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# Aceclofenac Nanoemulsions for Transdermal Delivery: Stability and In-vitro Evaluation

Narendra Chary.T*[1], Prakash Katakam[2]

1. Department of Pharmaceutics, Anurag Pharmacy College, Ananthagiri, Kodad, Nalgonda, 508206, AP, India.

2. Nirmala College of Pharmacy, Mangalagiri, Guntur, 522503, AP, India.

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***ABSTRACT***

*Aceclofenac is a highly lipophilic drug, and its physicochemical properties suggest that it has good potential for transdermal drug delivery. Therefore, in the present study different nanoemulsions were prepared for transdermal delivery of aceclofenac. The objective of the present study was to investigate the potential of a nanoemulsion formulation for transdermal delivery of aceclofenac. Various oil-in-water nanoemulsions were prepared by the spontaneous emulsification method. The nanoemulsion area was identified by constructing pseudoternary phase diagrams. The prepared nanoemulsions were subjected to different thermodynamic stability tests. The nanoemulsion formulations that passed thermodynamic stability tests were characterized for viscosity, droplet size, transmission electron microscopy, and refractive index. Transdermal permeation of aceclofenac through rat abdominal skin was determined by Franz diffusion cell. The in vitro skin permeation profile of optimized formulations was compared with that of aceclofenac conventional gel and nanoemulsion gel. A significant increase in permeability parameters such as steady-state flux ($J_{ss}$), permeability coefficient ($K_p$), and enhancement ratio ($E_r$) was observed in optimized nanoemulsion formulation F1, which consisted of 2% wt/wt of aceclofenac, 10% wt/wt of Labrafil®, 5% wt/wt of Triacetin®, 35.33% wt/wt of Tween 80®, 17.66% wt/wt of Transcutol P®, and 32% wt/wt of distilled water. The anti-inflammatory effects of formulation F1 showed a significant increase ($P < .05$) in percent inhibition value after 24 hours when compared with aceclofenac conventional gel and nanoemulsion gel on carrageenan-induced paw edema in rats. These results suggested that nanoemulsions are potential vehicles for improved transdermal delivery of aceclofenac.*

***Keywords:*** *Lipophilic drug, Nanoemulsion, Transdermal, Anti-inflammatory.*

*Correspondence Author: Narendra Chary.T Email: tcnaren@gmail.com Contact No: 9948704181

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## INTRODUCTION

Non-steroidal anti-inflammatory drugs (NSAIDs) are the most commonly used drugs to reduce pain and inflammation.[1] Aceclofenac, an NSAID, has been recommended orally for the treatment of rheumatoid arthritis and osteoarthritis.[2,3] It also has anti-inflammatory, antipyretic, and analgesic activities.[4] The oral administration of aceclofenac causes gastrointestinal ulcers and gastrointestinal bleeding with chronic use.[2] Because of gastrointestinal bleeding, it also causes anemia. Using the transdermal

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route eliminates these side effects, increases patient compliance, avoids first-pass metabolism, and maintains the plasma drug level for a longer period of time. Therefore, an improved aceclofenac nanoemulsion formulation with a high degree of permeation could be useful in the treatment of locally inflamed skin and inflammatory and painful states of supporting structures of the body, such as bones, ligaments, joints, tendons, and muscles. There has been increased interest during recent years in the use of topical vehicle systems that could modify drug permeation through the skin. Many of the dermal vehicles contain chemical enhancers and solvents to achieve these goals.[5] But use of these chemical enhancers may be harmful, especially in chronic application, as many of them are irritants. Therefore, it is desirable to develop a topical vehicle system that does not require the use of chemical enhancers to facilitate drug permeation through the skin. One of the most promising techniques for enhancement of transdermal permeation of drugs is microemulsion or nanoemulsion. Nanoemulsions are thermodynamically stable transparent (translucent) dispersions of oil and water stabilized by an interfacial film of surfactant and cosurfactant molecules having a droplet size of less than 100 nm.[6,7] Many studies have shown that nanoemulsion formulations possess improved transdermal and dermal delivery properties in vitro,[8-16] as well as in vivo.[17-19]

Nanoemulsions have improved transdermal permeation of many drugs over the conventional topical formulations such as emulsions[20,21] and gels.[22,23] This article describes the potential of nanoemulsion systems in transdermal delivery of aceclofenac using nonirritating, pharmaceutically acceptable ingredients without using additional permeation enhancers, because excipients of nanoemulsions themselves act as permeation enhancers.

