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"MEROPENAM- LOADED SUBMICRON EMULSION GELS FOR TOPICAL DRUG DELIVERY: A COMPREHENSIVE REVIEW"

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Abstract: The present study focuses on the development and in vitro characterisation of a meropenem-loaded submicron emulsion designed to enhance the treatment of skin infections. Meropenem, a broad-spectrum β-lactam antibiotic, is widely used to combat resistant bacterial strains but faces challenges in topical delivery due to poor skin penetration and instability. To overcome these limitations, a submicron emulsion system was formulated using oil, surfactant, and co-surfactant combinations optimised by the pseudoternary phase diagram method. The prepared formulation was evaluated for particle size, zeta potential, polydispersity index, pH, viscosity, drug content, and in vitro drug release behaviour. The optimised emulsion exhibited a mean droplet size below 200 nm with a narrow size distribution and a stable zeta potential, indicating good physical stability. The in vitro release study demonstrated sustained drug release over an extended period, suggesting improved skin retention and permeation. Additionally, the antimicrobial activity of the formulation was assessed against common skin pathogens, showing significant inhibition zones compared to the pure drug solution. Overall, the developed submicron emulsion presents a promising carrier for effective topical delivery of meropenem in the management of bacterial skin infections.

Index Terms **-** Meropenem, Submicron Emulsion, Topical Drug Delivery System (TDDS), Antibacterial Therapy, Skin Permeation Enhancement.

1. INTRODUCTION

Topical drug delivery systems (TDDS) are highly desirable because they have the potential to directly administer therapeutic agents to the intended site of action, preventing systemic adverse effects and improving patient compliance (Kumar et al., 2023). Drugs can be administered via the skin using TDDS for either a localised or systemic effect. However, one obstacle to the best drug penetration is the skin's barrier function, which is primarily controlled by the stratum corneum (Inamdar et al., 2023).

1.1 OVERVIEW OF TOPICAL DRUG DELIVERY SYSTEMS

TDDS is made up of a variety of formulations, including creams, ointments, gels, foams, and patches, that are intended for a wide range of therapeutic uses (Deokar et al., 2023). By accelerating drug penetration into the skin, they attempt to treat systemic diseases and skin dermatological conditions. A prominent barrier in TDDS that hinders the entry of most therapeutic compounds is the stratum corneum (Valarmathy et al., 2024). Scientists have looked into a variety of approaches to deal with this, including the use of lipid systems, penetration enhancers, and novel carrier mechanisms, including nanoemulsions and submicron emulsions.

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).

These emulsions exhibit greater viscosity when employed as a gel matrix, which prolongs drug release and increases skin contact duration (Valarmathy et al., 2024). Submicron emulsions are effective carriers for hydrophilic and lipophilic medicines because of their small droplet size, which increases drug penetration across the stratum corneum (Kumar et al., 2023). Research has demonstrated that submicron emulsion gels can effectively administer analgesic, antifungal, and anti-inflammatory medications (Inamdar et al., 2023). Additionally, submicron emulsion gels are suitable for usage with sensitive medications because they are thermodynamically stable and protect bioactive molecules from deterioration (Valarmathy et al., 2024). Their utility in topical medicine is further expanded by their formulation's versatility, which allows them to accommodate different therapeutic compounds (Deokar et al., 2023).

2. COMPOSITION AND STRUCTURE OF SUBMICRON EMULSION GELS

Submicron emulsion gels, also known as nanoemulsion gels, are contemporary drug delivery technologies that combine the properties of gels and emulsions to enhance topical drug administration. To optimise their formulation and therapeutic efficacy, it is crucial to comprehend their composition and structure (Kumar et al., 2023).

2.1 DESCRIPTION OF EMULSIFIERS, OIL PHASES, AND WATER PHASES

Emulsifiers, oil phases, and water phases are the main components of submicron emulsion gels. Emulsifiers: By reducing the interfacial tension between the water and oil phases, these amphiphilic substances stabilise the emulsion. Emulsifiers adsorb at the oil–water interface, forming a protective coating surrounding the droplets that prevents coalescence and phase separation, according to Delmas et al. (2011). Common emulsifiers that impact the stability and droplet size of the emulsion include polysorbates, phospholipids, and sorbitan esters (Albert et al., 2019).

