A Review on The Future of Topical Delivery: Submicron Emulsion Gel Insights

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Abstract

Topical drug delivery systems are well known for their capacity to administer therapeutic substances directly to the site of action, thereby reducing systemic adverse effects and increasing patient compliance. One of the most recent developments in this area is the use of submicron emulsion gels as a new and efficient drug delivery system. Through the combination of emulsion and gel properties, these formulations provide greater stability, longer release, increased skin penetration, and enhanced drug solubility. Submicron emulsion gels' composition, preparation techniques, benefits, and uses are thoroughly examined in this paper, which also discusses their drawbacks and potential future developments. Topical and transdermal medication delivery methods are anticipated to undergo a significant transformation because to surmal delivery, drug stability, sustained release, skin penetration, nanotechnology, formulation science.

1. Introduction

Topical drug delivery systems (TDDS) are of great interest as they could deliver therapeutic entities to the desired site of action directly, and this would avoid systemic side effects as well as increase patient compliance (Kumar et al., 2023). TDDS is used for the delivery of drugs via the skin for a localized or a systemic effect. Still, one challenge for optimal drug permeation arises from the skin's barrier function, and that is essentially regulated by the stratum corneum (Inamdar et al., 2023).

1.1 Overview of Topical Drug Delivery Systems

TDDS consist of diversified formulations such as creams, ointments, gels, foams, and patches designed for several diverse therapeutic applications (Deokar et al., 2023). They try to overcome skin dermatological afflictions along with systemic illnesses through the acceleration

of drug penetration inside the skin. Stratum corneum represents a significant impediment in TDDS that slows the entry of the majority of therapy molecules (Valarmathy et al., 2024). To address this, scientists have investigated a number of strategies, such as the application of penetration enhancers, lipid systems, and new carrier mechanisms such as nanoemulsions and submicron emulsions (Kumar et al., 2023).

1.2 Importance of Submicron Emulsion Gels in Enhancing Drug Delivery

Submicron emulsion gels or nanoemulsion gels are the new promising topical drug delivery systems (Inamdar et al., 2023). The formulations combine the advantages of gels and submicron emulsions in order to maintain better drug stability and penetration in the skin. Submicron emulsions are two-phase systems with particle sizes ranging from 20–500 nm, which offer an extensive surface area for increased solubilization and absorption of the drug (Deokar et al., 2023).

When used as a gel matrix, these emulsions show higher viscosity, which results in increased contact time on the skin and prolonged drug release (Valarmathy et al., 2024). Submicron emulsions' small droplet size facilitates greater drug permeation across the stratum corneum, proving them to be good carriers for lipophilic and hydrophilic drugs (Kumar et al., 2023). Studies have shown the effective delivery of anti-inflammatory, antifungal, and analgesic drugs with submicron emulsion gels (Inamdar et al., 2023).

Moreover, submicron emulsion gels are thermodynamically stable and shield bioactive molecules from degradation, rendering them appropriate for use with sensitive drugs (Valarmathy et al., 2024). The flexibility in their formulation enables them to accommodate various therapeutic molecules, further broadening their use in topical therapy (Deokar et al., 2023).

2. Composition and Structure of Submicron Emulsion Gels

Submicron emulsion gels or nanoemulsion gels are modern drug delivery systems that fuse the characteristics of emulsions and gels to improve the topical delivery of drugs. An understanding of their composition and structure is essential to maximize their formulation and therapeutic effectiveness (Kumar et al., 2023).

2.1 Description of emulsifiers, oil phases, and water phases

The major constituents of submicron emulsion gels are emulsifiers, oil phases, and water phases.

Emulsifiers: These amphiphilic compounds stabilize the emulsion by lowering interfacial tension between the oil and water phases. Delmas et al. (2011) state that emulsifiers adsorb at the oil–water interface, creating a protective film around the droplets, which inhibits coalescence and phase separation. Polysorbates, phospholipids, and sorbitan esters are some

common emulsifiers that affect the stability and droplet size of the emulsion (Albert et al., 2019).

Oil Phase: The oil phase is composed of lipophilic compounds in which hydrophobic drugs are dissolved. Jesser et al. (2020) reported that oils like medium-chain triglycerides and soybean oil are essential for drug solubilization and stability. The concentration and type of oil phase have a profound effect on the drug release profile and permeation efficiency.

