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Advancements in Emulgel Drug Delivery

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Abstract: Topical drug administration systems are widely used for the treatment of localized skin disorders due to their ability to deliver drugs directly to the site of action while reducing systemic side effects. However, topical formulations such as creams, ointments, and gels often exhibit limitations such as poor stability, low drug-loading capacity, inadequate delivery of hydrophobic drugs, and reduced patient acceptability. Emulgels, which combine the properties of emulsions and gels, have emerged as promising carriers capable of overcoming these limitations. The combination of emulsion and gel systems enables improved delivery of both hydrophilic and lipophilic therapeutic agents while providing improved spreadability, stability, controlled drug release, and enhanced skin permeation. This review summarizes the formulation principles, preparation methods, evaluation parameters, and therapeutic applications of emulgels. The influence of formulation components such as oils, emulsifiers, gelling agents, penetration enhancers, and preservatives on product performance is discussed. Recent developments including nanoemulgels, microemulgels, herbal emulgels, and natural polymer-based systems are also highlighted. Furthermore, current challenges, research gaps, and future prospects are presented. Overall, emulgels represent a versatile and effective topical drug delivery platform with considerable potential for pharmaceutical, dermatological, and cosmeceutical applications.

Keywords: *Emulgel, Topical Drug Administration, Nanoemulgel, Microemulgel, Carbopol, Herbal Emulgel, Controlled Release.*

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I. INTRODUCTION

Topical drug delivery systems (TDDS) are widely used because they deliver drugs directly to the site of action, minimize systemic adverse effects, avoid first-pass metabolism, and improve patient compliance. Conventional topical formulations such as creams, ointments, lotions, and gels have been extensively employed for the treatment of dermatological disorders, pain, inflammation, fungal infections, and cosmetic conditions.

Despite their benefits, these formulations possess several limitations. Ointments are often greasy and cosmetically unacceptable, creams may undergo phase separation during storage, and gels exhibit limited capacity for incorporating lipophilic drugs due to their hydrophilic nature.

To overcome these challenges, emulgel technology has emerged as an innovative topical delivery system. Emulgels are biphasic formulations produced by incorporating an emulsion into a gel matrix. This approach enables efficient delivery of hydrophobic drugs through the oily phase while maintaining the favorable rheological properties of gels. Consequently, emulgels offer improved drug loading, enhanced stability, better spreadability, prolonged drug release, and increased skin retention compared with conventional semisolid formulations.

Recent studies have demonstrated the successful application of emulgels for delivering anti-inflammatory, antifungal, antibacterial, corticosteroid, herbal, antioxidant, and cosmetic agents. Additionally, advances such as nanoemulgels and microemulgels have further expanded their therapeutic potential, making emulgels a promising platform for modern topical drug delivery.

II. SKIN AND TOPICAL DRUG DELIVERY

The skin, the largest organ of the human body, functions as a protective barrier that regulates body temperature, prevents water loss, and shields the body from microbes, ultraviolet radiation, and environmental pollutants. Anatomically, the skin consists of three principal layers:

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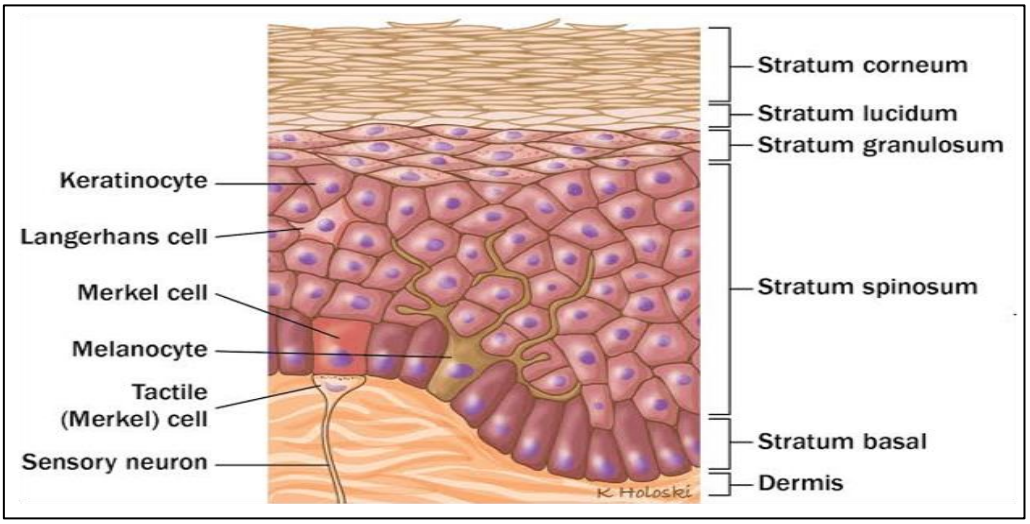


