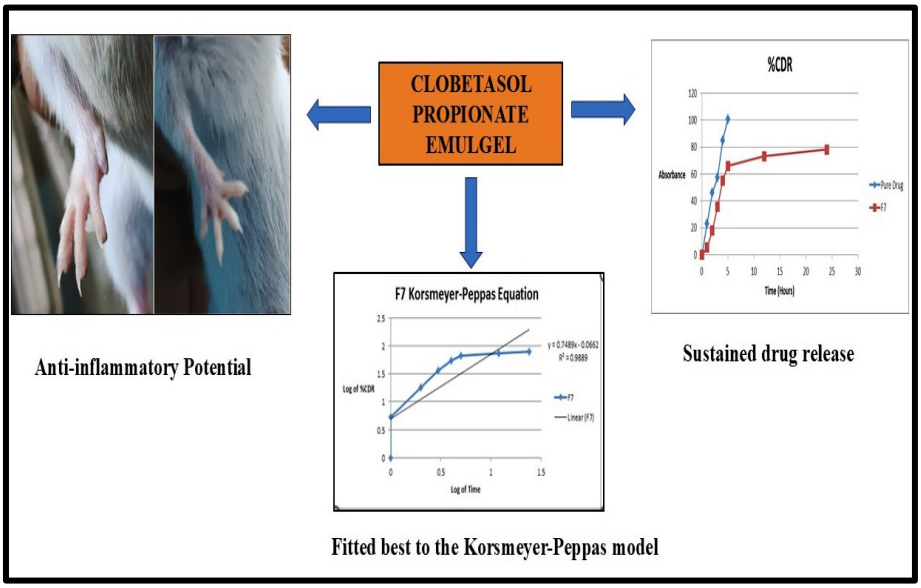
Formulation Development and Evaluation of a Topical Anti-inflammatory Emulgel Containing Clobetasol Propionate

Ramkumar Chaudhary[1*], Saravanan Kaliyaperumal[2]

[1*]Research Scholar, Faculty of Pharmacy, Bhagwant Global University, Kotdwar–246149, Uttarakhand, India.
Email: rkchaudhary1986@gmail.com (Corresponding Author)
[2]Faculty of Pharmacy, Bhagwant Global University, Kotdwar, India

Graphical Abstract



Abstract

Background: Clobetasol propionate (CP) is a potent corticosteroid with limited skin penetration due to its poor water solubility. Formulating CP into an emulgel may enhance dermal delivery, prolong release, and improve therapeutic efficacy. The objective was to develop and evaluate a CP-loaded emulgel for optimized topical delivery with improved physicochemical properties, drug release, and anti-inflammatory activity. **Methodology:** An optimized formulation (F6) was prepared and characterized for pH, drug content, viscosity, spreadability, and swelling index. In vitro drug release was studied using phosphate buffer pH 7.4, and release kinetics were evaluated. In vivo anti-inflammatory activity was assessed using carrageenan-induced paw edema in rats, with comparisons to a standard drug and control groups. **Results and Discussion:** The optimized emulgel showed pH 6.38, drug content 98.42%, viscosity 3341 cps, and desirable spreadability. In vitro, 78.30% of CP was released over 24 h, fitting the Korsmeyer–Peppas model, indicating diffusion-controlled release. In vivo, the formulation significantly reduced paw edema, with efficacy approaching that of the standard drug. **Conclusion:** The CP-loaded emulgel exhibited improved permeability, sustained drug release, and potent anti-inflammatory activity, demonstrating its potential as an effective topical delivery system for CP.