## MATERIALS & METHOD

Aceclofenac was a gift sample from Karnatka Antibiotics and Pharmaceuticals Limited. Caprylic/capric triglyceride polyethylene glycol-4 complex (Labrafac®), caprylocaproyl macrogol-8-glyceride (Labrasol®), polyglyceryl-6-dioleate (Plurol Oleique®), and oleoyl macroglycerides EP (Labrafil) were gift samples from Gattefossé (Cedex, France). Isopropyl myristate (IPM), oleic acid, glycerol triacetate (Triacetin), olive oil, diethylene glycol monoethyl ether (Transcutol P), and ethanol were purchased from E-Merck (Mumbai, India). Tween 80 and polyoxy-35-castor oil (Cremophor EL®) were purchased from Sigma Aldrich (St. Louis, MO). All other chemicals used in the study were of analytical reagent grade.

### Screening of Excipients

The solubility of aceclofenac in various oils (Triacetin, Labrafac, oleic acid, Labrafil, IPM, and olive oil), surfactants (Labrasol, Tween 80, and Cremophor EL), and cosurfactants (Transcutol P and Plurol Oleique) was determined by dissolving an excess amount of aceclofenac in 2 mL of each of the selected oils, surfactants, and cosurfactants in 5-mL-capacity stoppered vials separately. A combination of oils was also used for determination of solubility. An excess amount of aceclofenac was added to each 5-mL-capacity stoppered vial and mixed using a vortex mixer (Nickel-Electro Ltd, Oldmixon Crescent, UK). The mixture vials were then kept at 37°C ± 1.0°C in an isothermal shaker (Nirmal International, New Delhi, India) for 72 hours to get to equilibrium. The equilibrated samples were removed from the shaker and centrifuged at 3000 rpm for 15 minutes. The

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supernatant was taken and filtered through a 0.45-µm membrane filter. The concentration of aceclofenac was determined in each oil, surfactant, cosurfactant, and combination of oils by UV spectrophotometer at their respective $\lambda_{max}$.

**Pseudoternary Phase Diagram Study**

On the basis of the solubility studies, the combination of Labrafil and Triacetin (2:1) was selected as the oil phase. Tween 80 and Transcutol P were selected as surfactant and cosurfactant, respectively. Distilled water was used as an aqueous phase. Surfactant and cosurfactant ($S_{mix}$) were mixed in different weight ratios (1:0, 1:2, 1:3, 1:1, 2:1, 3:1, and 4:1). These $S_{mix}$ ratios were chosen in increasing concentration of surfactant with respect to cosurfactant and increasing concentration of cosurfactant with respect to surfactant for detailed study of the phase diagrams needed for nanoemulsion formation.

For each phase diagram, oil and $S_{mix}$ were combined in different weight ratios from 1:9 to 9:1 in different glass vials. Sixteen different combinations of oil and $S_{mix}$ (1:9, 1:8, 1:7, 1:6, 1:5, 1:4, 1:3.5, 1:3, 1:2.3, 1:2, 1:1.5, 1:1, 1:0.7, 1:0.43, 1:0.25, and 1:0.1) were made so that maximum ratios were covered for the study to delineate the boundaries of phases precisely formed in the phase diagrams. Pseudoternary phase diagrams of oil, $S_{mix}$, and aqueous phase were developed using the aqueous titration method. Slow titration with the aqueous phase was done to each weight ratio of oil and $S_{mix}$, and visual observations were made for transparent and easily flowable oil-in-water (o/w) nanoemulsions.

The physical state of the nanoemulsion was marked on a pseudo-3-component phase diagram with 1 axis representing the aqueous phase, 1 representing oil, and the third representing a mixture of surfactant and cosurfactant at fixed weight ratios ($S_{mix}$ ratios).

**Selection of Nanoemulsion Formulations**

From each phase diagram constructed, different formulas were selected from the nanoemulsion region so that the drug could be incorporated into the oil phase.

Exactly 2% wt/wt of aceclofenac, which was kept constant in all the selected formulations, was dissolved in the oil phase of the nanoemulsion formulation. Selected formulations were subjected to different thermodynamic stability tests.