Water Phase: Hydrophilic components such as water-soluble drugs, preservatives, and pH-adjusting agents are present in the aqueous phase. Kumar et al.2023) stressed that drug solubility and emulsion stability are affected by the pH and ionic strength of the water phase. Effective formulation of this phase guarantees uniform distribution of active pharmaceutical ingredients within the gel matrix.

2.2 Mechanism of gel formation and drug encapsulation

Submicron emulsion gel formation is through emulsification and subsequent gelation, which provides enhanced viscosity and prolonged drug release.

Emulsion Formation: The oil phase is emulsified into the water phase using emulsifiers, followed by high-energy techniques such as ultrasonication or high-pressure homogenization (Delmas et al., 2011). The emulsifier molecules are oriented at the oil–water interface, stabilizing the droplets and avoiding coalescence (Fessi et al., 1989).

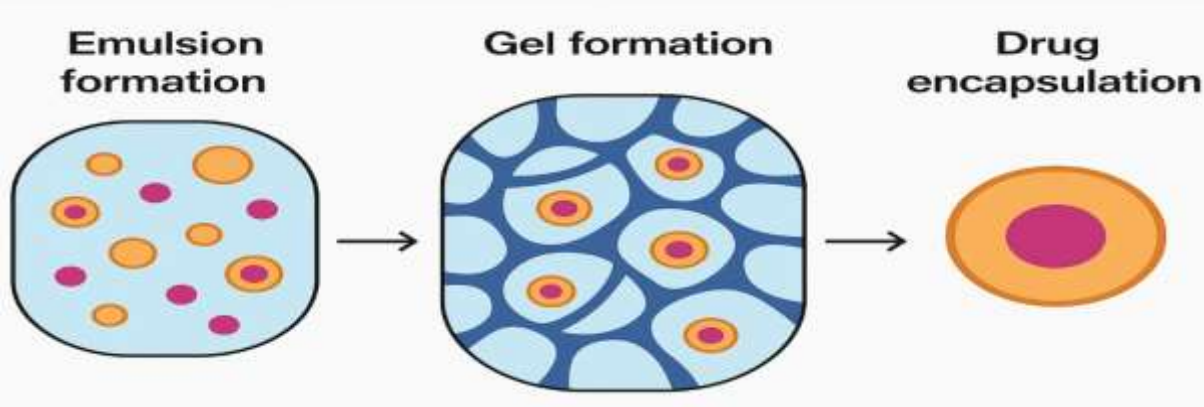


Fig. Mechanism of gel formation and drug encapsulation

Gel Formation: After the formation of stable submicron emulsion, the gelling agents like carbomers and xanthan gum are added to increase the viscosity. (Amselem and Friedman 1998) described that gel matrix is responsible for a three-dimensional network that increases the skin retention of the formulation and helps in the controlled release of drugs.

Drug Encapsulation: Either in the water or oil phase, the drug can be loaded based on solubility profiles. (Moghassemi et al.2022) noted that hydrophobic drugs are dissolved preferentially in the oil phase, while hydrophilic drugs are partitioned in the aqueous phase.

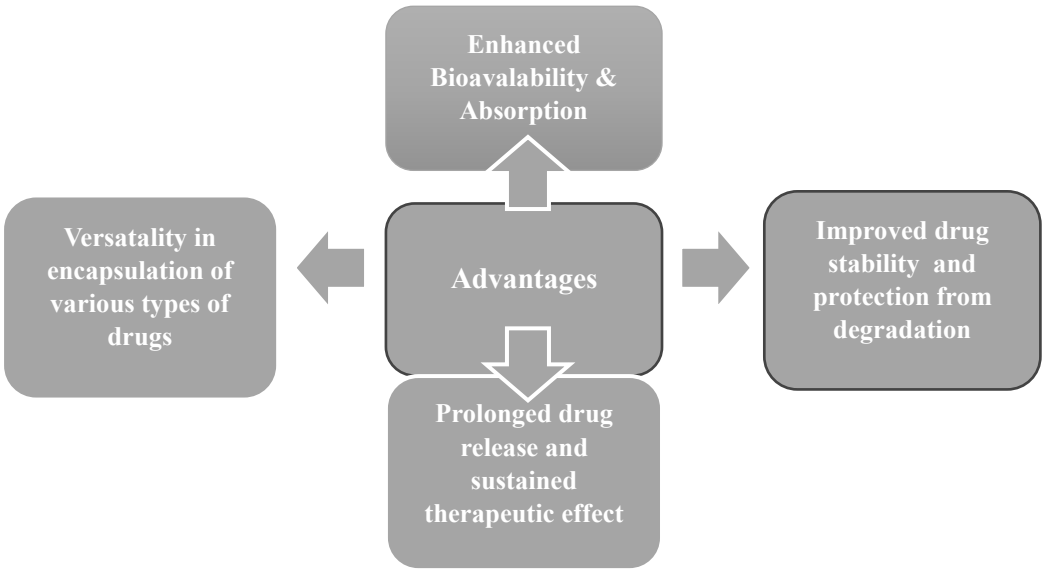
The droplet size less than submicron increases the surface area to facilitate effective encapsulation of drugs and uniform distribution (Jesser et al., 2020). Encapsulation also shields bioactive molecules from degradation and adjusts the release pattern to maximize therapeutic effects (Fessi et al., 1989).