Keywords: Clobetasol propionate, Emulgel, Sustained release, Korsmeyer–Peppas model, Anti-inflammatory activity, Topical delivery

How to cite this article: Chaudhary R, Kaliyaperumal S. Formulation Development and Evaluation of a Topical Anti-inflammatory Emulgel Containing Clobetasol Propionate. Int J Drug Deliv Technol. 2026;16(14s): 990-997. DOI: 10.25258/ijddt.16.14s.110

INTRODUCTION

Topical drug delivery systems are designed to administer medications through the skin or mucous membranes, offering advantages such as ease of use and localized treatment [1]. These systems include conventional forms like creams, gels, and patches, as well as novel approaches such as liposomes, nanoparticles, and sol-gel microcapsules [2, 3]. The market for topical drug delivery systems is expected to grow rapidly by 2025 [4]. Recent research has focused on developing innovative formulations to improve efficacy, reduce side effects, and enable

unique drug combinations [2]. These advancements aim to enhance skin permeability and drug retention in the dermis, overcoming limitations of conventional systems such as poor retention and low bioavailability [3]. Despite numerous delivery systems under investigation, only sol-gel microencapsulation has reached clinical stages [3].

The recent advancements in topical and transdermal drug delivery systems have significantly improved the efficacy of anti-inflammatory medications. Nanoemulsions and submicron emulsions enhance the penetration and bioavailability of both steroidal and nonsteroidal anti-inflammatory drugs (NSAIDs), offering superior performance compared to conventional creams [5,6]. These systems, along with innovative techniques like iontophoresis and sonophoresis, enable more localized treatment with minimal systemic side effects [7]. Hydrogels have emerged as promising delivery vehicles due to their biocompatibility and controlled release properties, addressing limitations of traditional delivery methods [8]. The integration of nanotechnology and advanced formulations, such as solid lipid nanoparticles and vesicular systems, further enhances NSAID effectiveness in managing pain and inflammation [7].

Emulgel is a novel topical drug delivery system that combines the properties of emulsions and gels, offering enhanced delivery of hydrophobic drugs [9-11]. This dual-control release system provides improved patient adherence for treating various conditions, including muscle pain, headaches, acne, and psoriasis [9-11]. Emulgels overcome the limitations of traditional gels in delivering hydrophobic drugs through the skin by utilizing an emulsion-based approach [9-11]. The formulation employs polymers that act as emulsifying and thickening agents, increasing viscosity while decreasing interfacial and surface tension [10]. This results in stable emulsions with favorable properties such as being greaseless, thixotropic, and easily spreadable [10]. The unique combination of emulsion and gel characteristics makes emulgels a promising advancement in topical drug delivery, offering improved efficacy and patient comfort [9-11].

Clobetasol propionate is a highly potent topical corticosteroid used to treat various skin conditions, including psoriasis, atopic dermatitis, and vulvar lichen sclerosus [12]. It exerts anti-inflammatory, immunosuppressive, and antimitotic effects on skin cells [12]. While traditionally believed that ointments are the most potent form, studies have shown similar efficacy across different vehicles, including solutions, foams, creams, and lotions [13]. This allows for patient preference in choosing the most suitable formulation, potentially improving treatment adherence [13]. Clobetasol propionate is particularly effective for medium to severe psoriasis and steroid-resistant dermatoses [14]. However, its potency is associated with potential side effects, such as skin atrophy and hypothalamic-pituitary-adrenal axis suppression [12].

Recent studies have explored the development of emulgel formulations containing clobetasol propionate for enhanced topical delivery in treating dermatological conditions. These formulations offer improved drug solubility, skin penetration, and extended release compared to conventional forms [15]. Encapsulation of clobetasol propionate in PLGA microspheres within emulgels has shown promise in prolonging drug release and potentially reducing side effects [16]. Researchers have also investigated polyherbal emulgels containing natural anti-inflammatory agents as alternatives to allopathic medications, demonstrating comparable efficacy to marketed diclofenac sodium preparations [17].

Furthermore, nanoemulsion formulations using algal oil rich in omega-3 fatty acids have been developed to enhance clobetasol propionate permeability and anti-inflammatory effects. These formulations exhibited significant inhibition of inflammation and improved skin permeation, as evidenced by DSC and histopathology studies [18].

Despite its efficacy, clobetasol propionate poor water solubility limits skin penetration and may cause side effects. This study focuses on preparing and evaluating an emulgel of clobetasol propionate for improved dermal delivery and anti-inflammatory activity.

MATERIAL AND METHODS

Material

Clobetasol propionate was obtained from N.R. Life Care, Ahmedabad, India. Span 60, Tween 80, soybean oil, eucalyptus oil, methanol, ethanol, Carbopol 940, potassium dihydrogen phosphate, disodium hydrogen phosphate, sodium chloride, and sodium hydroxide were sourced from Loba Chemi Pvt. Ltd., India. Distilled water was used throughout the study.