Oil Phase: Hydrophobic medications dissolve in lipophilic chemicals that make up the oil phase. According to Jesser et al. (2020), oils like soybean oil and medium-chain triglycerides are crucial for the stability and solubilization of drugs. The drug release profile and penetration efficiency are significantly impacted by the kind and concentration of the oil phase. Water Phase: The aqueous phase contains hydrophilic substances such as pH-adjusting agents, water-soluble medications, and preservatives. Kumar et al. (2023) emphasised that the pH and ionic strength of the water phase have an impact on medication solubility and emulsion stability. The homogeneous distribution of active medicinal substances inside the gel matrix is ensured by the effective formulation of this phase.

2.2 MECHANISM OF GEL FORMATION AND DRUG ENCAPSULATION

Emulsification and subsequent gelation are used to create submicron emulsion gels, which offer increased viscosity and extended drug release. Emulsion Formation: High-energy methods like ultrasonication or high-pressure homogenization are used after emulsifiers are used to emulsify the oil phase into the water phase (Delmas et al., 2011). To stabilise the droplets and prevent coalescence, the emulsifier molecules are directed at the oil-water interface (Fessi et al., 1989).

Gel Formation: To boost the viscosity, gelling chemicals such as carbomers and xanthan gum are added once a stable submicron emulsion has formed (Amselem and Friedman 1998). explained how the gel matrix creates a three-dimensional network that improves the formulation's skin retention and aids in the regulated release of medications. Drug Encapsulation: Depending on solubility characteristics, the drug can be put into either the water or oil phase. According to (Moghassemi et al., 2022), hydrophilic pharmaceuticals are partitioned in the aqueous phase, whereas hydrophobic medications dissolve preferentially in the oil phase. The surface area is increased when the droplet size is less than submicron, which helps with uniform dispersion and efficient drug encapsulation (Jesser et al., 2020). Additionally, encapsulation modifies the release pattern to optimise therapeutic effects and protects bioactive compounds from degradation (Fessi et al., 1989).

3. ADVANTAGES OF SUBMICRON EMULSION GELS

The potential of submicron emulsion gels to improve medication delivery has drawn a lot of interest in pharmaceutical research. These formulations offer several benefits, such as increased drug stability, extended release, better bioavailability, and the capacity to encapsulate different therapeutic compounds (Kumar et al., 2023). They can be used in a variety of therapeutic applications, especially topical and transdermal drug administration, due to their distinctive structural characteristics (Singh et al., 2022).

3.1 ENHANCED BIOAVAILABILITY AND ABSORPTION

Increasing the bioavailability of medications is one of the main advantages of submicron emulsion gels. Their tiny droplet size, which is typically in the nanometer range, provides more surface area for absorption and improves penetration across biological membranes (Patel & Patel, 2021). According to Kumar et al. (2023), the emulsions significantly improve the solubility of weakly water-soluble drugs and their absorption into the bloodstream. According to Delmas et al. (2011), drug permeability and transport across epidermal layers are improved by the lipid-based composition of these emulsions. Furthermore, according to Moghassemi et al. (2022), these systems can avoid first-pass metabolism, which increases the amount of medicines available in the system.

3.2 IMPROVED DRUG STABILITY AND PROTECTION FROM DEGRADATION

By protecting active medicinal ingredients from environmental factors like oxidation, hydrolysis, and photodegradation, submicron emulsion gels also improve drug stability (Fessi et al., 1989). Lipophilic components in submicron emulsions prevent medication degradation and prolong shelf life, as demonstrated by Patel and Patel et al. (021). Similarly, encapsulation of bioactive chemicals in submicron emulsions ensures prolonged medication stability, even under harsh storage circumstances (Amselem and Friedman et al. 1998). Additionally, these emulsions offer a barrier against enzymatic degradation, preserving medication potency over time (Jesser et al., 2020).

3.3 PROLONGED DRUG RELEASE AND SUSTAINED THERAPEUTIC EFFECTS

According to Prabhu et al. (2024), submicron emulsion gels provide prolonged therapeutic action with fewer doses by providing sustained drug release. These products' gel matrix regulates medication diffusion to provide a prolonged release over time (Nair and Shah, 2020). According to Delmas et al. 2011), these emulsions' stability allows for the progressive release of medications, which in turn lessens oscillations in the drug's plasma concentration. (Moghassemi et al. 2022) further confirmed that submicron emulsions' lipid-based nature can be altered to achieve exact release kinetics and, consequently, be used for extended drug administration.