**Preparation of Conventional Aceclofenac Gel**

Conventional aceclofenac gel (CG) was prepared by dispersing the 1 g of the Carbopol 940® in a sufficient quantity of distilled water.[24] After complete dispersion, the Carbopol 940 solution was kept in the dark for 24 hours for complete swelling. Then 2 g of aceclofenac was dissolved in a specified quantity of polyethylene glycol 400. This solution of drug was added slowly to the aqueous dispersion of Carbopol 940. Then other ingredients like isopropyl alcohol, propylene glycol, and triethanolamine were added to obtain a homogeneous dispersion of gel (Table 1).

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**Table 1**. Formula for Preparation of Aceclofenac Gel*

| Aceclofenac Gel | Ingredients (for 100 g of gel) |
|---|---|
| Aceclofenac (% wt/wt) | 2 |
| Carbopol 940 (% wt/wt) | 1 |
| IPA (% wt/wt) | 10 |
| PEG-400 (% wt/wt) | 10 |
| PG (% wt/wt) | 10 |
| TEA (g) | 0.5 |
| Distilled water (qs) | 100 |

*IPA indicates isopropyl alcohol; PEG, polyethylene glycol; PG, propylene glycol;

TEA, triethanolamine; qs, quantity sufficient.

**Thermodynamic Stability Studies**

To overcome the problem of metastable formulation, thermodynamic stability tests were performed.[25] Selected formulations were centrifuged at 822 g for 30 minutes. The formulations that did not show any phase separations were taken for the heating and cooling cycle. Six cycles between refrigerator temperature (4°C) and 45°C with storage at each temperature of not less than 48 hours were done. The formulations, which were stable at these temperatures, were subjected to a freeze-thaw cycle test. Three freeze-thaw cycles were done for the formulation between –21°C and 25°C. The formulations that survived thermodynamic stability tests were selected for further study.

**Characterization of Nanoemulsions**

**Transmission Electron Microscopy**

Morphology and structure of the nanoemulsion were studied using transmission electron microscopy (TEM), with Topcon 002B operating at 200 kV (Topcon, Paramus, NJ) and capable of point-to-point resolution.

To perform the TEM observations, a drop of the nanoemulsion was directly deposited on the holey film grid and observed after drying.

**Nanoemulsion Droplet Size Analysis**

Droplet size distribution of the nanoemulsion was determined by photon correlation spectroscopy that analyzes the fluctuations in light scattering due to

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Brownian motion of the particles,[26] using a Zetasizer 1000 HS (Malvern Instruments, Worchestershire, UK). Light scattering was monitored at 25°C at a 90° angle.

**Viscosity Determination**

The viscosity of the formulations (0.5 g) was determined using a Brookfield DV III ultra V6.0 RV cone and plate rheometer (Brookfield Engineering Laboratories, Middleboro, MA) using spindle # CPE40 at 25°C ± 0.3°C. The software used for the calculations was Rheocalc V2.6.

**Refractive Index**

The refractive index of placebo formulations and drug-loaded formulations was determined using an Abbe-type refractometer (Nirmal International).

**In Vitro Skin Permeation Studies**

In vitro skin permeation studies were performed on a Franz diffusion cell with an effective diffusional area of 0.636 $cm^2$ and 4 mL of receiver chamber capacity using rat abdominal skin. The automated transdermal diffusion cell sampling system (SFDC6, Logan Inst, Avalon, NJ) was used for these studies. The full-thickness rat skin was excised from the abdominal region, and hair was removed with an electric clipper. The subcutaneous tissue was removed surgically, and the dermis side was wiped with isopropyl alcohol to remove adhering fat. The cleaned skin was washed with distilled water and stored in the deep freezer at –21°C until further use. The skin was brought to room temperature and mounted between the donor and receiver compartment of the Franz diffusion cell, where the stratum corneum side faced the donor compartment and the dermal side faced the receiver compartment.