Methods

UV-Visible spectrophotometer

A stock solution was prepared by dissolving 100 mg of the drug in 100 ml of HPLC-grade methanol. From this stock, standard solutions in the concentration

range of 2-12µg/ml were prepared through appropriate dilutions. The 10µg/ml solution was then scanned using a UV spectrophotometer (Shimadzu) to determine the λmax 239nm. The obtained data were subsequently used to validate the drug using the UV spectroscopic method [19].

Preparation of Emulgel

Clobetasol propionate emulgel was formulated by preparing an oily phase containing eucalyptus oil, isopropyl myristate, and Span 60, and an aqueous phase comprising methylparaben, propylparaben, disodium EDTA, BHT, propylene glycol, and clobetasol propionate dispersed in purified water. The oily phase was gradually incorporated into the aqueous phase with continuous stirring for 30 minutes to obtain a primary emulsion, which was then homogenized at 8000 rpm for 5 minutes and sonicated for 15 minutes.

Table 1: Formulation Table

Formulation	Carbopol 940 (%)	Eucalyptus oil (%)	Span 60 (%)
F1	0.5	0.5	1.0
F2	0.5	1.25	2.25
F3	0.5	2.0	3.5
F4	0.75	0.5	1.0
F5	0.75	1.25	2.25
F6	0.75	2.0	3.5
F7	1.0	0.5	1.0
F8	1.0	1.25	2.25
F9	1.0	2.0	3.5

Separately, Carbopol 940 was dispersed in water and added to the emulsion at 80 °C with magnetic stirring for 15 minutes to form the gel base, after which the pH was adjusted to 5.0–6.0 using triethanolamine. Nine trial batches (F1–F9) were prepared with varying levels of Carbopol 940, eucalyptus oil, and Span 60, while the concentrations of other excipients remained constant: Tween 80 (1.0%), propylene glycol (10.0%), isopropyl myristate (2.0%), EDTA-Na_2 (0.02%), BHT (0.02%), methylparaben (0.18%), propylparaben (0.02%), triethanolamine (0.6%), and clobetasol propionate (0.05%). Purified water was added q.s. to adjust the final water content, which ranged between 79.61% and 84.11% depending on the variable excipient composition as shown in Table 1 [20-22].

Evaluation Emulgel

Physical Examination

The emulgel formulations were visually evaluated for parameters such as grittiness, appearance, uniformity, phase separation, color, consistency, resilience, and any signs of phase division [23].

Measurement of pH

The pH of each emulgel was determined by dispersing 1 g of gel in 100 ml distilled water, storing at 4 °C for 2 h, and recording the average of three readings using a digital pH meter [23].

Viscosity

Viscosity was determined using a Brookfield viscometer (spindle D) by rotating the spindle in gel samples at shear rates of 0.5–5 rpm, recording forward and reverse dial readings, averaging them, and calculating viscosity using the instrument's calibration factors [23].

Spreadability

Spreadability was evaluated using a wooden block and glass slides, where 2 g of emulgel was placed between slides under a 1 kg weight for 5 min to form a uniform layer. After removing excess, an 80 g force was applied, and the time taken for the upper slide to move 7.5 cm was recorded shorter times indicating better spreadability. Spreadability was calculated by using the formula [23].

$S = M.L/T$ ------ (1)

Where, S = spreadability

M = Weight tied to upper slide,

L = Length of glass slides

T = Time taken to separate the slides completely from each other.

Extrudability

Extrudability was assessed by measuring the weight required to extrude at least a 0.5 cm ribbon of emulgel from a lacquered aluminum tube within 10 s. Higher extrusion indicates better extrudability. Each formulation was tested in triplicate, and average values were calculated [23].

Extrudability = Applied weight to extrude emulgel from tube (gm)/Area (cm^2) ---- (2)

Swelling Index

One gram of emulgel was spread on porous aluminum foil and immersed in 10 ml of 0.1 N NaOH. Samples were removed at set intervals, dried, and reweighed to calculate the swelling index [24].