Fig 1 Structure of Human Skin

➢ *Epidermis*

The epidermis is the outermost layer of the skin and acts as the primary barrier against external substances. It is composed of five distinct layers:

- Stratum corneum
- Stratum lucidum
- Stratum granulosum
- Stratum spinosum
- Stratum basale

The stratum corneum is the primary barrier to transdermal drug delivery, consisting of dead keratinized cells embedded in a lipid-rich matrix often described as a "brick-and-mortar" structure.

➢ *Dermis*

The dermis, located beneath the epidermis, contains blood vessels, lymphatics, hair follicles, sweat glands, sebaceous glands, and connective tissue. Drugs penetrating the epidermis generally reach the dermis, where systemic absorption may occur.

➢ *Hypodermis*

The hypodermis, or subcutaneous layer, is mainly composed of adipose and connective tissue. It acts as an energy reserve, provides cushioning, and supports systemic drug absorption.

- *Routes of Drug Penetration*

Topically applied drugs may penetrate the skin through three primary pathways:

✓ Transcellular Route
✓ Intercellular Route
✓ Follicular Route

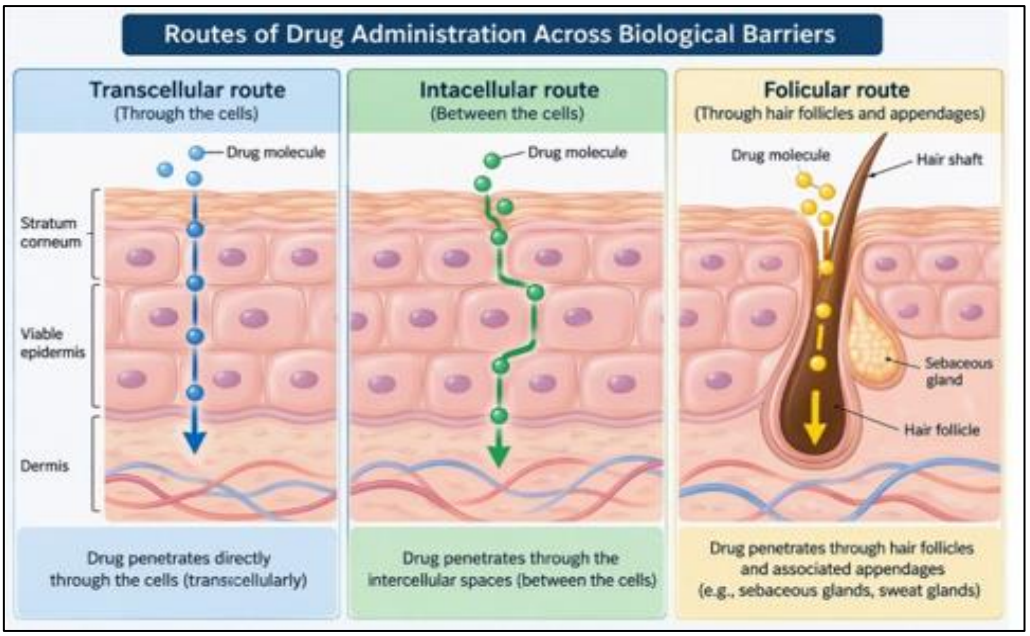


Fig 2 Major Pathways of Percutaneous Drug Absorption

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- *Transcellular Route*

Drug molecules pass directly through corneocytes of the stratum corneum, requiring repeated partitioning between hydrophilic and lipophilic regions, which limits diffusion.

- *Intercellular Route*

This is the primary penetration pathway, where drugs diffuse through lipid channels between corneocytes. Most emulgels and permeation enhancers facilitate transport via this route.

