. Lipid-Based Nanocarriers as Drug Delivery System and Its Applications. Nanopharmaceutical advanced delivery systems., 2021 Jan 12: 1-29.
66. Souto EB, Cano A, Martins-Gomes C, Coutinho TE. Zieli nska, A. Silva, AM Microemulsions and nanoemulsions in skin drug delivery. Bioengineering, 2022; 9: 158.
67. Ansari A, Verma M, Majhi S. Nanoemulgel: A Comprehensive Review of Formulation Strategies, Characterization, Patents and Applications. Micro and Nanosystems., 2025 Mar; 17(1): 12-26.
68. Lal DK, Kumar B, Saeedan AS, Ansari MN. An overview of nanoemulgels for bioavailability enhancement in inflammatory conditions via topical delivery. Pharmaceutics., 2023 Apr 7; 15(4): 1187.
69. Mohseni-Motlagh SF, Dolatabadi R, Baniassadi M, Baghani M. Application of the quality by design concept (QbD) in the development of hydrogel-based drug delivery systems. Polymers., 2023 Nov 14; 15(22): 4407.
70. Grumezescu AM. Nano-and microscale drug delivery systems: design and fabrication. William Andrew; 2017 Mar 27.

71. Raj G, Halagali P, S P, CS S, Somanna P, Sharma H. Formulation and Evaluation of a Nanoemulsion Gel for the Improved Topical Delivery of Dithranol in Psoriasis. Nanoscience & Nanotechnology-Asia., 2025 Aug; 15(4): E22106812377833.
72. Petrovici AG, Spennato M, Bîtcan I, Péter F, Cotarcă L, Todea A, Ordodi VL. A comprehensive review of azelaic acid pharmacological properties, clinical applications, and innovative topical formulations. Pharmaceuticals, 2025 Aug 26; 18(9): 1273.
73. Menon R, Shripathy D, Shabaraya AR. International Journal of Modern Pharmaceutical Research. system., 3(4): 5.
74. Dumitriu Buzia O, Păduraru AM, Stefan CS, Dinu M, Cocoș DI, Nwabudike LC, Tatu AL. Strategies for improving transdermal administration: New approaches to controlled drug release. Pharmaceutics., 2023 Apr 7; 15(4): 1183.
75. Hakemi-Vala M, Rafati H, Aliahmadi A, Ardalan A. Nanoemulsions: a novel antimicrobial delivery system. InNano-and microscale drug delivery systems 2017 Jan 1 (pp. 245-266). Elsevier.
76. Jain A, Kumar P, Verma A, Mohanta BC, Ashique S, Pal R, Kumar S, Mishra N. Emulgel: A cutting edge approach for topical drug delivery system. Current Drug Research Reviews., 2025 Jul; 17(2): 217-36.
77. Prakash D, Chaudhary A. Development of nanoemulsion-Based gel of betulin for the treatment of psoriasis-like skin inflammation in a small animal model. Pharmaceutical Nanotechnology, 2024 Dec 30.
78. Mishra RK, Soni GC, Mishra R. Nanoemulsion: a novel drug delivery tool. International Journal of Pharma Research & Review., 2014 Jul; 3(7): 32-43.
79. Baveloni FG, Riccio BV, Di Filippo LD, Fernandes MA, Meneguin AB, Chorilli M. Nanotechnology-based drug delivery systems as potential for skin application: a review. Current Medicinal Chemistry, 2021 May 1; 28(16): 3216-48.
80. Ain S, Kumar B, Pathak K. Development and characterization of controlled release famotidine matrix tablets containing complexes. Int J Appl Pharm., 2017; 9(4): 3.
81. Ain S, Ain Q, Parveen S. An overview on various approaches used for solubilization of poorly soluble drugs. Pharma Res., 2010; 2: 84–104.
82. Gupta V, Ain S, Babita K, Ain Q, Dahiya J. Solubility enhancement of the poorly water-soluble antiulcer drug famotidine by inclusion complexation. Int J Pharm Sci Nanotechnol., 2013; 6(1): 1983–1989.

83. Ali M, Ain S, Kumar B, Ain Q. Development and evaluation of eugenol-based gel formulation for analgesic and anti-inflammatory action. Ann Phytomed., 2022; 11(1): 338–345.
84. Dhama PK, Ain S, Kumar B, Ain Q. Development and evaluation of topical ointment formulation containing gallic acid as an active pharmaceutical ingredient against bacterial infection and oxidative damage. Ann Phytomed., 2022; 11(1): 439–449.
85. Kumar V, Ain S, Kumar B, Ain Q. Optimization and evaluation of topical gel containing solid lipid nanoparticles loaded with luliconazole and its antifungal activity. Int J Pharm Res., 2021.
86. Ain S, Mishra G, Kumar B, Ain Q, Garg RK. Antidiabetic potential of developed solid lipid nanoparticles loaded with quercetin: In vitro and in silico studies. Ann Phytomed., 2022; 11(2): 732–742.
87. Verma HK, Kumar V, Ain S, Kumar B, Ain Q. Optimization and evaluation of developed topical ointment formulation containing cefadroxil and its antibacterial activity. Int J Pharm Res., 2021; 13(2).
88. Ain S, Ain Q, Pandey S, Tyagi V, Vats Y, Ruhela N, et al. Assessment of ground water quality in different areas of Uttar Pradesh and Haryana. Cuest Fisioter., 2022; 54(2): 3557–3574.
89. Ain S, Ain Q, Chaturvedi S, Kumar B. Comparative assessment of groundwater quality in different areas of Delhi NCR (Ghaziabad, Noida) and East UP (Varanasi). Indian J Pharm Pharmacol., 2021; 8(1): 58–64.
90. Uzair M, Ain S, Ain Q, Kumar B, Kumar V, Pandey S. CRISPR-Cas systems in targeted drug delivery and gene therapy: An emerging approach to precision medicine. Int J Res Pharm Allied Sci., 2022; 5(2): 66–87.