Swelling Index (SW) % = [(Wt – Wo) / Wo] × 100 ---- (3)

Where, (SW) % = Equilibrium percent swelling,

Wo = Original weight of emulgel at zero time,

Wt = Weight of swollen Emulgel after time t

Drug content

One gram of gel was dissolved in 20 mL of solvent, volume adjusted with 10% methanol, and absorbance

measured at 239nm using a UV spectrophotometer, with plain bases as blanks [24].

***In-vitro* Release Study**

In-vitro drug release from gels was evaluated using a Franz diffusion cell with a cellophane/dialysis membrane. A 1g emulgel sample placed in the donor compartment, while the receptor compartment was filled with 25 mL of phosphate buffer (pH 7.4). The setup was maintained at 37±0.5°C, with continuous stirring at 100 rpm using magnetic beads and absorbance measured at 239nm using a UV spectrophotometer [25].

Kinetics Study

The *in-vitro* drug release data of the formulation were analyzed using four kinetic models: Zero-order, First-order, Higuchi, and Korsmeyer–Peppas. The release values were fitted into each model, and the correlation coefficients (R^2 values) were determined [24-26].

***In-vivo* Animal Study**

The *in-vivo* anti-inflammatory activity of the test formulation was evaluated in Wistar rats using the carrageenan-induced paw edema model as described by Winter et al. (1962) with slight modifications [27]. Adult Wistar rats (180–220 g, n = 6 per group) were acclimatized under standard laboratory conditions (25±2°C, 12 h light/dark cycle) with free access to food and water. Inflammation was induced by subplantar injection of 0.1 mL of 1% w/v carrageenan suspension in sterile saline into the right hind paw. Animals were divided into three groups: negative control (vehicle only), standard (diclofenac sodium, 10 mg/kg p.o.), and test compound (dose as per formulation; 0.05%). Treatments were administered once daily for four consecutive days, starting immediately after carrageenan injection. Paw thickness was measured using a digital vernier caliper at 0-, 1-, 2-, and 3-days post-induction. Paw edema was calculated as the difference between the right and left paw thickness. The data were expressed as mean±SEM and analyzed by one-way ANOVA followed by Dunnett's test to compare treated groups with the negative control. A significant reduction in paw edema in the standard and test compound groups compared to the negative control indicated anti-inflammatory activity of the formulation [27].

RESULT AND DISCUSSION

UV-Visible Spectrophotometer

Clobetasol Propionate showed a λmax at 239 nm, with linearity between 2-12µg/ml.

Table 2: Calibration Table of of Clobetasol Propionate

Sr. No.	Concentration	Absorbance
1	0	0.000
2	2	0.0765
3	4	0.1558
4	6	0.2327
5	8	0.3004
6	10	0.3749
7	12	0.4523

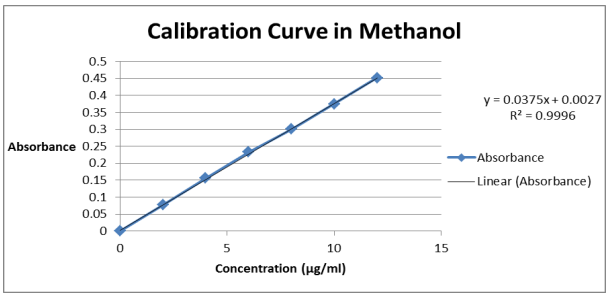


Fig. 1 Calibration Curve of Clobetasol Propionate

The calibration curve (Fig. 1 and Table 2) was generated, and data analyzed by linear regression.

Preparation of Emulgel

Table 3: Formulation Table

Formulation	Carbopol 940 (%)	Eucalyptus oil (%)	Span 60 (%)	Viscosity (cp)	Cumulative Drug Release (%)
F1	0.5	0.5	1.0	1462	48.3
F2	0.5	1.25	2.25	1658	61.7
F3	0.5	2.0	3.5	1836	73.5
F4	0.75	0.5	1.0	2947	45.1
F5	0.75	1.25	2.25	3124	67.8
F6	0.75	2.0	3.5	3341	78.3
F7	1.0	0.5	1.0	4495	40.6
F8	1.0	1.25	2.25	4723	59.4
F9	1.0	2.0	3.5	4982	71.9

Batch F6 was identified as selected, offering balanced viscosity (3341 cp) and the highest drug release (77.2%) as shown in Table 3.