- *Follicular Route*

Drugs may also penetrate through hair follicles, sweat glands, and sebaceous glands, which act as reservoirs for topical drug delivery.

➢ *Emulgel*

Emulgel is a biphasic dosage form obtained by incorporating an oil-in-water (o/w) or water-in-oil (w/o) emulsion into a gel base. It was developed to improve the topical delivery of poorly water-soluble drugs that cannot be effectively incorporated into conventional gels.

The combination of emulsion and gel provides dual benefits: the emulsion acts as a reservoir for lipophilic drugs, while the gel enhances viscosity, spreadability, and patient acceptability. In o/w emulgels, hydrophobic drugs are dissolved in the oil phase before emulsification, resulting in improved stability and controlled drug release.

➢ *Mechanism of Drug Release from Emulgel*

Drug release occurs through the following steps:

- Drug dissolution in the oil phase
- Diffusion across the oil-water interface
- Migration through the gel matrix
- Penetration through the stratum corneum
- Distribution into deeper skin layers

This multistep process provides sustained drug release and enhanced bioavailability. Due to their versatility, emulgels are widely used for delivering anti-inflammatory, antifungal, antibacterial, herbal, and cosmetic agents.

III. FORMULATION COMPONENTS OF EMULGEL

The performance of an emulgel depends on the appropriate selection of formulation components. The major ingredients include the oil phase, aqueous phase, emulsifying agents, gelling agents, penetration enhancers, preservatives, and active pharmaceutical ingredients. Each component plays an important role in maintaining formulation stability, drug release, rheological behavior, and therapeutic efficacy.

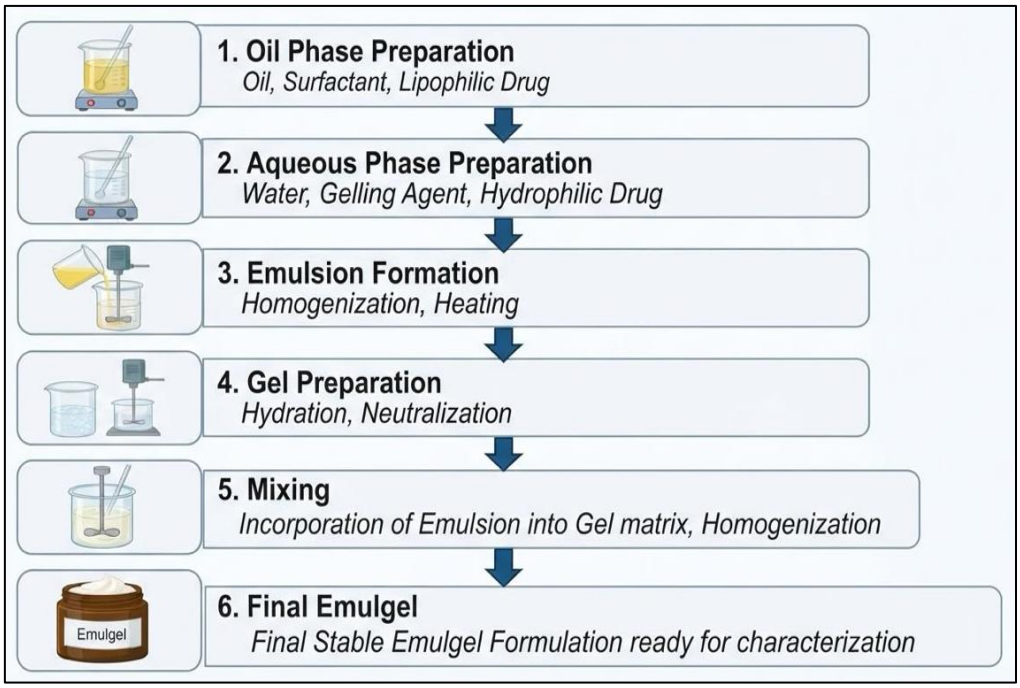


Fig 3 Preparation of Emulgel

➢ *Oil Phase*

The oil phase acts as a reservoir for lipophilic drugs and influences drug solubility and skin permeation. Commonly used oils include liquid paraffin, olive oil, sunflower oil, sesame oil, castor oil, and jojoba oil. Natural oils such as olive and sunflower oil may provide additional therapeutic benefits and can affect the stability and release characteristics of emulgels.