3. Advantages of Submicron Emulsion Gels

Submicron emulsion gels have gained considerable attention in pharmaceutical research due to their ability to enhance drug delivery. These formulations provide multiple advantages, including improved bioavailability, enhanced drug stability, prolonged release, and the ability to encapsulate various drug molecules (Kumar et al., 2023). Their unique structural properties make them suitable for a wide range of therapeutic applications, particularly in topical and transdermal drug delivery (Singh et al., 2022).

3.1 Enhanced Bioavailability and Absorption

Among the major benefits of submicron emulsion gels is an increase in the bioavailability of drugs. Their small droplet size, commonly in the range of nanometers, offers greater surface area for absorption, with enhanced permeation through biological membranes (Patel & Patel, 2021). Kumar et al. (2023) indicated that the emulsions greatly enhance poorly water-soluble drug solubility and their absorption into systemic circulation. Equally, (Delmas et al. 2011) pointed out that the lipid-based nature of such emulsions enhances drug permeability and transport through skin layers. Additionally, (Moghassemi et al.2022) mentioned that such systems are capable of evading first-pass metabolism, thus increasing the availability of drugs in the system.



3.2 Improved drug stability and protection from degradation

Submicron emulsion gels also provide enhanced drug stability by safeguarding active pharmaceutical ingredients against environmental conditions like oxidation, hydrolysis, and photodegradation (Fessi et al., 1989). Patel and Patel et al.021) proved that the presence of

lipophilic constituents in submicron emulsions inhibits drug degradation and extends shelf life. In the same vein, (Amselem and Friedman et al. 1998) highlighted that encapsulation of bioactive compounds in submicron emulsions guarantees extended drug stability, even under extreme storage conditions. (Jesser et al.2020) also added that these emulsions provide a protective barrier against enzymatic degradation, maintaining drug efficacy over time.

3.3 Prolonged drug release and sustained therapeutic effects

Submicron emulsion gels offer sustained release of the drug, facilitating extended therapeutic activity with less frequency of dosing (Prabhu et al. 2024). The gel matrix within these products controls drug diffusion so that there is a sustained release over a period of time (Nair & Shah, 2020). (Delmas et al. 2011) pointed out that the stability of such emulsions is the reason for them to offer gradual release of drugs, which in turn reduces oscillations in the plasma concentration of the drug. (Moghassemi et al. 2022) also corroborated that the lipid-based character of submicron emulsions can be modified to obtain precise release kinetics and thus be utilized for prolonged drug delivery.

3.4 Versatility in encapsulating various types of drugs

The other primary benefit of submicron emulsion gels is that they are highly versatile to encapsulate a great variety of therapeutic agents, ranging from hydrophilic to lipophilic and amphiphilic drugs (Albert et al., 2019). (Nair and Shah 2020) documented that the formulations are especially helpful in the delivery of drugs with poor solubility by enhancing their transport and solubilization capacities. Amselem and Friedman et. al.1998) showed that submicron emulsions may be modified for the delivery of peptides, proteins, and other macromolecules, thereby widening their scope as pharmaceutical agents. Additionally, (Fessi et al. 1989) explained that submicron emulsions might find applications in controlled drug release in targeted therapy, thus being applicable to several medical conditions.

4. Preparation Methods for Submicron Emulsion Gels

The preparation of submicron emulsion gels requires specialized methods that provide consistent droplet size, increased drug stability, and better bioavailability. Different methods, such as high-pressure homogenization, ultrasonication, and phase inversion, are commonly employed to create stable submicron emulsions with reproducible physicochemical characteristics (Kumar et al., 2023). The choice of the right technique is based on drug solubility, emulsifier nature, oil-water ratio, and desired therapeutic use (Singh et al., 2022). In addition to preparation methods, gel stability and drug release factors are also important in formulating the optimized formulation. Moreover, quality control and characterization procedures are essential to ensure reproducibility and efficacy of the formulated emulsion gel.