Initially the donor compartment was empty and the receiver chamber was filled with ethanolic phosphate-buffered saline (PBS) pH 7.4 (20:80% vol/vol). The receiver fluid was stirred with a magnetic rotor at a speed of 600 rpm, and the assembled apparatus was placed in the Logan transdermal permeation apparatus and the temperature maintained at 32°C ± 1°C. All the ethanolic PBS was replaced every 30 minutes to stabilize the skin. It was found that the receiver fluid showed negligible absorbance after 4.5 hours and beyond, indicating complete stabilization of the skin. After complete stabilization of the skin, 1 mL of nanoemulsion formulation (20 mg/mL aceclofenac) or 1 g of CG (20 mg/g) was placed into each donor compartment and sealed with paraffin film to provide occlusive conditions. Samples were withdrawn at regular intervals (0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 20, 22, and 24 hours), filtered through a 0.45-membrane filter, and analyzed for drug content by UV spectrophotometer at $\lambda_{max}$ of 274 nm.

The formulation F1 provided the highest release as compared with the other nanoemulsion formulations. The formulation F1 was also converted into nanoemulsion gel formulations by adding 1% wt/wt Carbopol 940 and was coded as NG1. The skin permeation profile of the optimized nanoemulsion formulation was compared with nanoemulsion gel (NG1) and CG using the Dunnett test of 1-way analysis of variance (ANOVA).

**Permeation Data Analysis**

The cumulative amount of drug permeated through the skin ($mg/cm^2$) was plotted as a function of time (t) for each formulation. Drug flux (permeation rate) at steady state ($J_{ss}$) was calculated by dividing the slope of the linear portion of the graph by the area of the diffusion cell. The permeability coefficient ($K_p$) was

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calculated by dividing $J_{ss}$ by the initial concentration of drug in the donor cell ($C_0$):

$$K_p = J_{ss} / C_0 \quad (1)$$

Enhancement ratio ($E_r$) was calculated by dividing the $J_{ss}$ of the respective formulation by the $J_{ss}$ of the control formulation:

$$E_r = J_{ss} \text{ of formulation} / J_{ss} \text{ of control} \quad (2)$$

**Skin Irritation Test**

The skin irritation test was carried out on male Swiss albino mice weighing 20 to 25 g. The animals were kept under standard laboratory conditions, with temperature of 25°C ± 1°C and relative humidity of 55% ± 5%.

The animals were housed in polypropylene cages, 6 per cage, with free access to a standard laboratory diet (Lipton feed, Mumbai, India) and water ad libitum. A single dose of 10 µL of the nanoemulsion was applied to the left ear of the mouse, with the right ear as a control. The development of erythema was monitored for 6 days using the method of Van-Abbe et al.[27]

**In Vivo Efficacy Study**

The anti-inflammatory and sustaining action of the optimized formulation F1 was evaluated by the carrageenan-induced hind paw edema method developed by Winter et al in Wistar rats.[28] Young Wistar rats weighing 120 to 150 g were randomly divided into 4 groups: control, nanoemulsion (F1), nanoemulsion gel (NG1), and CG, each containing 6 rats.

The animals were kept under standard laboratory conditions, with temperature of 25°C ± 1°C and relative humidity of 55% ± 5%. The animals were housed in polypropylene cages, 6 per cage, with free access to a standard laboratory diet (Lipton feed) and water ad libitum. The dose for the rats was calculated based on the weight of the rats according to the surface area ratio.[29] The abdominal region of the rats was shaved 12 hours before the experiments started, except in the control group. F1, NG1, and CG were applied on the shaved abdominal region of all animals (except in control group) half an hour before subplanter injection of carrageenan in right paws. Paw edema was induced by injecting 0.1 mL of the 1% wt/wt homogeneous suspension of carrageenan in distilled water. The volume of paw was measured at 1, 2, 3, 6, 12, and 24 hours after injection using a digital plethysmometer. The amount of paw swelling was determined for 24 hours and expressed as percent edema relative to the initial hind paw volume. Percent inhibition of edema produced by each formulation-treated group was calculated against the respective control group. Results of anti-inflammatory activity were compared using the Dunnett test of 1-way ANOVA.

**RESULTS AND DISCUSSION**

**Excipient Selection**

The excipients selected needed to be pharmaceutically acceptable, nonirritating, and nonsensitizing to the skin and to fall into the GRAS (generally regarded as safe) category. Higher solubility of the drug in the oil phase was another important criterion, as it would help the nanoemulsion to maintain the drug in solubilized form.