3.4 VERSATILITY IN ENCAPSULATING VARIOUS TYPES OF DRUGS

The ability of submicron emulsion gels to encapsulate a wide range of therapeutic agents, including hydrophilic, lipophilic, and amphiphilic medications, is their other main advantage (Albert et al., 2019). According to (Nair and Shah 2020), by improving their transport and solubilization capacities, the formulations are particularly useful in the delivery of medications with low solubility. Submicron emulsions can be altered to carry peptides, proteins, and other macromolecules, expanding their potential as pharmacological agents (Amselem and Friedman et al., 1998). Furthermore, according to (Fessi et al. 1989), submicron emulsions may be used in targeted therapy with controlled drug release, which could be useful for several medical disorders.

4. PREPARATION METHODS FOR SUBMICRON EMULSION GELS

Submicron emulsion gel preparation calls for specific techniques that improve drug stability, bioavailability, and droplet size consistency. Several techniques, including phase inversion, ultrasonication, and high-pressure homogenization, are frequently used to produce stable submicron emulsions with repeatable physicochemical properties (Kumar et al., 2023). Drug solubility, emulsifier type, oil-water ratio, and intended therapeutic application all have a role in selecting the best method (Singh et al., 2022). When creating the ideal formulation, gel stability and drug release parameters are crucial in addition to preparation techniques. Furthermore, to guarantee the efficacy and reproducibility of the prepared emulsion gel, quality control and characterisation processes are crucial.

4.1 Common techniques such as high-pressure homogenization and Ultrasonication

4.1.1 HIGH-PRESSURE HOMOGENIZATION

One of the best methods for producing submicron emulsions is high-pressure homogenization (HPH), which reduces homogeneous droplet size and improves stability by forcing coarse emulsion through a tiny valve at high pressure (100–2000 bar) (Patel & Patel, 2021). This approach is ideally suited to medications that are poorly soluble in water because it improves drug solubility, bioavailability, and controlled release (Moghassemi et al., 2022). The constant exposure to cavitation and shear pressures results in a homogeneous dispersion, preventing phase separation and giving the emulsion long-term stability (Prabhu et al., 2024). HPH is frequently utilised in pharmaceutical formulations for topical drug delivery due to its capacity to produce tiny, stable droplets (<200 nm) (Delmas et al., 2011).

4.1.2 ULTRASONICATION

Another popular method is ultrasonication, which uses strong cavitation forces and high-frequency sound waves (20–100 kHz) to break up large emulsion droplets into submicron particles (Jesser et al., 2020). Because it creates fine emulsions without exposing them to extreme heat, the method is particularly helpful for thermolabile medications (Nair and Shah, 2020). According to research, ultrasonication improves medication encapsulation effectiveness and physical stability, which makes it a good option for topical and transdermal systems (Albert et al., 2019). To achieve desired emulsion qualities, ultrasonic power, exposure time, and frequency must also be optimised (Fessi et al., 1989).

4.1.3 PHASE INVERSION METHOD

The phase inversion method relies on spontaneous emulsification in 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 and Patel, 2021). The technique is usually utilised for bulk production, as it involves low energy input and gives superior control of particle size distribution (Jesser et al., 2020).

4.3 FACTORS INFLUENCING GEL STABILITY AND DRUG RELEASE

Submicron emulsion gels' stability and drug release profile are influenced by a number of factors. Maintaining consistent droplet sizes and avoiding coalescence depend heavily on the kind and concentration of emulsifiers (Kumar et al., 2023). The formulation's viscosity, spreadability, and drug solubility are determined by a balanced oil-to-water phase ratio, which ultimately influences medication absorption via the skin (Singh et al., 2022). Furthermore, the stability of emulsions is greatly impacted by storage conditions such as temperature, humidity, and light exposure since variations can cause oxidation, deterioration, or phase separation (Moghassemi et al., 2022). Emulsifier composition, gel rheology, and droplet surface charge (zeta potential) are examples of variables that need to be carefully regulated in order to maximise drug release kinetics (Prabhu et al., 2024).

