

Novel Emulgel-Based Formulations of Clobetasol Propionate for a Topical Drug Delivery System

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Abstract: Clobetasol propionate (CP) is a potent synthetic corticosteroid used for the treatment of various inflammatory and pruritic dermatoses. Despite its efficacy, the clinical use of CP is limited due to its poor water solubility, which results in poor skin penetration and potential adverse effects. To overcome these limitations, novel nanoformulations of CP have been developed for enhanced dermal delivery. This review provides an update on the recent advancements in nanoformulations of CP for dermal delivery. Various nano-based delivery systems, including liposomes, nanoparticles, nanoemulsions, and nanogels, are discussed in terms of their formulation, characterization, and in vitro/in vivo performance. Furthermore, the potential benefits, challenges, and future perspectives of these novel nanoformulations are critically evaluated. Overall, the development of nanoformulations presents promising strategies to enhance the dermal delivery of CP, thereby improving its therapeutic efficacy while minimizing adverse effects.

Keywords: clobetasol propionate; nanoformulations; dermal delivery; lipid-based nanoparticles; polymeric nanoparticles; nanoemulsions; solid lipid nanoparticles.

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1. Introduction

People widely use glucocorticoids, extremely potent molecules, to treat the pruritic and inflammatory presentations of various dermatological disorders. However, prolonged use of these typically results in significant adverse consequences. Steroid formulations. Based on their therapeutic efficacy, we categorize steroid formulations for topical administration into four types: mild, moderate, potent, and strong. Among these, clobetasol propionate (CP), a synthetic chemical, is a frequently prescribed FDA-approved prescription drug and belongs to the "strongest" category of topical glucocorticoids, meaning it is the most powerful [1]. Conventional CP formulations, including foams, creams, gels, ointments, lotions, shampoos, and sprays, are commonly used in dermatology. Commercially marketed CP formulations, Cormax®, Clobex®, Dermovate®, and Temovate® alleviate the pruritic and inflammatory aspects of corticosteroid-responsive dermatoses. To address these issues, scientists have focused on developing cutting-edge CP nanoformulations for topical application. Nanoformulations offer several benefits, including enhanced skin penetration, targeted distribution, reduced systemic adverse effects, and improved drug solubility [2]. The

development of several nanoformulations of CP, including nanoemulsions, nanogels, nanoparticles, and nanostructured lipid carriers, has advanced significantly in recent years. This study provides an update on current developments in the creation of innovative nanoformulations of CP for cutaneous distribution. It covers the various types of nanoformulations, their characterization methods, formulation procedures, in vitro and in vivo investigations, and their therapeutic applications. We also discuss the challenges and future paths in this field. The CP controls the release of arachidonic acid, a substance that starts inflammation, from membrane phospholipids by increasing the expression of phospholipase A2 suppressor proteins [3]. Compared to hydrocortisone, this topical synthetic corticosteroid has a vasoconstrictor potential that is approximately 1,800 times greater. However, compared to comparable substances, the associated adverse effects are somewhat greater. Adverse effects include skin shrinkage, hypopigmentation at the application site, steroid-induced acne, allergic contact dermatitis, Cushingoid syndrome, suppression of the hypothalamic-pituitary-adrenal axis, osteonecrosis, dermal striae, telangiectasia, tachyphylaxis, pruritus, and folliculitis.

Researchers have studied CP in relation to numerous skin conditions, including vitiligo, psoriasis, eczema, and autoimmune cell-mediated illnesses [4]. Given its enormous healing potential, the US FDA has approved CP for the treatment of inflammatory skin conditions. Furthermore, CP has emerged as one of the most commonly used corticosteroids for various skin conditions. As a result, over the last several decades, CP applications have undergone significant improvements. With the potential to inform future research and development in the exciting field of dermatological drug delivery, the overall goal of this study is to provide a comprehensive overview of the state-of-the-art in nanoformulations of CP for dermal administration [5].