Safety is a major determining factor in choosing a surfactant, as a large amount of surfactants may cause skin irritation. Non-ionic surfactants are less toxic than ionic surfactants. An important criterion for

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selection of the surfactants is that the required hydrophilic lipophilic balance (HLB) value to form the o/w nanoemulsion be greater than 10. The right blend of low and high HLB surfactants leads to the formation of a stable nanoemulsion formulation.[30] In this study, we selected Tween 80 as a surfactant with an HLB value of 15. Transient negative interfacial tension and fluid interfacial film are rarely achieved by the use of single surfactant; usually, addition of a cosurfactant is necessary. The presence of cosurfactant decreases the bending stress of interface and allows the interfacial film sufficient flexibility to take up different curvatures required to form nanoemulsions over a wide range of composition.[31,32] Thus, the cosurfactant selected for the study was Transcutol P, which has an HLB value of 4.2.Aceclofenac is a highly lipophilic drug, and its physicochemical properties suggest that it has good potential for transdermal drug delivery.[4] Therefore, in the present study different nanoemulsions were prepared for transdermal delivery of aceclofenac.

**Screening of Excipients**

The most important criterion for screening of excipients is the solubility of the poorly soluble drug in oil, surfactants, and cosurfactants. Since the aim of this study is to develop a transdermal formulation, it is important to determine the solubility of the drug in oils, surfactants, and cosurfactants. The solubility of aceclofenac was found to be highest in a 2:1 combination of Labrafil and Triacetin (48.95 ± 2.22 mg/mL) as compared with other oils and combinations of oils. Thus, this combination was selected as the oil phase for the development of the optimal formulation. The highest solubility of the drug was seen in Tween 80 (398.21 ± 2.89 mg/mL) and Transcutol P (292.42 ± 2.80 mg/mL). Therefore, Tween-80 and Transcutol P were selected as surfactant and cosurfactant, respectively, for the phase study (Table 2).

**Table 2**. Solubility of Aceclofenac in Various Excipients (n = 3)*

| Excipients | Solubility Mean ± SD (mg/mL)[a] | Excipients | Solubility Mean ± SD (mg/mL)[a] |
|---|---|---|---|
| Triacetin | 8.22 ± 1.12 | Labrafil + Triacetin (2:1) | 48.95 ± 2.22 |
| Labrafac | 6.31 ± 0.52 | Labrafil + Triacetin (3:1) | 39.44 ± 1.98 |
| Oleic acid | 4.01 ± 0.92 | Labrasol | 386.45 ± 3.28 |
| Labrafil | 32.56 ± 2.43 | Tween80 | 398.21 ± 2.89 |
| IPM | 2.97 ± 1.01 | Cremophor EL | 272.32 ± 2.94 |
| Olive oil | 1.69 ± 0.35 | Transcutol P | 292.42 ± 2.80 |
| Labrafil + Triacetin (1:1) | 35.24 ± 2.14 | Plurol Oleique | 110.52 ± 2.19 |

*IPM indicates isopropyl myristate.

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**Pseudoternary Phase Diagram Study**

Constructing phase diagrams is time-consuming, particularly when the aim is to accurately delineate a phase boundary.[31] Care was taken to ensure that observations were not made on metastable systems—although the free energy required to form an emulsion is very low, the formation is thermodynamically spontaneous.[30] The relationship between the phase behavior of a mixture and its composition can be captured with the aid of a phase diagram.[33] Pseudoternary phase diagrams were constructed separately for each $S_{mix}$ ratio (Figure 1), so that o/w nanoemulsion regions could be identified and nanoemulsion formulations could be optimized.