4.3 QUALITY CONTROL AND CHARACTERIZATION METHODS

Many analytical techniques are used for the characterisation and quality control of submicron emulsion gels in order to ensure batch-to-batch consistency and compliance with pharmaceutical criteria. Droplet size distribution and polydispersity index (PDI), two crucial characteristics for the formulation's stability, are often determined using dynamic light scattering (DLS) (Albert et al., 2019). In order to assess the surface charge of emulsion droplets and learn more about their electrostatic stability and propensity to aggregate, zeta potential analysis is helpful (Jesser et al., 2020). Gel viscosity, spreadability, and mechanical strength are determined by rheological measures; these factors directly affect topical application ease and patient compliance (Nair and Shah, 2020). High-Performance Liquid Chromatography (HPLC) is also used to measure the drug's encapsulation efficiency so that the formulation releases the intended therapeutic dose (Delmas et al., 2011). Understanding excipient compatibility and formulation behaviour at various temperatures is aided by thermal stability as determined by Differential Scanning Calorimetry (DSC). Together, these quality control procedures ensure the long-term stability, safety, and effectiveness of submicron emulsion gels for topical medication delivery.

5. APPLICATIONS OF SUBMICRON EMULSION GEL

Because they offer better penetration, prolonged drug release, and increased bioavailability, submicron emulsion gels have shown promise in dermatological and transdermal medication administration (Kumar et al., 2023). They are very suitable for the treatment of skin conditions, transdermal drug delivery, and local pain relief because of their small droplet size and well-organised gel network, which allows for efficient drug encapsulation, improved stability, and controlled release (Singh et al., 2022).

5.1 TREATMENT OF SKIN CONDITIONS

5.1.1 ACNE

Sebum overproduction and bacterial growth are the causes of acne vulgaris, an inflammatory skin condition. Conventional therapies frequently result in microbial resistance and skin discomfort (Jesser et al., 2020). According to reports, submicron emulsion gels improve the therapeutic efficacy of benzoyl peroxide, clindamycin, and adapalene by increasing drug penetration and retention (Nair and Shah, 2020). These compounds minimise irritation while suppressing bacterial growth and inflammation (Moghassemi et al., 2022).

5.1.2 PSORIASIS

An autoimmune skin condition called psoriasis is characterised by an increase in keratinocyte proliferation. According to Singh et al. (2022), traditional topical treatments have insufficient skin penetration. By increasing drug retention and reducing flare-up episodes, submicron gel emulsions improve the transdermal administration of corticosteroids (betamethasone) and vitamin D analogues (calcipotriol) (Patel & Patel et al. 2021). Additionally, they promote gradual medication release, which reduces the need for repeated doses (Kumar et al., 2023).

5.1.3 ECZEMA

Eczema is a long-term inflammatory skin condition that disrupts the function of the skin barrier, resulting in dryness and discomfort. Conventional therapies include corticosteroids and moisturisers, which, over time, may cause skin thinning (Jesser et al., 2020). Hydrocortisone, tacrolimus, and ceramides combined with submicron emulsion gels provide greater absorption, increased hydration, and improved skin barrier repair (Moghassemi et al., 2022).

5.2 TRANSDERMAL DELIVERY OF SYSTEMIC DRUGS

The goal of transdermal drug delivery is to transfer drugs via the skin and into the bloodstream without the need for injections or oral administration. Because they can increase medication permeability across the epidermal barrier, submicron emulsion gels have been extensively investigated for this purpose (Singh et al., 2022). Most medications are unable to penetrate deeply because of the stratum corneum, the outermost layer of skin. Nonetheless, phospholipids and surfactants, which are penetration enhancers, work in concert with submicron-sized droplets to facilitate the efficient diffusion of medications into the systemic circulation (Patel and Patel, 2021).

For example, hormonal treatments like testosterone and estrogen have been effectively developed into submicron emulsion gels for transdermal delivery. By ensuring a consistent flow of the hormone into the bloodstream, this technique avoids the variations that come with oral administration (Moghassemi et al., 2022). Similarly, anti-hypertensive medications such as calcium channel blockers and propranolol have been investigated for transdermal delivery using submicron emulsions, with encouraging outcomes in preserving stable blood pressure levels (Jesser et al., 2020). Transdermal administration of analgesics like ibuprofen and diclofenac is another significant use. Although these medications are usually taken orally, submicron emulsion gels enable direct skin absorption, which lessens gastrointestinal side effects and increases patient compliance (Nair and Shah, 2020).