2. Inflammatory Skin Disorders in Relation to Clobetasol Propionate Use

Inflammatory skin disorders, such as psoriasis, eczema, and dermatitis, are chronic conditions characterized by inflammation, itching, redness, and disruption of the skin barrier. The management of these disorders often requires potent anti-inflammatory and immunosuppressive agents to alleviate symptoms and control disease progression. One of the most effective treatments for such conditions is clobetasol propionate (CP), a high-potency corticosteroid that works by inhibiting the release of pro-inflammatory cytokines and mediators [6].

Clobetasol propionate, traditionally used in ointment, cream, or lotion forms, has been the mainstay for managing severe inflammatory skin diseases. However, these conventional formulations often present challenges, including poor patient compliance due to greasiness, reduced permeability, and potential for systemic absorption leading to side effects such as skin thinning or hypothalamic-pituitary-adrenal (HPA) axis suppression. Moreover, the occlusive nature of traditional ointments can cause discomfort, and creams may have a short retention time on the skin surface [7].

In this context, novel emulgel-based formulations have gained significant attention for improving the topical delivery of clobetasol propionate. Emulgels, which combine the advantages of emulsions and gels, offer enhanced drug penetration, improved retention on the skin surface, and a better aesthetic feel [8]. This advanced delivery system is particularly promising for treating inflammatory skin disorders, as it enables localized delivery of the drug with reduced systemic absorption, thereby minimizing adverse effects. By incorporating clobetasol propionate into an emulgel matrix, these formulations ensure sustained release,

improved skin permeation, and enhanced patient adherence, making them a novel approach to effectively managing inflammatory skin conditions [9].

3. Propionate Clobetasol's Thermodynamics and Physicochemical Characteristics

The crystalline powder known as clobetasol-17-propionate has a white to cream colour and is odourless. It dissolves in water at a rate of 2 µg/mL. Figure 1 illustrates the chemical structure of this moiety. With a molecular weight of 466.97 g/mol, a melting point of 196.25°C, and a log p value of 2.98, it is an analogue of prednisolone [10]. It has the chemical name (8S, 9R, 10S, 11S, 13S, 14S, 16S, 17R) (2-chloroacetyl). The empirical formula C₂₅H₃₂ClFO₅, known as -17-Propanoate, originates from -9-fluoro-11-hydroxy-10,13,16-trimethyl-3-oxo-6,7,8,11,12,14,15,16-octahydrocyclopenta[a] phenanthren-17-yl. In methanol, CP exhibits a distinctive UV absorption at λ_{max} 237 nm. Its two spatially split chromophores—the cyclohexadiene moiety in ring A and the carbonyl group at C-20—make it an extremely striking moiety from a photochemical perspective [11]. Hepatic microsomal enzymes metabolize corticosteroids by eliminating 4, 5, and 6 double bonds, hydroxylating the 3-keto group, and reducing the 20-keto to the 20-hydroxy state. Moreover, the urine eliminates the metabolites after conjugating them with either glucuronic acid or sulphate. After cutaneous application, there is very minimal systemic absorption of CP [12].

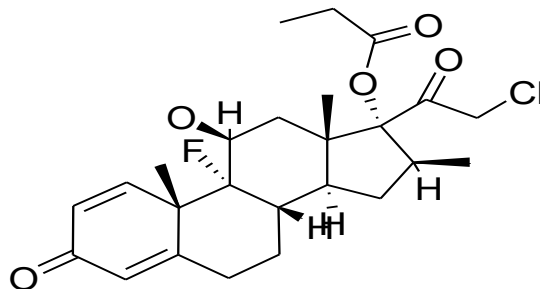


Figure 1. Chemical structure of clobetasol propionate.