➢ *Aqueous Phase*

The aqueous phase forms the continuous phase of oil-in-water emulsions and supports gel formation. Purified water is commonly used, while ethanol, propylene glycol, and glycerol may be incorporated as co-solvents to improve drug solubility and skin permeation.

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➢ *Emulsifying Agents*

Emulsifying agents stabilize the oil and water phases by reducing interfacial tension. Tween 20 and Tween 80 are commonly used for oil-in-water emulsions, whereas Span 20 and Span 80 are preferred for water-in-oil systems. Appropriate surfactant selection improves emulsion stability and drug release.

➢ *Gelling Agents*

Gelling agents convert liquid emulsions into semisolid systems and improve viscosity, spreadability, and drug retention. Common agents include Carbopol 934, Carbopol 940, HPMC, NaCMC, κ-carrageenan, xanthan gum, and guar gum. Natural polymers are increasingly used due to their biodegradability and sustainability.

➢ *Penetration Enhancers*

Penetration enhancers improve drug permeation by temporarily modifying the barrier function of the stratum corneum. Common examples include oleic acid, menthol, eucalyptus oil, clove oil, propylene glycol, and urea.

➢ *Preservatives and Stabilizers*

Preservatives such as methyl paraben and propyl paraben prevent microbial contamination, while stabilizers and antioxidants protect formulations from degradation and phase separation, particularly in herbal emulgels.

➢ *Comparative Analysis of Gelling Agents Used in Emulgel Formulations*

The gelling agent directly dictates emulgel viscosity, spreadability, rheological profiles, and active drug release kinetics. Synthetic, semi-synthetic, and natural polymers are selected based on their specific structural behaviors:

- Synthetic Carbomers: Carbopol grades are the most widely studied thickeners due to their high structural clarity and strong bioadhesive capabilities. Comparative evaluations show that Carbopol 934 frequently provides superior active diffusion over Carbopol 940; for example, an Etoricoxib emulgel optimized with Carbopol 934 yielded a higher cumulative release profile matching commercial standards. Conversely, Carbopol 940 delivers excellent structural uniformity and baseline physical stability in complex polyherbal matrices containing Nirgundi oil, Turmeric, Capsaicin, and *Aloe vera* fillets.
- Natural Hydrocolloids: Driven by sustainable pharmaceutical development, plant-derived alternatives offer excellent biocompatibility and high swelling indices. Textural profiling of κ-carrageenan shows that increasing polymer concentrations triggers a sharp increase in matrix hardness and viscosity while systematically decreasing network springiness. A fine-tuned 1.0% κ-carrageenan framework provides the ideal balance between raw mechanical firmness and processing flowability.

The modern formulation trend heavily favors the development of hybrid gelling networks that blend synthetic carbomers with natural hydrocolloids to achieve optimal thixotropic performance while maximizing environmental sustainability.

Table 1 Comparison of Common Gelling Agents Used in Emulgel Formulations

Gelling Agent	Advantages	Limitations	Key Findings
Carbopol 934	Excellent viscosity, spreadability, drug release	pH sensitive	Higher drug release observed in Etoricoxib emulgel
Carbopol 940	High gel strength, stability	Greater viscosity at high concentrations	Suitable for herbal formulations
HPMC	Good film-forming property, low irritation	Lower viscosity than Carbopol	Widely used in controlled-release formulations
κ-Carrageenan	Natural, biodegradable, good rheology	Increased rigidity at high concentrations	1.0% concentration showed optimum performance
Xanthan Gum	Biocompatible and economical	Lower clarity	Useful in herbal topical formulations

➢ *Preparation Methods of Emulgel*

Emulgel fabrication follows a systematic three-stage compounding sequence:

- Preparation of Gel Base: Gelling agents are dispersed into purified water under continuous mechanical agitation (200–900 rpm). Synthetic carbomers require prolonged hydration followed by neutralization with triethanolamine or sodium hydroxide. This process induces polymer chain distension to achieve optimal thickness and eliminate grittiness.
- Preparation of Emulsion: The oil phase (lipophilic surfactants and oil-soluble APIs) and the aqueous phase (hydrophilic surfactants, preservatives, and polar components) are formulated in separate vessels. Both phases are heated independently to 60–80°C, mixed under mechanical stirring, and cooled to yield a stable o/w or w/o system.
- Incorporation of Emulsion into Gel: The final emulgel is obtained by gradually blending the emulsion into the hydrated gel base under low-shear stirring (optimized at 200 rpm). Excessive agitation must be avoided to prevent emulsion destabilization and air bubble entrapment.