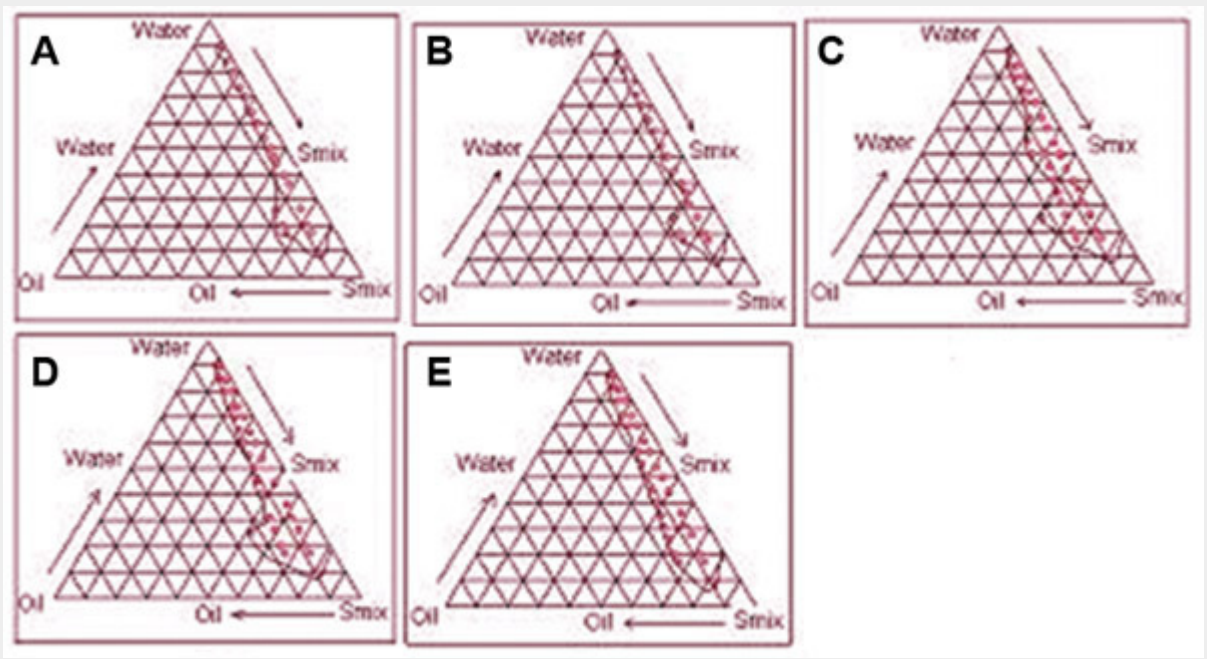


**Figure 1**. Pseudoternary phase diagrams indicating oil-in-water nanoemulsion (shaded area) region of Labrafil and Triacetin (oil), Tween 80 (surfactant), and Transcutol P (cosurfactant) at different $S_{mix}$ ratios indicated in parts A ($S_{mix}$ 1:0), B ($S_{mix}$ 1:1), C ($S_{mix}$ 2:1), D ($S_{mix}$ 3:1), and E ($S_{mix}$ 4:1).

In Figure 1, the $S_{mix}$ ratio 1:0 (Figure 1A) has a low nanoemulsion area. An o/w nanoemulsion region was found toward the water-rich apex of the phase diagram. The maximum concentration of oil that could be solubilized in the phase diagram was only 16% wt/wt using 67% wt/wt of $S_{mix}$. As the surfactant concentration was increased in the $S_{mix}$ ratio 1:1 (Figure 1B), a higher nanoemulsion region was observed, perhaps because of further reduction of the interfacial tension, increasing the fluidity of the interface, thereby increasing the entropy of the system. There may be greater penetration of the oil phase in the hydrophobic region of the surfactant monomers.[31,32]

The maximum concentration of oil that could be solubilized in the phase diagram was only 16% wt/wt using 67% wt/wt of $S_{mix}$. As we further increased surfactant concentration, $S_{mix}$ 2:1 (Figure 1C), the nanoemulsion region increased as compared with the

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region in 1:0 and 1:1. The maximum concentration of oil that could be solubilized by this ratio was 22% wt/wt using 52% wt/wt of $S_{mix}$. When the $S_{mix}$ ratio of 3:1 was studied (Figure 1D), the nanoemulsion region decreased slightly as compared with 1:1, which may have been due to the increased concentration of the surfactant, although the maximum oil that could be solubilized by this ratio of $S_{mix}$ was 22% wt/wt with 52% wt/wt of $S_{mix}$. Similarly, when the $S_{mix}$ ratio of 4:1 was studied (Figure 1E), the nanoemulsion area further decreased as compared with 3:1 and 2:1 but increased as compared with 1:0 and 1:1.