4. Mode of Action

The strong corticosteroid clobetasol propionate works in several ways to reduce inflammation, treat pruritus, and constrict blood vessels. Clobetasol propionate enters the skin after application and attaches itself to intracellular glucocorticoid receptors. After entering the nucleus, this complex modifies gene transcription [13]. Clobetasol propionate reduces the production of inflammatory mediators, such as prostaglandins and leukotrienes, while suppressing the expression of pro-inflammatory cytokines, including interleukins and tumor necrosis factor-alpha. As a result, it reduces inflammation, which in turn lessens erythema, edema, and pruritus associated with various dermatological disorders [14]. The emulgel formulation enhances the skin penetration of clobetasol propionate, resulting in improved effectiveness and faster relief from inflammation and related symptoms. Corticosteroids can control transcription indirectly by blocking the activity of other transcription factors, in addition to directly regulating gene transcription. Specifically, these moieties stimulate the production of the IκBα gene, thereby increasing the inhibitory nuclear factor-kappa B (IκBα) at the cellular level [15]. The IκBα protein, on the other hand, inhibits transcription by binding to NF-κB, or nuclear factor-kB, to block translocation to the nucleus. Corticosteroids may influence gene transcription that is not susceptible to glucocorticoids. Corticosteroids also inhibit the growth of T lymphocytes, as demonstrated [16]. CP can block the synthesis of

metabolic products from arachidonic acid. Although the exact mechanism remains unclear, these activities may both inhibit cytokine expression and reduce the antiproliferative effects of cytokines. Patients receiving glucocorticoids for a range of inflammatory skin conditions have shown reduced levels of prostaglandins, leukotrienes, and arachidonic acid metabolic products in their blood [17].

5. Emulgel-based Formulations for Clobetasol Propionate

Clobetasol propionate, a potent corticosteroid, is widely used to treat various inflammatory skin conditions. Emulgel-based formulations provide an effective means of delivering clobetasol propionate, thanks to their enhanced drug solubilization and skin permeation properties. Ten different Emulgel-based formulations of clobetasol propionate were developed using various carrier systems and fabrication methods [18]. The carrier systems included various combinations of emulsifying agents, such as Tween 80, Span 80, and Carbopol 934. The fabrication methods involved simple mixing, homogenization, and sonication techniques. The formulations were evaluated for various parameters, including pH, viscosity, drug content, spreadability, and in vitro drug release [19]. The preparation of these formulations involved dispersing clobetasol propionate in the Emulgel base, followed by the addition of selected carrier systems and fabrication techniques. The effect of these formulations was assessed in terms of their anti-inflammatory and skin permeation properties. Table 1 presents the Emulgel-based formulations for clobetasol propionate, along with their carrier systems, fabrication methods, evaluation, and preparation methods [20].

Table 1. Emulgel-based formulations for clobetasol propionate, along with carrier systems, fabrication methods, evaluation, and preparation methods.

Carrier System	Fabrication Method	Evaluation Parameters	Preparation Method	Ref
Emulgel	Simple mixing	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Dispersing clobetasol propionate in Emulgel base	[8]
Emulgel + Tween 80	Homogenization	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Dispersing clobetasol propionate in Emulgel base, followed by homogenization	[21]
Emulgel + Span 80	Sonication	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Dispersing clobetasol propionate in Emulgel base, followed by sonication	[22]
Emulgel + Carbopol 934	Simple mixing	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Dispersing clobetasol propionate in Emulgel base, followed by the addition of Carbopol 934 with simple mixing	[23]
Emulgel + Tween 80 + Span 80	Homogenization	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Dispersing clobetasol propionate in Emulgel base, followed by the addition of Tween 80 and Span 80 with homogenization	[24]
Emulgel + Tween 80 + Carbopol 934	Sonication	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Dispersing clobetasol propionate in Emulgel base, followed by the addition of Tween 80 and Carbopol 934 with sonication	[25]
Emulgel + Span 80 + Carbopol 934	Simple mixing	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Dispersing clobetasol propionate in Emulgel base, followed by the addition of Span 80 and Carbopol 934 with simple mixing	[26]
Emulgel + Tween 80 + Span 80 + Carbopol 934	Homogenization	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Dispersing clobetasol propionate in Emulgel base, followed by the addition of Tween 80, Span 80, and	[27]