➢ *Evaluation Parameters of Emulgel*

Rigorous physicochemical and biological validation is required to ensure formulation quality, uniformity, and safety:

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- Physical Appearance and Homogeneity: Formulations undergo visual inspection under high-intensity light to evaluate color, consistency, and texture. An optimized matrix must present a uniform, creamy layout completely free of lumps, grittiness, or phase separation.

- pH Determination: Values are recorded using a calibrated digital pH meter. Dermal products require a biocompatible range of 5.5 to 6.8 to minimize contact irritation, while validated herbal systems typically settle between 5.6 and 5.9.

- Viscosity Measurement: Tracked at controlled temperatures using a digital rotational viscometer (e.g., Brookfield cone-and-plate or spindle systems). High-performance emulgels exhibit pseudoplastic shear-thinning and thixotropic flow parameters to allow easy skin application.

- Spreadability: Measures the ease of distribution across a tissue interface under minimal shear force using "slip" and "drag" pulley apparatuses. Spreadability is directly governed by polymer density, matrix viscosity, and internal phase volumes.

- Extrudability: Evaluates the mechanical force required to expel a uniform ribbon of emulgel from a collapsible aluminum or plastic tube. Acceptable ribbon weight percentages confirm appropriate flowability and package compatibility.

- Drug Content Determination: Extracted via total droplet sonic disruption in an organic solvent (e.g., methanol) and quantified using UV-Visible spectrophotometry or HPLC. Optimized formulations must demonstrate narrow uniformity margins between 95% and 100%.

- In Vitro Drug Release Studies: Conducted using vertical Franz diffusion cells across a semipermeable or natural membrane into a physiological receptor buffer at 37°C. Optimized NSAID configurations (e.g., Etoricoxib emulgels) demonstrate complete cumulative release exceeding 95%, following controlled diffusion pathways.

- Stability Studies: Samples are stored inside hot air stability chambers under controlled temperature regimes (37°C, 45°C, and 60°C) for up to 3 months according to ICH guidelines. Stable systems must retain their visual clarity, target viscosity, pH bounds, and drug content profile without undergoing syneresis or droplet coalescence.

IV. THERAPEUTIC APPLICATIONS OF EMULGEL

Emulgels are highly versatile topical delivery systems that combine hydrophilic (water-loving) and lipophilic (fat-loving) components. By blending these elements, they improve drug solubility, increase skin retention, provide controlled release, and enhance patient compliance.

Advancements in polymer science and nanotechnology (such as nanoemulgels) have expanded their clinical potential across various fields:

- Pharmaceuticals & Medicine**:** Used to treat inflammatory disorders, fungal and bacterial infections, acne vulgaris, psoriasis, eczema, wound healing, and oral ulcers.
- Cosmeceuticals & Cosmetics**:** Applied in skin hydration, anti-aging, and managing hyperpigmentation disorders.
- Herbal Medicine**:** Serves as an efficient carrier for plant-derived bioactive compounds.

➢ *Anti-Inflammatory and Analgesic Applications*

Inflammation and pain are among the most common pathological conditions treated through topical drug delivery systems. Oral administration of non-steroidal anti-inflammatory drugs (NSAIDs) is frequently associated with gastrointestinal irritation, ulcer formation, hepatic metabolism, and systemic adverse effects. Consequently, topical delivery has become an attractive alternative for achieving localized therapeutic action while minimizing systemic toxicity.

Emulgels have demonstrated remarkable success in delivering NSAIDs because many anti-inflammatory drugs exhibit poor aqueous solubility. The oil phase of emulgels provides an ideal environment for dissolving hydrophobic drugs, while the gel matrix controls drug release and prolongs contact time with the skin.