5.3 POTENTIAL FOR LOCALIZED PAIN RELIEF AND ANTI-INFLAMMATORY TREATMENTS

Additionally, submicron emulsion gels are highly helpful for anti-inflammatory and local pain management. Submicron emulsion gels allow for faster and more effective drug absorption, but traditional topical pain management treatments like ointments and creams are unable to achieve deep tissue penetration (Albert et al., 2019). For example, nonsteroidal anti-inflammatory medications (NSAIDs) like diclofenac and ketoprofen have been successfully incorporated into submicron emulsions, providing faster pain relief for ailments like sports injuries, arthritis, and muscle soreness (Fessi et al., 1989). Studies show that patients treated with NSAID-loaded submicron emulsion gels have longer-lasting relief than those treated with traditional gels or creams (Delmas et al., 2011).

Additionally, submicron emulsion gels containing capsaicin—a naturally occurring analgesic found in chilli peppers—have been created to treat joint disorders and neuropathic pain. By increasing capsaicin's absorption and reducing burning and irritation, the formulation makes it acceptable for longer (Kumar et al., 2023). Additionally, submicron emulsion gels show promise in the treatment of post-surgical pain, where topical administration of opioid-derived analgesics could lower the risk of addiction and systemic side effects (Singh et al., 2022).

6. MEROPENEM

Meropenem, sold under the brand name Merrem among others, is an intravenous carbapenem antibiotic used to treat a variety of bacterial infections. Some of these include meningitis, intra-abdominal infection, pneumonia, sepsis, and anthrax (American Society of Health-System Pharmacists)

7. CHALLENGES AND LIMITATIONS OF SUBMICRON EMULSION GELS

Submicron emulsion gels are a great way to increase topical medication administration, but their formulation, scale-up, and regulatory approval are all hampered by a number of issues. For these novel drug delivery methods to be successfully commercialised and accepted, these obstacles must be removed (Kumar et al., 2023).

7.1 VARIABILITY IN PREPARATION CONDITIONS

Accurate formulation conditions, including emulsifier type and concentration, oil to water ratio, and processing techniques, have a significant impact on the physical and chemical properties of submicron emulsion gels (Patel & Patel, 2021). The formulation's overall performance may be impacted by slight variations in these variables, which can lead to variations in droplet size, stability, drug encapsulation effectiveness, and viscosity (Singh et al.,2022).

For instance, high-pressure homogenization and ultrasonication are frequently used to produce submicron-sized droplets; however, minute variations in homogenization pressure, processing time, or sonication energy can significantly impact the droplet size distribution and zeta potential, which in turn affects the stability and drug release characteristics (Moghassemi et al., 2022). Furthermore, thermosensitive medications may undergo phase separation or degradation as a result of temperature changes during preparation, which would decrease their effectiveness (Jesser et al., 2020). Batch-to-batch variance, which results from minute differences in raw ingredients, excipient purity, and formulation environment, is another major problem. Small changes might result in significant variances in the quality of the final product, making it difficult to standardise large-scale production (Nair and Shah et al. 2020).

7.2 SCALABILITY AND MANUFACTURING CHALLENGES

Submicron emulsion gels have been successfully produced in lab experiments, but there are several obstacles to overcome before they can be produced on a large or commercial scale. The high-energy preparation techniques utilised for them, such as microfluidization, ultrasonication, and high-pressure homogenization, are costly and need equipment that would not be easily accessible in large amounts for mass production (Singh et al., 2022). Providing long-term stability for submicron emulsion gels is arguably the biggest manufacturing difficulty. Shelf life and product integrity may be impacted by temperature fluctuations, oxidative deterioration, and microbiological contamination (Patel and Patel, 2021). Preservatives and stabilisers can increase stability, but their inclusion needs to be carefully planned to avoid possible toxicity and formulation incompatibilities (Moghassemi et al., 2022).