Carrier System	Fabrication Method	Evaluation Parameters	Preparation Method	Ref
Emulgel + Carbopol 934 (0.5%)	Sonication	pH, Viscosity, Drug content, Spreadability, In vitro drug release	Carbopol 934 with homogenization Dispersing clobetasol propionate in Emulgel base, followed by the addition of Carbopol 934 (0.5%) with sonication	[28]

6. Novel Formulations for Clobetasol Propionate Announced

Novel formulations of clobetasol propionate, a potent corticosteroid, have been announced, promising more efficient and targeted treatment for various dermatological conditions. These formulations aim to enhance drug delivery, potentially reducing side effects and improving patient compliance [15]. The advancements in formulation technology represent a significant stride in the field of dermatology, offering more tailored and effective treatment options for patients suffering from conditions such as eczema, psoriasis, and other inflammatory skin disorders [15]. Table 2 presents the List of novel formulations, carrier systems, fabrication methods, doses, benefits-risk evaluations, effects, and evaluations [29].

Table 2. List of novel formulations, carrier systems, fabrication methods, dose, benefits-risk evaluation, effects, and evaluation.

Formulation	Fabrication Method	Dose	Benefits	Risks	Efficacy	Evaluation
Liposomal	Thin-film hydration	0.05% cream/gel	Enhanced drug delivery, prolonged drug release, reduced side effects	Risk of allergic reaction, skin irritation, burning, itching, or redness	Reduced systemic absorption, decreased adverse effects, increased patient compliance	Clinical trials show promising results, a significant reduction in inflammatory symptoms
Nano emulsion	High-pressure homogenization	0.05% lotion	Enhanced drug permeation, improved stability, reduced greasiness	Risk of skin atrophy, telangiectasia, striae, acneiform eruptions, secondary infections, hypopigmentation, perioral dermatitis, and allergic contact dermatitis	Rapid onset of action, improved patient compliance, reduced side effects	In vivo studies demonstrate increased efficacy and safety
Microemulsion	Phase inversion temperature method	0.05% foam	Enhanced skin penetration, sustained drug release, and non-sticky formulation	Risk of skin thinning, blistering, or discoloration, especially in sensitive areas	Improved patient convenience, reduced application frequency, decreased systemic absorption	Comparative studies with conventional formulations show superior efficacy and safety
Solid lipid nanoparticles	Hot homogenization followed by ultrasonication	0.05% ointment	Controlled drug release, increased stability, reduced frequency of application	Risk of skin irritation, erythema, burning, itching, or peeling	Reduced systemic absorption, improved safety profile, enhanced patient compliance	In vitro and in vivo studies demonstrate prolonged drug release and improved efficacy

6.1. Nanoemulsions.

Multicomponent fluid dispersions that are thermodynamically unstable but kinetically stable are known as nanoemulsions. An electrolyte, an intermediate-chain length alkanol, an aqueous phase, an oily phase, a main surfactant acting as an emulsifying agent, a cosurfactant, and other components make up these compositions [30]. They fall into two categories: water in oil (w/o) and oil in water (o/w). Increased skin retention and duration, decreased drug-protein binding, enhanced drug penetration, sustained drug release, fewer systemic side effects, and ease of use for the inclusion of both hydrophilic and hydrophobic pharmaceuticals are just a few of the major advantages of nanoemulsions [31]. Alam *et al.* [32] employed an aqueous phase titration method to formulate oil-in-water (o/w) nanoemulsions using Tween 20 (Polysorbate 20), eucalyptus oil, ethanol, and distilled water to facilitate the delivery of clobetasol propionate (CP) to the skin more effectively. We tested the nanoemulsions we made to assess their effectiveness in reducing inflammation in living organisms, their ability to alleviate irritation, and their compatibility with lymphocyte NTPDase activity. We observed a significant increase in NTP-Dase potential in the lymphocytes when we applied the CP-loaded nanoemulsion, compared to the other treatment groups. Even with a high surfactant content, the nanoformulation's improved anti-inflammatory activity and lack of irritation confirmed its safety and effectiveness [32]. The same study team also examined the use of algal oil, which contains omega-3 fatty acids, in nanoemulsions to administer CP topically. We used the aqueous phase titration method to mix Tween® 20 (Polysorbate 20), algal oil, PEG-200 (Polyethylene Glycol), and water to make the nanoemulsions. Hydrogel was filled with the chosen nanoemulsion using Carbopol® 971 (viscosity: 97.57 ± 0.04 PaS).