Several synthetic anti-inflammatory drugs have been successfully incorporated into emulgel formulations, including:

- Diclofenac diethylamine
- Ketoprofen
- Piroxicam
- Mefenamic acid
- Etoricoxib
- Aceclofenac

Etoricoxib emulgels are widely researched for their potent anti-inflammatory and COX-2 inhibitory effects. Studies show that Carbopol 934-based formulations outperform Carbopol 940, delivering superior stability and an optimal drug release exceeding 95%.

- Herbal Alternatives: Polyherbal emulgels mixing Nirgundi, Turmeric, Aloe vera, Amla, and Capsicum oils offer stable, effective pain relief with excellent viscosity and skin applicability.
- Clinical Uses: Because they maintain high, prolonged drug concentrations at the application site, these emulgels are ideal for treating musculoskeletal issues like arthritis, sports injuries, sprains, and muscle pain.

➢ *Antifungal Applications*

Superficial fungal infections affect millions of individuals worldwide and represent one of the most common dermatological disorders. Conventional creams and

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ointments frequently require repeated application and may not provide adequate drug retention within infected skin layers.

Emulgels have emerged as promising carriers for antifungal agents because they facilitate deeper drug penetration into the stratum corneum while maintaining prolonged drug residence at the site of infection. The incorporation of lipophilic antifungal drugs into the oil phase significantly improves their solubilization and bioavailability.

Common antifungal drugs formulated as emulgels include:

- Clotrimazole
- Ketoconazole
- Itraconazole
- Miconazole nitrate
- Terbinafine hydrochloride
- Fluconazole

The enhanced permeability of emulgels improves drug transport through the stratum corneum and promotes drug accumulation in infected tissues. Their controlled-release properties provide sustained antifungal activity and reduce application frequency. Antifungal emulgels also offer better spreadability, improved patient compliance, enhanced therapeutic outcomes, and greater acceptance due to their non-greasy nature.

➢ *Antibacterial Applications*

Bacterial skin infections remain a major healthcare concern and range from superficial lesions to chronic infected wounds. Effective topical delivery of antibiotics is often limited by poor skin penetration and inadequate drug retention.

Emulgels have shown considerable potential in addressing these challenges by enhancing local drug concentrations while reducing systemic antibiotic exposure. The incorporation of antibiotics into emulgel systems provides prolonged contact with infected tissues and facilitates controlled drug release.

Antibacterial drugs investigated in emulgel formulations include:

- Ciprofloxacin
- Clarithromycin
- Gentamicin
- Metronidazole
- Mupirocin
- Fusidic acid

These formulations offer improved stability, enhanced penetration, and prolonged antimicrobial activity. The incorporation of natural oils such as clove oil and tea tree oil provides synergistic antibacterial effects and may help reduce microbial resistance. Emulgel-based antibacterial formulations are effective for treating wound infections, folliculitis, impetigo, cellulitis, diabetic ulcers, and post-operative skin infections.

➢ *Anti-Acne Applications*

Acne vulgaris is one of the most prevalent dermatological disorders, particularly among adolescents and young adults. Conventional acne treatments may cause excessive dryness, irritation, and poor patient adherence due to their unpleasant sensory characteristics.

Emulgels have become attractive vehicles for acne management because they provide superior cosmetic acceptability and allow controlled delivery of anti-acne agents directly to pilosebaceous units.

Frequently incorporated anti-acne agents include:

- Benzoyl peroxide
- Clindamycin phosphate
- Adapalene
- Tretinoin
- Salicylic acid
- Azelaic acid

The follicular route plays a key role in acne treatment, and emulgels effectively deliver active agents into hair follicles due to their enhanced spreadability and penetration, while minimizing skin dryness. Their non-greasy nature is especially beneficial for acne patients, as oily formulations can promote comedone formation and worsen symptoms.

➢ *Wound Healing Applications*

Wound healing involves inflammation, tissue proliferation, angiogenesis, and remodeling, requiring formulations that maintain moisture, prevent microbial contamination, and support tissue regeneration. Emulgels meet these requirements by carrying bioactive molecules, maintaining hydration, and providing sustained drug release, thereby enhancing tissue repair.