The results demonstrate that formulation variables significantly influenced both viscosity and cumulative drug release. A progressive increase in viscosity was observed with increasing Carbopol 940 concentration (0.5–1.0%), which is consistent with the known swelling and crosslinking behavior of Carbopol that enhances gel network density and resistance to flow.

Correspondingly, higher polymer concentrations resulted in reduced drug release, likely due to increased matrix rigidity and longer diffusional path length, as explained by diffusion-controlled release mechanisms described in the Higuchi model. Conversely, increasing the concentrations of eucalyptus oil and Span 60 within each polymer level markedly enhanced cumulative drug release. This effect can be attributed to the permeation-enhancing property of eucalyptus oil, particularly due to its cineole content that disrupts lipid barriers, and the surfactant action of Span 60, which improves drug solubilization and interfacial characteristics, thereby facilitating diffusion. Notably, formulation F6 (0.75% Carbopol with higher oil and surfactant levels) demonstrated the highest drug release with moderate viscosity, indicating an optimal balance between matrix integrity and enhanced diffusion. Overall, the findings align with existing literature on Carbopol-based gel systems and essential oil-mediated permeation enhancement, confirming that drug release is governed by a combined effect of polymer-controlled diffusion and enhancer-assisted permeation.

Evaluation Emulgel

Physical Examination

The selected formulation (F6) exhibited homogeneity with a yellowish-creamy color, a smooth texture, and good washability, showed no phase separation, was odourless, and demonstrated occlusiveness.

Measurement of pH

The selected formulation had a pH of 6.38, which is within the normal skin pH range and suitable for topical application without causing irritation.

Viscosity

The viscosity was recorded at 3341 cps, indicating non-Newtonian behavior and suggesting favorable flow properties, spreadability, and patient acceptability

Spreadability

A spreadability value of 7.9 cm was observed, confirming that the emulgel can be applied smoothly and evenly on the skin.

Extrudability

The extrudability was measured at 23.15 g/cm², indicating that the formulation can be easily dispensed from its container without excessive effort.

Swelling Index

The swelling index was found to be 76.84%, reflecting the formulation's ability to absorb fluid while maintaining its structure.

Drug Content

The drug content was 98.42% clobetasol propionate, confirming uniform distribution of the drug in the base and no interaction with excipients.

Table 4: Various parameters of selected formulation

Sr. No.	Parameters	Value
1.	Drug Content	98.42%
2.	pH	6.38
3.	Viscosity	3341cps
4.	Spreadability	7.92 cm
5.	Extrudability	23.15g/cm^2
6.	Swelling Index	76.84%

The results of all parameters are shown in Table 4.

***In-vitro* Release Study**

Table 5: *In-vitro* Release Study

Time (Hours)	Pure Drug	F6-Formulation
0	0	0
1	23.14	5.3
2	45.94	17.91
3	57.49	35.83
4	84.67	54.94
5	100.8	65.98
12	---	73.20
24	---	78.30

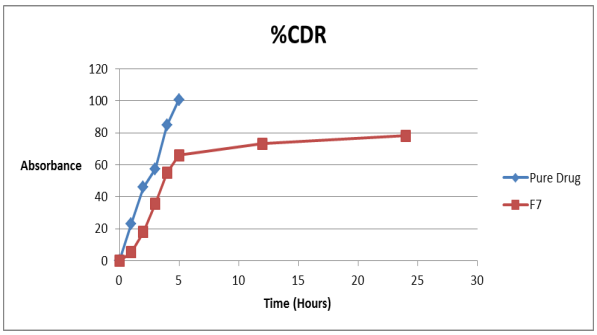


Fig.2: *In-vitro* Release Study of F6 formulation

The *in-vitro* release profile (Fig. 2 and Table 5) showed that after 24 h, the emulgel released 78.30% of clobetasol propionate. The enhanced permeability of the emulgel enabled greater and sustained drug release.