We assessed the *in vivo* irritation potential, anti-inflammatory action, and potential for skin dermatitis of the manufactured cargos. Heat analysis and histopathology were used to evaluate skin penetration and identify changes in the skin's layers, particularly the epidermal membrane. After a 14-day trial, the CP-loaded nanoemulsion gel's skin irritation score was 1.66 ± 0.81 , whereas the placebo nanoemulsion gel's score was 0.83 ± 0.75 [33]. This demonstrated the improved nanoemulsion's safety for cutaneous distribution. Kaur *et al.* [35] developed CP and calcipotriol-delivering nanoemulsions as a treatment for psoriasis. We created these using oil and a surfactant or co-surfactant, selecting them based on their ability to dissolve and emulsify, respectively [34]. Capsaicin had the highest percentage increase in TEWL and irritation potential. A free CP and calcipotriol (CP-CT) embedded gel was more likely to irritate the skin than the nanoemulsion gel, so it was better tolerated. We arranged the skin irritation ratings for the capsaicin, free CP-CT gel, and nanoemulsion gel samples in this order. We found that greater medication penetration caused discomfort in rats [35].

Furthermore, the drug-loaded nanoemulsion gel had very little direct drug-skin contact. In addition, compared to conventional dose forms, the nanoemulsion gel increased the concentration of CP locally, thereby reducing its systemic side effects. The nanoemulsion gel demonstrated greater antipsoriatic potential than both the sold commercial dose form and the free medication, despite causing minimal skin irritation [36].

6.2. Solid lipid nanoparticles.

Surfactants, acting as stabilizers, dissolve solid lipids in an aqueous medium to form SLNs, which are nanoparticles ranging from 10 to 1000 nm. Adding physiologically suitable lipids reduces the toxicity and irritation that can sometimes be present in other nanoparticulate

systems. Additional benefits include resistance to degradation, in vivo acceptability, superior physical stability, regulated and prolonged drug release, and flexibility with different drug delivery systems [37,38]. Hu *et al.* [39] used the solvent diffusion approach to create CP-loaded SLNs. We assessed the manufactured formulations in terms of encapsulation effectiveness, PDI, zeta potential, and particle size. Using an acidic aqueous medium significantly enhanced the recovery of SLNs compared to the regularly used aqueous medium (pH 5.73) with an equal (1%) polyvinyl alcohol content. We observed a daily drug release of approximately 6% for four days, following an initial burst release within the first three hours, which suggests the suitability of SLNs for long-term use [39].