4.1 Common techniques such as high-pressure homogenization and ultrasonication

4.1.1 High-Pressure Homogenization:

High-pressure homogenization (HPH) is among the best approaches for creating submicron emulsions, where coarse emulsion is pressed through a small valve under high pressure (100–2000 bar), resulting in homogenous droplet size reduction and improved stability (Patel & Patel, 2021). This method increases drug solubility, bioavailability, and controlled release and is thus well adapted to poorly water-soluble drugs (Moghassemi et al., 2022). The continuous exposure to shear forces and cavitation leads to a uniform dispersion, avoiding phase separation and providing long-term stability to the emulsion (Prabhu et al., 2024). Because of its ability to generate small, stable droplets (<200 nm), HPH is commonly used in pharmaceutical formulations for topical drug delivery (Delmas et al., 2011).

4.1.2 Ultrasonication

Ultrasonication is another common technique that employs high-frequency sound waves (20–100 kHz) to disintegrate large emulsion droplets into submicron particles by strong cavitation forces (Jesser et al., 2020). The technique is especially useful for thermolabile drugs since it produces fine emulsions without subjecting them to excessive heat (Nair & Shah, 2020). Research has established that ultrasonication increases drug encapsulation efficiency and physical stability, and thus it is a good method of choice for topical and transdermal systems(Albert et al., 2019).

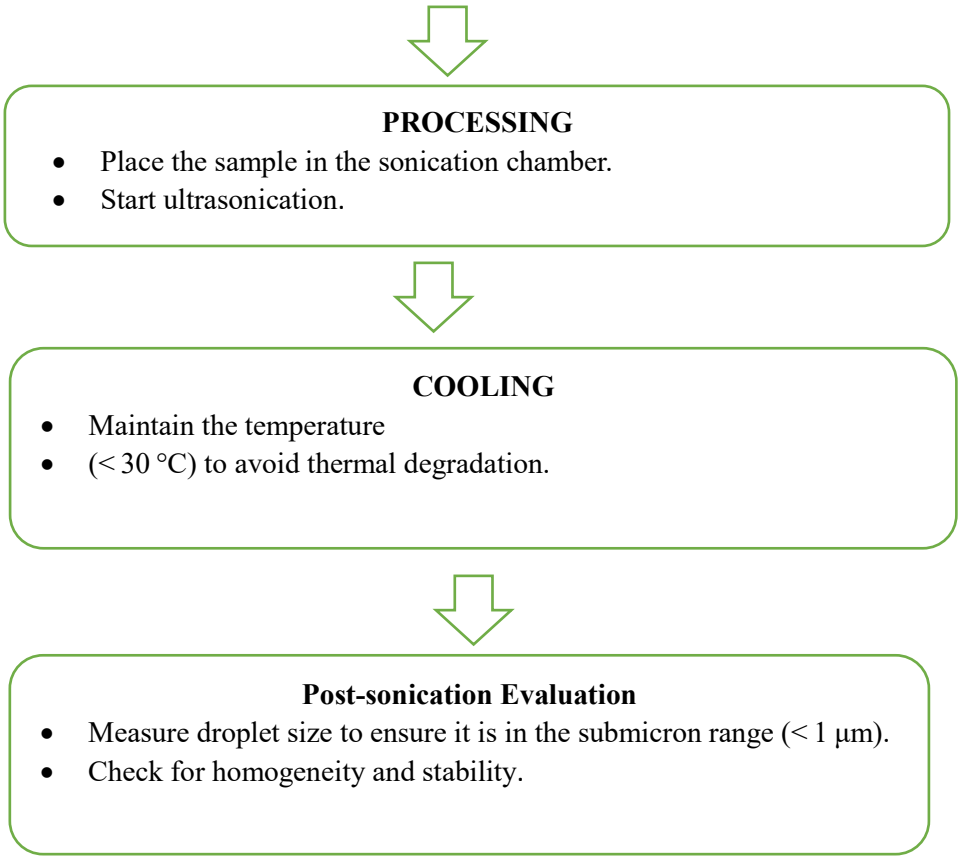
ULTRASONICATION OF SUBMICRON EMULSION GEL

PRE-COOLING(OPTIONAL)

- Maintain emulsion at ~ 5-10°C.