Several active ingredients investigated for wound-healing emulgels include:

- Aloe vera
- Curcumin
- Atorvastatin
- Silver sulfadiazine
- Honey extracts
- Herbal polyphenols

Atorvastatin-loaded nanoemulgels have shown significant improvements in wound healing and pain reduction compared with placebo, highlighting their potential in advanced wound management. Additionally, herbal emulgels containing Aloe vera and curcumin promote tissue repair and reduce scar formation through their antioxidant and anti-inflammatory effects.

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➢ *Psoriasis and Eczema Management*

Psoriasis and eczema are chronic inflammatory skin disorders that require long-term treatment. Emulgels enable effective localized delivery of topical corticosteroids while minimizing systemic absorption. They also enhance skin hydration and reduce irritation, leading to improved treatment outcomes.

Common active agents include:

- Clobetasol propionate
- Betamethasone dipropionate
- Hydrocortisone
- Tacrolimus
- Calcipotriol

The controlled-release properties of emulgels contribute to prolonged therapeutic activity and reduced dosing frequency, thereby improving patient compliance.

➢ *Cosmeceutical Applications*

The cosmetic industry has rapidly adopted emulgels because of their appealing appearance, pleasant skin feel, excellent spreadability, and rapid absorption.

Cosmeceutical emulgels are widely utilized for:

- Skin hydration
- Anti-aging treatments
- Hyperpigmentation management
- Sun protection
- Antioxidant delivery

Kojic acid emulgels have been widely studied for treating hyperpigmentation by inhibiting tyrosinase activity and reducing melanin production, while enhancing drug stability and skin penetration. Similarly, antioxidant-containing emulgels protect against oxidative damage, premature aging, and UV-induced skin injury.

➢ *Herbal and Polyherbal Emulgels*

Growing interest in natural medicine has significantly increased research on herbal and polyherbal emulgels. These systems combine the therapeutic benefits of plant-derived bioactive compounds with the pharmaceutical advantages of modern emulgel technology.

Herbal extracts commonly incorporated into emulgels include:

- Curcuma longa (Turmeric)
- Aloe vera
- Vitex negundo (Nirgundi)
- Capsicum annum
- Emblica officinalis (Amla)
- Clove oil
- Tea tree oil
- Neem extracts

Polyherbal emulgels offer multiple therapeutic benefits, including anti-inflammatory, antioxidant, antimicrobial, and wound-healing activities. Their oil phase protects phytoconstituents from degradation and enhances skin penetration. Studies have shown that these formulations possess satisfactory physicochemical properties and effectively treat inflammatory and dermatological disorders.

Table 2 Major Therapeutic Applications of Emulgels

Therapeutic Area	Common Drugs/Actives	Major Benefits
Anti-inflammatory	Etoricoxib, Diclofenac, Ketoprofen	Localized pain and inflammation control
Antifungal	Clotrimazole, Ketoconazole, Itraconazole	Enhanced skin retention and penetration
Antibacterial	Ciprofloxacin, Clarithromycin	Sustained antimicrobial action
Anti-acne	Benzoyl peroxide, Clindamycin	Follicular targeting and improved compliance
Wound healing	Atorvastatin, Aloe vera, Curcumin	Accelerated tissue regeneration
Psoriasis/Eczema	Clobetasol, Betamethasone	Controlled delivery and reduced irritation
Cosmeceutical	Kojic acid, Antioxidants	Skin brightening and anti-aging effects
Herbal Therapy	Nirgundi, Turmeric, Aloe vera	Multi-target therapeutic action

V. RECENT ADVANCES IN EMULGEL TECHNOLOGY

The continuous evolution of topical drug delivery systems has led to several innovations in emulgel technology. Recent developments focus on improving drug permeation, therapeutic efficiency, formulation stability, and patient compliance. Among these advancements, nanoemulgels, microemulgels, herbal emulgels, and biodegradable polymer-based emulgels have attracted significant scientific interest.

➢ *Nanoemulgels*

Nanoemulgels are advanced systems formed by incorporating nanoemulsions into gels, with droplet sizes of 20-200 nm. Their small droplet size enhances skin permeation, bioavailability, and stability. They are widely used for delivering anti-inflammatory, antimicrobial, anticancer, antioxidant, and wound-healing agents. Atorvastatin-loaded nanoemulgels have shown promising results in improving wound healing and pain management.