Duong *et al.* [40] employed the high-pressure homogenization method to produce CP-loaded solid-liquid nanoparticles (SLNs) and investigated their capacity to retain CP, as well as their shape and average particle size. We found 92.5% drug encapsulation in selected CP-loaded SLNs, which were smooth and spherical with a mean particle size of 177 nm. We also combined them with a cream foundation [40]. We conducted skin absorption investigations and drug penetration trials on human cadaver skin using CP cream and CP SLN cream. The results showed that CP-loaded SLN cream had a low flux value and strong cutaneous absorption of the drug compared to regular CP cream. We subsequently conducted a controlled, double-blind clinical investigation involving 16 patients with persistent eczema. Compared to the marketed cream, the CP-loaded SLN application showed a significant improvement in the presentation of chronic eczema (1.9 times inflammation and 1.2 times itching). The effectiveness of the nanoformulations developed for treating eczema was determined by the study's outcomes. In 2019, Reddy *et al.* [41] employed the emulsification-homogenization method to prepare CP-loaded SLN. They aimed to rapidly deliver CP to the skin and investigate how various factors, such as surfactant, homogenization time, and the lipid-to-drug ratio, impacted the particulate features of the nanoformulation. The optimal nanoformulation revealed a 133.3 ± 3.66 nm size of particles, 0.179 ± 0.081 of PDI, -36.2 ± 0.11 mV of zeta potential, and $78.1 \pm 1.11\%$ of entrapment efficiency [42]. The investigation of skin penetration of the prepared CP-SLN suspension demonstrated the sustained release of the CP molecule for up to 24 hours. Maximum drug deposition ($48.22 \mu\text{g/mL}$) was reached after formulating CP into SLN, in contrast to pure CP's drug deposition ($19.12 \mu\text{g/mL}$). SLN has been recognized as a viable colloidal particle carrier system due to its sustained drug release for a longer duration and increased skin permeability for CP molecules [43].

6.3. Microemulsion.

Microemulsions are colloidal dispersions of water, oil, co-surfactant, and surfactant with droplet sizes up to 100 nm. They are optically isotropic, monophasic, transparent, and thermodynamically stable. The primary distinctions between microemulsions and nanoemulsions are their transparency and thermodynamic stability [44]. Despite the smaller droplet size of a microemulsion compared to a nanoemulsion, both terms remain in use. The prefix micro was used to refer to microemulsions, as they were the first to be formulated and had minuscule droplet sizes. Nanoemulsions eventually became part of nanoscale systems. To avoid confusion, we continued to classify them in that manner [45].

Researchers use low-energy emulsification processes to create microemulsions. Patel *et al.* [46] created a CP-encapsulated microemulsion gel to treat vitiligo. Patel *et al.* [46] adjusted the microformulation using a D-optimal mixture experimental design by adjusting the ratios of oil, water, surfactant, and cosurfactant. The optimized microemulsion had a globule

size of 18.26 nm and a CP solubility of 36.42 mg/mL. The composition of the optimized microemulsion consisted of 3% oil, 50% water, and a mixture of 45% surfactant and cosurfactant [46]. We incorporated the produced microemulsion into Carbopol® 934P gel for topical application. We used skin from male Albino Wistar rats in an ex vivo permeation test. A microemulsion-based gel (CP permeated $28.43 \pm 0.67 \mu\text{g cm}^2$) was found to keep more CP in the skin layers than commercial formulations (CP permeated $37.73 \pm 0.77 \mu\text{g cm}^2$). Studies on irritation have shown that a microemulsion-based gel is less prone to irritation than both microemulsion and commercial formulations [47]. The study's conclusions all supported the use of CP-loaded microemulsion gel as a potentially effective dosage form for treating vitiligo. The same research team continued to work on validating the CP microemulsion-based gel for the treatment of vitiligo in 2014. The produced product was subjected to occlusive tests, as well as characterization of viscosity, rheology, and gel strength [48].

In comparison to the cream formulation, the in vitro release experiments of the manufactured formulation (conducted using a cellulose nitrate membrane) showed greater release, improved accumulation, and enhanced skin penetration of CP. In vivo imaging of dermal uptake using laser scanning microscopy determined the epidermal and skin targeting of CP. This study's dermatopharmacokinetic examination also showed improved CP deposition in skin layers [49]. We conducted the microemulsion gel pilot clinical research in a single-anonymized, randomized manner, using the Vitiligo Area Scoring Index method for assessment. The clinical study's results determined that the microemulsion-based gel had a quicker potential for repigmentation than the control group. Therefore, researchers reported that the CP-loaded microemulsion gel improved skin localization and demonstrated promising therapeutic potential in patients with vitiligo [50].