SONICATION PARAMETER

- Amplitude: 30–50%
- Pulse: 5 seconds on / 5 seconds off
- Time: 5–10 minutes
- Frequency: 40 kHz



In addition, optimization of ultrasonic power, exposure time, and frequency is also essential to obtain desirable emulsion properties (Fessi et al., 1989).

4.1.3 Phase Inversion Method

The phase inversion method relies on spontaneous emulsification, wherein an oil-water system inverts because of changes in temperature or composition, resulting in the creation of a stable submicron emulsion (Singh et al., 2022). The method guarantees high drug-loading capacity and homogeneity and retains long-term stability (Patel & Patel, 2021). The technique is usually utilized for bulk production, as it involves low energy input and gives superior control of particle size distribution (Jesser et al., 2020).

4.2 Factors Influencing Gel Stability and Drug Release

Several factors influence the **stability and drug release profile** of submicron emulsion gels. The **type and concentration of emulsifiers** are crucial in maintaining **droplet size uniformity and preventing coalescence** (Kumar et al., 2023). A balanced **oil-to-water phase ratio** determines the formulation's **viscosity, spreadability, and drug solubility**, ultimately affecting **drug absorption through the skin** (Singh et al., 2022). Additionally, **storage conditions such as temperature, humidity, and light exposure** significantly impact the stability of emulsions, as fluctuations can lead to **oxidation, degradation, or phase separation** (Moghassemi et al., 2022). To optimize **drug release kinetics**, factors such as **emulsifier**

composition, gel rheology, and droplet surface charge (zeta potential) must be precisely controlled (Prabhu et al., 2024).

4.2 Quality Control and Characterization Methods

For batch-to-batch reproducibility and conformity to pharmaceutical requirements, numerous analytical methods are utilized for characterization and quality control of submicron emulsion gels. Dynamic Light Scattering (DLS) is generally utilized for determining droplet size distribution and polydispersity index (PDI), which are both essential parameters for the stability of the formulation (Albert et al., 2019). Zeta potential analysis is useful in evaluating the surface charge of emulsion droplets and gaining information about their electrostatic stability and tendency to aggregate (Jesser et al., 2020). Rheological measurements determine gel viscosity, spreadability, and mechanical strength, which have a direct bearing on topical application ease and patient compliance (Nair & Shah, 2020). In addition, encapsulation efficiency of the drug is determined using High-Performance Liquid Chromatography (HPLC) so that the formulation releases the desired therapeutic dose (Delmas et al., 2011). Thermal stability by Differential Scanning Calorimetry (DSC) helps in understanding compatibility of excipients and behavior of the formulation at different temperatures (Fessi et al., 1989). These measures of quality control together guarantee the safety, efficacy, and long-term stability of submicron emulsion gels for topical drug delivery purposes.

5. Applications of Submicron emulsion gel

Submicron emulsion gels have been a promising solution in dermatology and transdermal drug delivery, providing improved penetration, extended drug release, and improved bioavailability (Kumar et al., 2023). Their low droplet size and organized gel network enable effective drug encapsulation, enhanced stability, and controlled release, making them extremely ideal for the treatment of skin diseases, transdermal drug delivery, and local pain relief (Singh et al., 2022).

5.1 Treatment of Skin Conditions

5.1.1 Acne

Acne vulgaris is an inflammatory skin disease due to overproduction of sebum and bacterial proliferation. Traditional treatments tend to cause irritation of the skin and microbial resistance (Jesser et al., 2020). Submicron emulsion gels have been reported to increase drug penetration and retention, enhancing the therapeutic efficacy of benzoyl peroxide, clindamycin, and adapalene (Nair & Shah, 2020). These products suppress inflammation and bacterial proliferation with reduced irritation (Moghassemi et al., 2022).

5.1.2 Psoriasis

Psoriasis is an autoimmune cutaneous disorder involving increased proliferation of keratinocytes. Classical topical therapies encounter inadequate skin permeation (Singh et al.,

2022). Submicron gel emulsions enhance the transdermal delivery of corticosteroids (betamethasone) and vitamin D analogs (calcipotriol) by improving the retention of the drug and mitigating flare-up episodes (Patel & Patel,et al. 2021). They also facilitate slow drug release, decreasing the necessity for repeated dosing (Kumar et al., 2023).