The in-vitro release study shows a clear difference between the pure drug and F6 formulation. The pure drug exhibited rapid release, reaching nearly complete release within 5 hours, indicating immediate availability. In contrast, F6 demonstrated a sustained and controlled release pattern, with gradual drug release up to 78.30% at 24 hours. The slower release from F6 is attributed to the Carbopol 940 gel matrix,

which increases viscosity and restricts drug diffusion, resulting in matrix-controlled release. The presence of eucalyptus oil and Span 60 further supports controlled diffusion by improving drug solubilization. Overall, F6 successfully converts the immediate release profile of the pure drug into a prolonged release system.

Kinetics Study

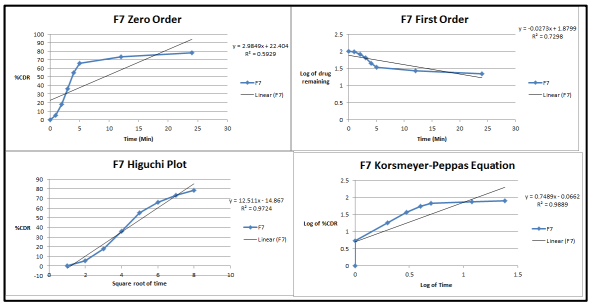


Fig.3: Release Kinetics Study

Drug release data (Fig. 3) fitted best to the korsmeyer-peppas model, showing strong linearity (R^2=0.9889) and a better correlation than the zero-order model, indicating the release followed korsmeyer-peppas kinetics. The kinetic analysis of formulation F7 indicates that drug release primarily follows the Higuchi model, as shown by a high correlation coefficient (R^2 = 0.9724), suggesting diffusion-controlled release from the polymer matrix. The zero-order (R^2 = 0.5929) and first-order (R^2 = 0.7298) models showed lower linearity, indicating they are less suitable. The Korsmeyer–Peppas model showed the highest correlation (R^2 = 0.9889), with an exponent (n ≈ 0.75) indicating anomalous (non-Fickian) transport, meaning drug release occurs through a combination of diffusion and polymer swelling.

***In-vivo* Animal Study**

Table 6: *In-Vivo* Activity Showing Mean Increase in Paw Volume

Treatment	Means increase in paw volume			
	0th day	1st day	2nd day	3rd day
Negative Control	0.81±0.07	1.45±0.06	1.58±0.14	2.12±0.18
Standard	0.77±0.02**	1.05±0.04***	1.10±0.07	0.87±0.06***
Test Compound	0.80±0.04	0.95±0.05*	0.97±0.09**	0.99±0.07**

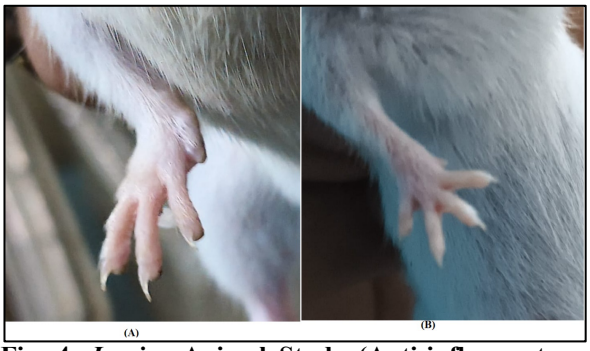


Fig. 4: *In-vivo* Animal Study (Anti-inflammatory Action)

With a sample size of N = 6 per group, the data were analyzed using one-way ANOVA followed by Dunnett's test and expressed as Mean ± SEM. Carrageenan administration produced a significant and progressive increase in paw edema in the negative control group, reaching 2.12 mL by day 3, confirming successful induction of acute inflammation. In contrast, both the standard drug and the test compound significantly ($p < 0.05$) reduced paw swelling over the 4-day treatment period. The standard treatment exhibited the most pronounced anti-inflammatory effect, decreasing paw volume from 1.05 mL on day 1 to 0.87 mL on day 3, nearly restoring normal paw size. The test compound also showed considerable edema inhibition, reducing paw volume to 0.99 mL by day 3, demonstrating significant protection compared to the untreated control group. These findings indicate that the test compound possesses substantial anti-inflammatory activity, though slightly less potent than the standard, as illustrated in Table 6 and Fig. 4.