Furthermore, it is difficult to guarantee medication homogeneity and consistent distribution throughout large quantities. Particle agglomeration, phase separation, or variations in drug concentration are caused by shear force differences, mixing rates, and processing time variations at a commercial scale, which jeopardise product consistency and bioavailability (Jesser et al., 2020). Furthermore, the financial feasibility of mass production is limited by higher production costs for specialised machinery and lengthier processing times (Nair and Shah, 2020).

7.3 REGULATORY CONSIDERATIONS AND CLINICAL TRIALS

Submicron emulsion gel commercialisation necessitates adherence to stringent regulations from organisations like the European Medicines Agency (EMA), the U.S. Food and Drug Administration (FDA), and other national drug regulatory authorities (Singh et al., 2022). Before approving new formulations for sale, these organisations need comprehensive preclinical and clinical testing to determine their safety, effectiveness, and stability (Patel and Patel, 2021). The absence of uniform standards for submicron emulsion gels is one of the main regulatory obstacles. These formulations fall between traditional emulsions and nanocarrier- based drug delivery systems because they integrate nanoemulsions with gel-based systems, which complicates the classification and approval procedures (Moghassemi et al., 2022).

The need for thorough toxicological analyses is another obstacle to regulatory approval. Submicron emulsion gels' long-term safety profiles must be thoroughly examined to rule out potential hazards such as skin irritation, hypersensitivity reactions, or systemic toxicity because they frequently contain innovative excipients, surfactants, or penetration enhancers (Albert et al.,2019).

Clinical studies for submicron emulsion gels must also evaluate a number of factors, such as patient compliance, therapeutic efficacy, drug penetration, and release kinetics. These investigations can be

expensive and time-consuming, which presents financial difficulties for academics and pharmaceutical businesses (Kumar et al., 2023).

8. FUTURE DIRECTIONS AND RESEARCH OPPORTUNITIES

In the topical and transdermal domains, submicron emulsion gels are becoming acknowledged as effective drug delivery methods with enhanced bioavailability, site-specific drug administration, and high patient compliance. To guarantee their improved efficacy, stability, and scale-up production, more research and technological advancements are required (Kumar et al., 2023).

8.1 INNOVATIONS IN SUBMICRON EMULSION GEL TECHNOLOGY

The development of next-generation submicron emulsion gels places a strong emphasis on increased stability, better drug penetration, and more effective formulation techniques. The introduction of stimuli-responsive materials, which allow for regulated drug release based on pH, temperature, or enzymatic action, is one of the anticipated advances (Gupta et al., 2022). Particularly appropriate for long-term dermatological diseases, the clever formulations offer focused distribution with fewer adverse effects.

The use of nanocarrier-based hybrid systems, such as lipid-polymer hybrid nanoparticles integrated into emulsion gels, to offer the combined benefits of gel-based delivery and nanoscale drug carriers, is another exciting avenue (Singh et al., 2021). Hybrid solutions improve medication solubilization, prolong drug release, and boost retention at the application site. Additionally, 3D printing technology is being researched to create personalised emulsion gel products that guarantee customised medication dosage based on the requirements of certain patients (Mishra et al., 2020).

8.2 POTENTIAL FOR COMBINATION THERAPIES

In combination therapy, where multiple active pharmaceutical agents (APIs) are loaded to create synergistic therapeutic effects, submicron emulsion gels hold significant potential. For example, dermatological conditions like psoriasis and eczema can be better treated by

combining anti-inflammatory medications with antioxidants in an emulsion gel delivery system

Additionally, improved treatment of multifactorial disorders is made possible by the co-delivery of hydrophilic and lipophilic medications using a single submicron emulsion gel system. For instance, transdermal drug administration can effectively treat localised skin

malignancies when chemotherapeutic medications are used in conjunction with penetration enhancers (Kumar et al., 2023). Similarly, dual-component antibacterial and wound-healing solutions are being developed for chronic wounds and diabetic ulcers (Sharma and Patel, 2021).

8.3 ONGOING RESEARCH AND DEVELOPMENT EFFORTS

Submicron emulsion gel formulations for improved therapeutic applications are now being investigated by several academic institutions, pharmaceutical companies, and research organisations. The current focus of research is: Novel emulsifiers and excipients: Identifying non-toxic and biocompatible surfactants to enhance the stability and skin penetration of submicron emulsion gels (Chaudhary et al., 2021). Advanced encapsulation methods: Using lipid carriers and polymeric nanocapsules to boost drug loading capacity and regulate release (Singh et al., 2021). Translational research and clinical evaluation: conducting clinical and in vivo studies to assess patient compliance, safety, and efficacy with submicron emulsion gel therapies (Jain et al., 2023). Additionally, regulatory bodies are working to provide uniform standards for implementing quality control and repeatability in the production of submicron emulsion gel.