The maximum concentration of oil that could be solubilized by this ratio of $S_{mix}$ was 17% wt/wt with 67% wt/wt of $S_{mix}$. When surfactant concentration increased as compared with cosurfactant, the nanoemulsion area increased up to the 2:1 ratio, but in the 4:1 ratio the nanoemulsion region decreased again, so there was no need to try an $S_{mix}$ ratio of 5:1. No nanoemulsion regions were found in $S_{mix}$ ratios of 1:2 and 1:3.Thus, in the phase diagrams, it can be seen that the free energy of nanoemulsion formation can be considered to depend on the extent to which the surfactant lowers the surface tension of the oil-water interface and the change in dispersion entropy.[33] Thus, a negative free energy of formation is achieved when a large reduction in surface tension is accompanied by significant favorable entropic changes. In such cases, nanoemulsion formation is spontaneous and the resulting dispersions are thermodynamically stable.[30,33]

The surfactant or $S_{mix}$, which are able to increase the dispersion entropy, reduce the interfacial tension, increase the interfacial area, and thus lower the free energy of the system to a very low value with the minimum concentration (weight ratio), which is thermodynamically stable, and have the potential for the transdermal drug delivery.

**Selection of Nanoemulsion Formulations**

It is well known that large amounts of surfactants cause skin irritation[33-35]; therefore, it is important to determine the surfactant concentration properly and use the optimum concentration of surfactant in the formulation. From pseudoternary phase diagrams, the formulations in which the amount of oil phase completely solubilized the drug and which could accommodate the optimum quantity of $S_{mix}$ and distilled water were selected for the study.

**Thermodynamic Stability Studies**

Nanoemulsions are thermodynamically stable systems and are formed at a particular concentration of oil, surfactant, and water, making them stable and not subject to phase separation, creaming, or cracking. It is the thermostability that differentiates nano- or microemulsions from emulsions that have kinetic stability and eventually phase-separate.[33,36] Thus, the formulations were tested for their thermodynamic stability by using centrifugation, a heating-cooling cycle, and a freeze-thaw cycle.

Only formulations that survived the thermodynamic stability tests were selected for further study. The compositions of selected formulations are given in Table 3.

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**Table 3**. Composition of Selected Nanoemulsion Formulations

| | % Wt/Wt of Components in Nanoemulsion Formulation | | | | |
|---|---|---|---|---|---|
| **$S_{mix}$ Ratio** | **Oil** | **$S_{mix}$** | **Water** | **Oil:$S_{mix}$ Ratio** | **Code** |
| 2:1 | 15 | 53 | 32 | 1:3.53 | F1 |
| 2:1 | 20 | 53 | 27 | 1:2.65 | F2 |
| 3:1 | 15 | 50 | 35 | 1:3.33 | F3 |
| 3:1 | 20 | 51 | 29 | 1:2.55 | F4 |
| 4:1 | 15 | 50 | 35 | 1:3.33 | F5 |
| 4:1 | 20 | 51 | 29 | 1:2.55 | F6 |

**Table 4**. Droplet Size, Polydispersity Values, and Viscosity of the Nanoemulsion Formulations (n = 3)

| Formulation Code | Droplet Size Mean ± SD (nm) | Polydispersity | Viscosity Mean ± SD (cP) |
|---|---|---|---|
| F1 | 35.20 ± 1.24 | 0.035 | 92.20 ± 1.41 |
| F2 | 46.50 ± 2.96 | 0.063 | 103.40 ± 1.87 |
| F3 | 41.70 ± 3.15 | 0.075 | 107.60 ± 2.35 |
| F4 | 59.30 ± 4.23 | 0.071 | 115.40 ± 2.45 |
| F5 | 54.60 ± 4.09 | 0.074 | 117.20 ± 2.56 |
| F6 | 68.30 ± 5.26 | 0.077 | 125.30 ± 2.75 |