5.1.3 Eczema

Eczema is a chronic inflammatory skin disease that interferes with the skin barrier function, causing dryness and irritation. Conventional treatments are moisturizers and corticosteroids, which can lead to thinning of the skin with prolonged use (Jesser et al., 2020). Submicron emulsion gels with hydrocortisone, tacrolimus, and ceramides offer improved hydration, better absorption, and enhanced skin barrier repair (Moghassemi et al., 2022).

5.2 Transdermal Delivery of Systemic Drugs

Transdermal drug delivery aims to deliver medications through the skin into the bloodstream, avoiding the need for oral administration or injections. Submicron emulsion gels have been widely explored for this purpose due to their ability to improve drug permeability across the skin barrier (Singh et al., 2022). The stratum corneum (outermost skin layer) acts as a strong barrier, preventing most drugs from penetrating deeply. However, submicron-sized droplets combined with penetration enhancers like phospholipids and surfactants help drugs diffuse effectively into systemic circulation (Patel & Patel, 2021).

For instance, hormonal therapies such as estrogen and testosterone have been successfully formulated into submicron emulsion gels for transdermal administration. This method ensures a steady release of the hormone into the bloodstream, preventing fluctuations that occur with oral dosing (Moghassemi et al., 2022). Similarly, anti-hypertensive drugs like propranolol and calcium channel blockers have been studied for transdermal delivery using submicron emulsions, showing promising results in maintaining stable blood pressure levels (Jesser et al., 2020).

Another important application is the transdermal delivery of painkillers such as diclofenac and ibuprofen. These drugs are typically administered orally, but submicron emulsion gels allow for direct absorption through the skin, reducing gastrointestinal side effects and improving patient compliance (Nair & Shah, 2020).

5.3 Potential for Localized Pain Relief and Anti-Inflammatory Treatments

Submicron emulsion gels are also very useful in local pain treatment and anti-inflammatory therapy. Conventional topical pain relief preparations such as ointments and creams are not able to produce deep tissue penetration, while submicron emulsion gels enable quicker and more efficient drug uptake (Albert et al., 2019).

For instance, nonsteroidal anti-inflammatory drugs (NSAIDs) such as ketoprofen and diclofenac have been effectively loaded into submicron emulsions, resulting in quicker relief from pain in conditions like arthritis, muscle pain, and sports injuries (Fessi et al., 1989). Research indicates that patients treated with NSAID-loaded submicron emulsion gels have relief for a longer period than those treated with conventional gels or creams (Delmas et al., 2011).

Moreover, capsaicin (naturally occurring painkiller found in chili peppers) has been developed into submicron emulsion gels to treat neuropathic pain and joint conditions. The formulation enhances the bioavailability of capsaicin, minimizing burning and irritation, rendering it tolerable for extended periods (Kumar et al., 2023).
Submicron emulsion gels also have promise in the management of post-surgical pain, in which opioid-derived analgesics could be administered topically to reduce systemic side effects and risk of addiction (Singh et al., 2022)

6.Challenges and Limitations of Submicron Emulsion Gels

Although submicron emulsion gels offer major benefits in increasing topical drug delivery, a number of challenges and limitations impact their formulation, scale-up, and regulatory clearance. These need to be overcome for the successful commercialization and acceptance of these innovative drug delivery systems (Kumar et al., 2023).

6.1 Variability in Preparation Conditions

The physical and chemical characteristics of submicron emulsion gels are greatly influenced by accurate formulation conditions, such as the nature and concentration of emulsifiers, oil-to-water ratio, and processing methods (Patel & Patel, 2021). Minor changes in these factors can result in variability in droplet size, stability, drug encapsulation efficiency, and viscosity, impacting the overall performance of the formulation (Singh et al., 2022).

For example, ultrasonication and high-pressure homogenization are widely applied to obtain submicron-sized droplets, but slight differences in homogenization pressure, processing time, or sonication energy can dramatically influence the droplet size distribution and zeta potential, thereby affecting the stability and drug release characteristics (Moghassemi et al., 2022). In addition, temperature variations during preparation may result in phase separation or degradation of thermosensitive drugs, reducing efficacy (Jesser et al., 2020).

Another significant issue is batch-to-batch variation, which occurs because of minute variations in raw materials, purity of the excipients, and environmental conditions of formulation. Minor variations can lead to drastic differences in product quality, and it becomes challenging for large-scale production to standardize (Nair & Shah, et al. 2020).