CONCLUSION

The selected clobetasol propionate emulgel formulation (F6) demonstrated desirable physicochemical characteristics, including appropriate pH (6.38), high drug content (98.42%), suitable viscosity (3341 cps), good spreadability, extrudability, and swelling capacity. *In-vitro* studies confirmed a sustained and enhanced drug release of 78.30% over 24 h, with release kinetics best fitting the Korsmeyer–Peppas model, indicating a diffusion-controlled mechanism. In vivo evaluation showed significant anti-inflammatory activity, with the test formulation effectively reducing carrageenan-induced paw edema, approaching the efficacy of the standard drug. Overall, the emulgel system provided improved permeability, prolonged drug release, and notable therapeutic potential for topical delivery of clobetasol propionate.

Conflict of interest: None

Authors Contribution:

Ramkumar Chaudhary performed the experiments and generated the data. Drafted the manuscript. Saravanan Kaliyaperumal supervised and monitored the project

REFERENCES

1. Bhowmik D, Gopinath H, Kumar BP, Duraivel S, Kumar KP. Recent advances in novel topical drug delivery system. *Pharma Innov. J.*, 1, 12–31 (2012).
2. Fireman S, Toledano O, Neimann K, Loboda N, Dayan N. A look at emerging delivery systems for topical drug products. *Dermatol. Ther.*, 24(5), 477–488 (2011). https://doi.org/10.1111/j.1529-8019.2012.01464.x
3. Sharadha M, Gowda DV, Gupta NV, Akhila AR. An overview on topical drug delivery system – updated review. *Int. J. Res. Pharm. Sci.*, 11(1), 368–385 (2020). Available at: https://ijrps.com/home/article/view/496
4. Pavan. Topical drug delivery systems market set for rapid growth and trend by 2025. (2020).
5. Friedman D, Schwarz J, Weisspapir M. Submicron emulsion vehicle for enhanced transdermal delivery of steroidal and nonsteroidal anti-inflammatory drugs. *J. Pharm. Sci.*, 84(3), 324–329 (1995).
6. Shakeel F, Ramadan WM, Faisal MS, Rizwan M, Faiyazuddin M, Mustafa G, Shafiq S. Transdermal and topical delivery of anti-inflammatory agents using nanoemulsion/microemulsion: an updated review. *Curr. Nanosci.*, 6, 184–198 (2010).
7. Drosopoulou K, Kosheleva RI, Ofrydopoulou A, Tsoupras A, Mitropoulos AC. Topical and transdermal delivery of nonsteroidal anti-inflammatory drugs (NSAIDs) for inflammation and pain: current trends and future directions in delivery systems. *Processes*, (2025).
8. Pidda D, Kumar V, Verma TK, Vishwakarma PK, Singh D. Development of hydrogel delivery systems for anti-inflammatory action. *Int. J. Adv. Multidiscip. Res. Stud.*, (2024).
9. Lokeshvar, R., Ramaiyan, V., Nithin, V., Pavani, S., Vinod Kumar, T. (2025). Nanotechnology-driven therapeutics for liver cancer: Clinical applications and pharmaceutical insights. Asian Journal of Pharmaceutical and Clinical Research. 18(2):8-26. https://doi.org/10.22159/ajpcr.2025v18i2.53429
10. Rode RJ, Dixit GR, Upadhye KP, Bakhle SS, Durge RT. A comprehensive review on emulgel: a new approach for enhanced topical drug delivery. (2021).
11. Baibhav J, Gurpreet S, Seema S, Vikas S. Emulgel: a comprehensive review on the recent advances in topical drug delivery. (2011).
12. Pels R, Sterry W, Lademann J. Clobetasol propionate – where, when, why? *Drugs Today*, 44(7), 547–557 (2008).
13. Warino L, Balkrishnan R, Feldman SR. Clobetasol propionate for psoriasis: are ointments really more potent? *J. Drugs Dermatol.*, 5(6), 527–532 (2006).
14. Khlebnikova AN. Clobetasol propionate (Dermovate) gives new opportunities in the treatment of dermatoses. *Vestn. Dermatol. Venerol.*, 86(5), 124–134 (2010).
15. Singh K, Gupta JK, Jain D, Sharma MC, Kumar S, Chaudhary R, Mishra S. Emulgel-based formulations of clobetasol propionate: formulation development, characterization, and pharmacological evaluation. *Pharm. Nanotechnol.*, (2025).
16. Badıllı U, Şen T, Tarımcı N. Microparticulate based topical delivery system of clobetasol propionate. *AAPS PharmSciTech*, 12(3), 949–957 (2011).
17. Shrikhande PV. Formulation and evaluation of polyherbal topical anti-inflammatory emulgel. *Res. J. Pharm. Technol.*, 6, 118–122 (2013).
18. Alam MS, Ali MS, Zakir F, Alam N, Intakhab Alam M, Ahmad F, Siddiqui MR, Ali MD, Ansari MS, Ahmad S, Ali M. Enhancement of anti-dermatitis potential of clobetasol propionate by DHA-rich algal oil nanoemulsion gel. *Iran. J. Pharm. Res.*, 15, 35–52 (2016).
19. van Osdol WW, Novakovic J, Le Merdy M, Tsakalozou E, Ghosh P, Spires J, Lukacova V. Predicting human dermal drug concentrations using PBPK modeling and simulation: clobetasol propionate case study. *AAPS PharmSciTech*, 25(3), 39 (2024).