➢ *Microemulgels*

Microemulgels are gel-based systems containing thermodynamically stable microemulsions with droplet sizes of 10-100 nm. They improve viscosity, drug retention, solubilization, diffusion, and stability, resulting in prolonged therapeutic effects. These systems are particularly useful for antifungal, anti-inflammatory, and dermatological treatments.

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➢ *Herbal Emulgels*

Herbal emulgels incorporate plant-derived bioactive compounds such as *Aloe vera*, *Curcuma longa*, *Vitex negundo*, *Azadirachta indica*, and clove oil. They provide anti-inflammatory, antimicrobial, antioxidant, and wound-healing activities while enhancing phytoconstituent stability, skin penetration, and therapeutic efficacy.

➢ *Natural Polymer-Based Emulgels*

Natural polymer-based emulgels utilize materials such as κ-carrageenan, xanthan gum, alginate, pectin, guar gum, and cellulose derivatives. These polymers improve biodegradability, biocompatibility, rheological properties, and stability, offering sustainable alternatives to synthetic gelling agents.

➢ *Smart and Stimuli-Responsive Emulgels*

Smart emulgels are designed to respond to physiological triggers such as pH, temperature, or enzyme activity, enabling site-specific and controlled drug release. These innovative systems minimize systemic exposure and represent a promising approach for future personalized medicine.

➢ *Challenges and Research Gaps*

Despite significant advances, several challenges limit the broader clinical and commercial adoption of emulgels. Most studies focus on formulation development and laboratory evaluation, with limited clinical investigations. Although emulgels are generally more stable than conventional emulsions, long-term stability under varying environmental conditions remains insufficiently studied.

Research predominantly relies on synthetic polymers such as Carbopol, while natural and hybrid polymers remain underexplored. In addition, standardized comparisons of different gelling agents are scarce. Challenges related to large-scale manufacturing, process validation, industrial feasibility, and the application of Quality by Design (QbD) approaches also hinder commercialization. Furthermore, many formulations show promising in vitro results but lack adequate in vivo and clinical evidence regarding long-term safety, efficacy, and patient acceptance.

Consequently, future studies should focus on:

- Large-scale manufacturing feasibility.
- Long-term stability studies.
- Clinical efficacy and safety evaluation.
- Hybrid natural-synthetic polymer systems.
- Quality by Design (QbD) optimization.
- Advanced skin permeation and pharmacokinetic studies.

Addressing these limitations will significantly enhance the translational potential of emulgel-based therapeutics.

VI. FUTURE PROSPECTS

The future of emulgel technology is highly promising, driven by advances in nanotechnology, polymer science, pharmaceutical engineering, and personalized medicine. Nanoemulgels and nanocarrier-based systems are expected to enhance drug permeation, bioavailability, and controlled release, potentially enabling topical delivery of drugs currently administered orally or by injection.

Growing interest in herbal medicine is likely to promote the development of phytoemulgels and polyherbal emulgels that offer synergistic therapeutic effects with fewer adverse reactions. Natural polymers such as κ-carrageenan, alginate, xanthan gum, and pectin are also expected to gain importance due to their biodegradability and safety.

In addition, artificial intelligence and machine learning may accelerate formulation optimization, while stimuli-responsive or “smart” emulgels could enable targeted and controlled drug delivery. Overall, future research is expected to focus on improved efficacy, sustainability, personalized treatment, and industrial scalability.

VII. CONCLUSION

Emulgels have emerged as a promising topical drug delivery system by combining the advantages of emulsions and gels while overcoming many of their limitations. They enable efficient delivery of hydrophobic drugs and offer improved drug loading, stability, spreadability, residence time, controlled release, and patient acceptability compared with conventional semisolid formulations.

These benefits have supported their application in the treatment of inflammatory conditions, fungal and bacterial infections, acne, wound healing, psoriasis, eczema, and various cosmeceutical disorders. Advances such as nanoemulgels, microemulgels, herbal emulgels, and natural polymer-based formulations have further expanded their therapeutic potential.

However, challenges related to clinical validation, large-scale manufacturing, long-term stability, and regulatory standardization remain. Continued innovations in formulation design, polymer technology, and controlled-release approaches are expected to strengthen the future role of emulgels in pharmaceutical, cosmetic, and herbal therapies.

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