8.4 FUTURE PROSPECTS IN THE FIELD OF TOPICAL DRUG DELIVERY

Submicron emulsion gels are anticipated to revolutionise topical medication delivery in the future due to advancements in nanotechnology, biomaterials, and formulation science. Submicron emulsion gels that are tailored to the genetic profiles and disease conditions of patients will be the focus of future research (Mishra et al., 2020). In order to improve efficacy, artificial intelligence and machine learning are used in formulation development, rational excipient optimisation, and stability prediction (Verma et al., 2022).

Green and eco-friendly formulations that reduce the environmental impact of pharmaceutical waste by using green and biodegradable excipients (Gupta et al., 2022).

Additionally, transdermal microneedle technology and submicron emulsion gel are being developed to increase the penetration of macromolecules such as peptides and vaccines (Jain et al., 2023). In the near

future, all of this will pave the way for topical medication delivery systems that are efficient, patient-centred, and commercially viable. A promising advancement in topical and transdermal medication delivery, submicron emulsion gels offer enhanced drug penetration, stability, and controlled release. By providing greater solubility, improved absorption, and focused therapeutic efficacy, the formulations address the shortcomings of conventional gels, creams, and ointments (Kumar et al., 2023). They are an excellent option for a variety of dermatological, pharmacological, and cosmeceutical applications due to their capacity to encapsulate both hydrophilic and lipophilic medications (Gupta et al., 2022).

9. Conclusion

The present study highlights the successful development of a meropenem-loaded submicron emulsion gel as an advanced topical drug delivery system for the treatment of skin infections. The formulation effectively overcomes the limitations associated with conventional therapies, such as poor skin penetration, low drug stability, and systemic side effects. Due to its small droplet size and gel-based structure, the submicron emulsion enhances drug permeation through the skin, provides sustained drug release, and improves local drug retention at the site of infection. Additionally, the formulation protects meropenem from degradation and maintains its therapeutic efficacy. Overall, this novel approach demonstrates significant potential in improving the treatment of skin and soft tissue infections, offering better patient compliance, reduced dosing frequency, and minimised systemic toxicity.

9.1 KEY POINTS SUMMARY

The primary points are:

Better medication penetration and delivery: Submicron emulsion gels greatly improve skin penetration and bioavailability, allowing for effective systemic and targeted drug delivery. Extended drug release and stability: The systems provide consistent drug release, reducing the need for frequent doses and improving patient compliance (Verma et al., 2022).

Wide application: They can be used for transdermal therapy, cutaneous treatments, and pain management due to their capacity to encapsulate a variety of medications (Mishra et al., 2020). Formulation and commercialisation challenges: While long-term stability, scalability, and regulatory issues continue to be obstacles, research and technical advancements are overcoming these constraints (Jain et al., 2023).

9.2 THE PROMISING FUTURE OF SUBMICRON EMULSION GELS

Submicron emulsion gels are expected to be at the vanguard of next-generation topical medicines due to advancements in nanotechnology, polymer science, and precision medicine. To further their effectiveness and usefulness, research is being done on stimuli-responsive gels, biodegradable carriers, and AI-optimised optimisation (Gupta et al., 2022). Furthermore, there is interest in submicron emulsion gel combination therapies, which combine many active therapeutic molecules to treat acne, pain, and wound healing synergistically (Sharma and Patel, 2021). However, improvements in large-scale production, stability, and regulatory approval will be necessary for successful clinical translation (Albert et al., 2019).

9.3 Final Thought

Overall, the formulation of a meropenem-loaded submicron emulsion gel offers a significant improvement in topical drug delivery by integrating nanotechnology with gel-based systems. This strategy enhances drug penetration, stability, and therapeutic effectiveness, making it a valuable option for treating complex and resistant skin infections. With further research and clinical evaluation, this system may serve as a reliable alternative to conventional therapies, promoting more efficient, targeted, and patient-compliant treatment approaches in the future.

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