6.2 Scalability and Manufacturing Challenges

Even though submicron emulsion gels have been successfully made in laboratory studies, large-scale production up to an industrial scale is faced with several challenges. The methods of high-energy preparation used for them, i.e., high-pressure homogenization, ultrasonication, and micro fluidization, are expensive and utilize equipment that may not be readily available in large quantities for mass production (Singh et al., 2022).

Perhaps the most significant manufacturing challenge is providing long-term stability for submicron emulsion gels. Temperature variation, oxidative degradation, and microbial contamination can affect shelf life and product integrity (Patel & Patel, 2021). The incorporation of preservatives and stabilizers can improve stability, but their addition should be well-optimized to prevent potential toxicity and formulation incompatibilities (Moghassemi et al., 2022).

Moreover, ensuring homogeneity and uniform distribution of drugs throughout huge batches is challenging. Shear force disparities, mixing rates, and processing time variations at a commercial scale cause particle agglomeration, phase separation, or drug concentration variation, compromising product consistency and bioavailability (Jesser et al., 2020). Moreover, increased production expenses for specialized machinery and longer processing times restrict the financial viability of mass production (Nair & Shah, 2020).

6.3 Regulatory Considerations and Clinical Trials

The commercialization of submicron emulsion gels requires compliance with strict regulatory guidelines from agencies such as the U.S. Food and Drug Administration (FDA), European Medicines Agency (EMA), and other national drug regulatory bodies (Singh et al., 2022). These agencies mandate extensive preclinical and clinical testing to establish the safety, efficacy, and stability of new formulations before market approval (Patel & Patel, 2021).

One of the key regulatory challenges is the lack of standardized guidelines for submicron emulsion gels. Since these formulations combine nanoemulsions with gel-based systems, they fall between conventional emulsions and nanocarrier-based drug delivery systems, making classification and approval processes more complex (Moghassemi et al., 2022).

Another challenge in regulatory approval is the requirement for detailed toxicological evaluations. Since submicron emulsion gels often contain novel excipients, surfactants, or penetration enhancers, their long-term safety profiles must be extensively studied to rule out potential risks such as skin irritation, hypersensitivity reactions, or systemic toxicity (Albert et al., 2019).

Additionally, clinical trials for submicron emulsion gels need to assess multiple parameters, including drug penetration, release kinetics, therapeutic effectiveness, and patient compliance.

The cost and time required for these studies can be significant, posing financial challenges for pharmaceutical companies and researchers (Kumar et al., 2023).

7. Future Directions and Research Opportunities

Submicron emulsion gels are being recognized as viable drug delivery systems in the topical and transdermal domain with improved bioavailability, site-specific drug delivery, and high patient compliance. There is still a need for research and developments in technology to ensure their enhanced efficacy, stability, and scale-up production (Kumar et al., 2023). This section looks at the prominent future directions and areas of investigation for the construction of submicron emulsion gels.

7.1 Innovations in Submicron Emulsion Gel Technology

Next-generation submicron emulsion gel development emphasizes improved drug penetration, enhanced stability, and more optimized formulation methods. Among the upcoming innovations is the use of stimuli-responsive materials that enable controlled drug release according to pH, temperature, or enzymatic action (Gupta et al., 2022). The intelligent formulations provide targeted delivery with reduced side effects, especially suitable for chronic dermatological conditions.

Another promising direction is the application of nanocarrier-based hybrid systems, including lipid-polymer hybrid nanoparticles incorporated in emulsion gels, to provide dual advantages of nanoscale drug carriers and gel-based delivery (Singh et al., 2021). Hybrid systems enhance drug solubilization, extend drug release, and increase retention at the site of application. Further, 3D printing technology is also being investigated to design custom emulsion gel products to ensure tailored drug dosing according to the needs of individual patients (Mishra et al., 2020).

7.2 Potential for Combination Therapies

Submicron emulsion gels have great promise in combination therapies, where several active pharmaceutical ingredients (APIs) are loaded to produce synergistic therapeutic outcomes. For instance, the combination of anti-inflammatory drugs with antioxidants in an emulsion gel delivery system can improve the treatment of dermatological diseases such as psoriasis and eczema (Verma et al., 2022).