20. Ibrahim FA, Elmansi H, Fathy ME. Green RP-HPLC method for simultaneous determination of moxifloxacin combinations: investigation of the greenness for the proposed method. *Microchem. J.*, 148, 151–161 (2019).
21. Erum A, Tulain UR, Malik NS, Riaz A, Yaqoob M, Mahmood A, Rashid A, Shahid N, Gohar N, Malik A, Malik MZ, Tayyab M. Formulation and optimization of pectin-based emulgel isolated from *Abelmoschus esculentus* using response surface methodology. *Polym. Bull.*, 81(11), 10039–10059 (2024).
22. Sirisha VL, Mulukuri N, Kumar S, Dhara M, Rajesh GD, Kumar P. Statistical modeling, optimization and characterization of andrographolide loaded emulgel for its therapeutic application on skin cancer through enhancing its skin permeability. *Saudi Pharm. J.*, 32(6), 102068 (2024).
23. Li S, Jiao B, Faisal S, Zhang Y, Wu B, Li W, Shi A, Liu H, Wang Q. 50/50 oil/water emulsion stabilized by pea protein isolate microgel particles/xanthan gum complexes and co-emulsifiers. *Food Hydrocoll.*, 134, 108078 (2023).
24. Paswan BK, Kumar S, Mahto V. Evaluation of a soybean oil derived surfactant in the development of oil-in-water (O/W) emulsion drilling mud for shale formation. *J. Pet. Sci. Eng.*, 217, 110926 (2022).
25. Reddy, K. T. Kumar., Dharmamoorthy, G., Vasavi Devi. D., Vidiyala, N., Bagade, O. M., Elumalai, S., Sagar Dantinapalli, V.L., Kasimedu, S. (2025). Phytoconstituent Based Green Synthesis of Nanoparticles: Sources and Biomedical Applications in Cancer Therapy. Asian Journal of Green Chemistry. 9(3):329-354. Doi: 10.48309/AJGC.2025.501113.1669
26. Mulukuri NVLS, Dhara M, Gupta D, Devi K, Kumar P. Development and optimization of novel emulgel loaded with andrographolide-rich extract and sesame oil using quality by design approach: in silico and in vitro cytotoxic evaluation against A431 cells. *Gels* [Online], (2023).
27. Winter CA, Rishton GM, Nuss GW. Carrageenin-induced edema in hind paw of the rat as an assay for anti-inflammatory drugs. *Proc. Soc. Exp. Biol. Med.*, 111, 544–547 (1962). https://doi.org/10.3181/00379727-111-27849