Langasco and colleagues developed CP-loaded water-in-oil (w/o) microemulsions to treat scalp psoriasis. They constructed pseudo-ternary phase diagrams using a mix of biodegradable and biocompatible excipients. This investigation established the appropriateness of microemulsions through their low viscosity, excellent thermodynamic stability, and Newtonian flow characteristics. At increasing drug concentrations, we observed significant alterations in the stratum corneum and epidermis of the skin following treatment with microemulsions. The ex vivo permeation investigation might attribute the enhanced targeted impact to the intended drug retention in the upper skin layers. Therefore, the authors concluded that the combination of natural excipients used in this study's microemulsion formulation contributed to the improvement in CP effectiveness [51].

6.4. Liposomal.

Liposomal delivery systems have gained significant attention in recent years due to their ability to enhance the efficacy and bioavailability of various therapeutic agents, particularly anti-inflammatory drugs. These spherical vesicles, composed of lipid bilayers, can encapsulate both hydrophilic and hydrophobic substances, protecting them from degradation and improving their targeted delivery to inflamed tissues [52]. The use of liposomal formulations in anti-inflammatory therapy offers several advantages, including prolonged circulation time, reduced toxicity, and enhanced permeability and retention effect. This targeted approach not only maximizes the therapeutic impact of anti-inflammatory drugs but also minimizes systemic side effects, making liposomal drug delivery a promising strategy for treating inflammatory diseases. Studies have demonstrated the effectiveness of liposomal encapsulation in improving the pharmacokinetic profiles of anti-inflammatory agents such as

corticosteroids, nonsteroidal anti-inflammatory drugs (NSAIDs), and newer biologics, paving the way for more efficient and patient-friendly treatment regimens [53].

7. Challenges with Clobetasol Propionate's Stability

Most commonly used for its anti-inflammatory and immunosuppressive effects, the strong corticosteroid clobetasol propionate has caused some stability issues, especially in topical preparations. For it to be effective in treating inflammatory skin disorders, its stability is essential. Clobetasol propionate can break down over time or in certain situations. This can make it less effective as a medicine and increase the likelihood of side effects due to the breakdown products that are formed [54]. Several factors, including exposure to light, temperature variations, and the inclusion of specific excipients, can affect the stability of a formulation. Proper storage of the drug, such as keeping it out of direct sunlight and in a cool, dry location, can help mitigate these stability issues. Furthermore, producers often use stabilizing chemicals and packaging designed to protect the product from environmental elements. To maintain the ability of clobetasol propionate to reduce inflammation and keep patients comfortable, it is essential to understand and address these stability issues [55].

8. Conclusion

In conclusion, the development of novel emulgel-based formulations of clobetasol propionate offers a promising advancement in the field of topical drug delivery systems. These formulations combine the advantageous properties of both emulsions and gels, resulting in enhanced drug stability, controlled release, and improved patient compliance. The unique structure of emulgels facilitates better penetration of clobetasol propionate into the skin, ensuring effective and sustained therapeutic action. Moreover, the versatility in formulation allows for the incorporation of various excipients to optimize drug solubility and skin permeability. Consequently, emulgel-based systems represent a significant innovation for the topical administration of clobetasol propionate, providing a potential pathway for more effective treatment of inflammatory skin conditions with reduced side effects. Continued research and clinical evaluations will further elucidate their efficacy and pave the way for their integration into standard dermatological practice.

Author Contributions

Writing—original draft preparation, R.K.C.; validation, R.K.C.; data curation, S.K.; writing—review and editing, S.K.; All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Abbreviations

CP: Clobetasol Propionate; NLC: Nanostructured Lipid Carriers; SLN: Solid Lipid Nanoparticles; NANO: Nanoparticles; FDA: Food and Drug Administration; TDD: Transdermal Drug Delivery.

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