In addition, co-delivery of hydrophilic and lipophilic drugs using a single submicron emulsion gel system enables enhanced treatment of multifactorial diseases. In cancer treatment, for example, the use of chemotherapeutic drugs in combination with penetration enhancers can enable successful transdermal drug delivery to treat localized skin cancers (Kumar et al., 2023). Likewise, dual-component antimicrobial and wound-healing products are being formulated for diabetic ulcers and chronic wounds (Sharma & Patel, 2021).

7.3 Ongoing Research and Development Efforts

A number of academic institutions, pharmaceutical firms, and research institutes are actively investigating submicron emulsion gel formulations for enhanced therapeutic uses. Research is currently centered on:

Noval excipients and emulsifiers: Finding biocompatible and non-toxic surfactants to improve the stability and skin penetration of submicron emulsion gels (Chaudhary et al., 2021).

Advanced encapsulation techniques: Employing polymeric nano capsules and lipid carriers to increase drug loading capacity and controlled release (Singh et al., 2021).

Clinical assessment and translational research: Performing in vivo and clinical trials to evaluate safety, effectiveness, and patient compliance with submicron emulsion gel treatments (Jain et al., 2023).

Regulatory agencies are also striving to come up with standard guidelines to implement quality control and reproducibility in the manufacturing of submicron emulsion gel (Albert et al., 2019).

7.4 Future Prospects in the Field of Topical Drug Delivery

With the developments in nanotechnology, biomaterials, and formulation science, submicron emulsion gels are expected to transform topical drug delivery in the future. Future studies will aim at:

Personalized medicine strategies, where submicron emulsion gels are designed in response to patient genetic profiles and disease states (Mishra et al., 2020).

Artificial intelligence and machine learning in formulation development, rational optimization of excipients and prediction of stability for enhanced effectiveness (Verma et al., 2022).

Green and environmentally friendly formulations, employing biodegradable and green excipients to minimize the environmental footprint of pharmaceutical waste (Gupta et al., 2022).

The combination of submicron emulsion gel and transdermal microneedle technology is also in progress, permitting improved penetration by macromolecules, such as peptides and vaccines (Jain et al., 2023). All this will lead the way for effective, patient-centric, and business-feasible topical drug delivery systems in the near future.

8. Conclusion

Submicron emulsion gels are a promising development in topical and transdermal drug delivery that provides improved drug penetration, stability, and controlled release. The formulations overcome the drawbacks of traditional gels, creams, and ointments by offering increased solubility, enhanced bioavailability, and targeted therapeutic activity (Kumar et al., 2023). Their capability to encapsulate hydrophilic as well as lipophilic drugs makes them an ideal choice for various dermatological, pharmaceutical, and cosmeceutical applications (Gupta et al., 2022).

8.1 Key Points Summary

In this review, we considered the components, benefits, preparation techniques, usage, limitations, and potential future applications of submicron emulsion gels. The main points are: Improved drug delivery and penetration: Submicron emulsion gels enhance significantly the permeation across the skin and bioavailability, which enables efficient localized as well as systemic drug delivery (Singh et al., 2021).

Extended drug release and stability: The systems ensure steady drug release, minimizing frequent dosage and enhancing compliance by the patients (Verma et al., 2022).

Wide use: Their ability to encapsulate diverse drugs qualifies them for dermal treatments, transdermal therapy, as well as relief from pain (Mishra et al., 2020).

Formulation and commercialization challenges: Although scalability, regulatory challenges, and long-term stability are ongoing challenges, research and technological innovations are overcoming these limitations (Jain et al., 2023).

8.2 The Promising Future of Submicron Emulsion Gels

With developments in nanotechnology, polymer science, and precision medicine, submicron emulsion gels are likely to be at the forefront of next-generation topical products. Studies are investigating stimuli-responsive gels, biodegradable carriers, and AI-optimized optimization, which will further improve their efficacy and usability (Gupta et al., 2022).

In addition, combination therapies of submicron emulsion gels are receiving interest, wherein several active drug molecules are included for synergy in the treatment of acne, pain, and wound healing (Sharma & Patel, 2021). Successful clinical translation, however, will be reliant on advances in large-scale production, stability enhancements, and regulatory approval (Albert et al., 2019).

8.3 Final Thoughts

Submicron emulsion gels have great promise in transforming topical and transdermal drug delivery. Their special characteristics, such as improved penetration, sustained release, and versatility in formulation, render them better options than conventional formulations. With

continued scientific progress and regulatory adjustments, these new systems are likely to determine the future of pharmaceutical and cosmetic formulations, with improved therapeutic benefits and patient compliance.

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