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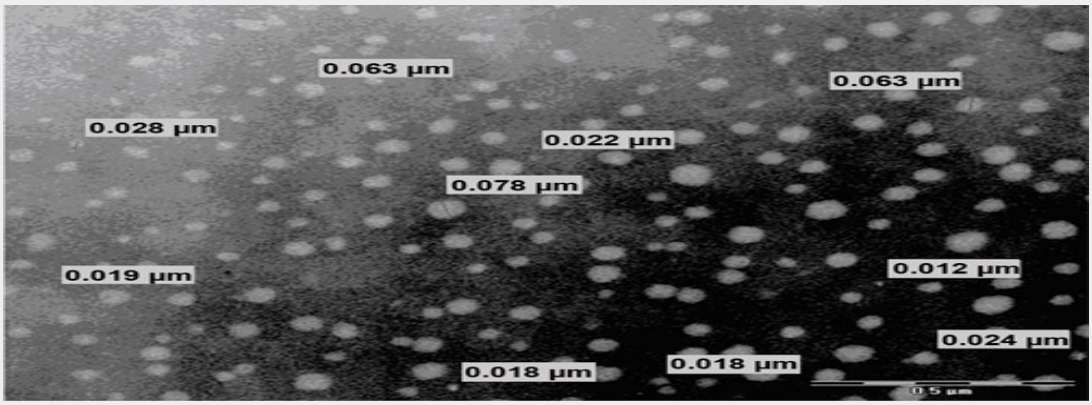


**Figure 2**. Transmission electron microscopic positive image of aceclofenac nanoemulsion showing the size of some oil droplets.

**Characterization of Nanoemulsions**

**TEM**

In the TEM positive image, the nanoemulsion appeared dark and the surroundings were bright (Figure 2). Some droplet sizes were measured, as TEM is capable of point-to-point resolution. These sizes were in agreement with the droplet size distribution measured using photon correlation spectroscopy (Table 4).

**Nanoemulsion Droplet Size Analysis**

The droplet size increased with the increase in concentration of oil in the formulations (Table 4). The droplet size of formulation F1, containing 15% oil, was lowest (35.20 ± 1.24 nm). The droplet size of formulation F6 was highest (68.3 ± 5.26 nm). All the formulations had droplets in the nano range, which is very well evident from the low polydispersity values. Polydispersity is the ratio of standard deviation to mean droplet size, so it indicates the uniformity of droplet size within the formulation. The higher the polydispersity, the lower the uniformity of the droplet size in the formulation. Although the polydispersity values of all formulations were very low, indicating uniformity of droplet size within each formulation, the polydispersity of formulation F1 was lowest (0.035).

**Viscosity Determination**

The viscosity of the selected formulations was determined (Table 4). The viscosity of formulation F1 (92.2 ± 1.41 cP) was lower than that of any other formulation, and this difference was significant ($P <$ .05). The viscosity of formulation F6 was highest (125.3 ± 2.75 cP), but it was observed that the viscosity of the nanoemulsion formulations generally was very low. This was expected, because one of the characteristics of nanoemulsion formulations is lower viscosity.[33]

**Refractive Index**

The mean values of the refractive index of drug-loaded formulations and placebo formulations are given in Table 5. When the refractive index values for formulations were compared with those of the placebo, it was found that there were no significant differences between the values. Therefore, it can be

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concluded that the nanoemulsion formulations were not only thermodynamically stable but also chemically stable and remained isotropic; thus, there were no interactions between nanoemulsion excipients and drug.

**In Vitro Skin Permeation Studies**

In vitro skin permeation studies were performed to compare the release of drug from 6 different nanoemulsion formulations (F1-F6), NG1, and CG, all having the same quantity (2% wt/wt) of aceclofenac. In vitro skin permeation was highest in formulation F1 and lowest for CG (Figures 3 and 4). The formulation NG1 showed an intermediate skin permeation profile. The skin permeation profile of F1 was significantly different when compared with that of CG and NG1 ($P < .05$). The significant difference in aceclofenac permeation between nanoemulsion formulations, NG1, and CG was probably due to the mean size of internal phase droplets, which were significantly smaller in nanoemulsions. The maximum release in F1 could be due to having the lowest droplet size and lowestviscosity of all the nanoemulsions.

**Permeation Data Analysis**

Permeability parameters like steady-state flux ($J_{ss}$), permeability coefficient ($K_p$), and enhancement ratio ($E_r$) were significantly increased in nanoemulsions and the NG1 formulation as compared with CG ($P < .05$). This is because nanoemulsions and NG1 excipients contain permeation enhancers like Labrafil, Triacetin, Tween 80, and Transcutol P. The permeability parameters of different formulations are given in Table 6.

**Skin Irritation Test**

The skin irritation test was performed to confirm the safety of the optimized nanoemulsion formulation. Van-Abbe et al[27] mentioned that a value between 0 and 9 indicates that the applied formulation is generally not an irritant to human skin. The mean skin irritation score for formulation F1 was 2.12 ± 0.45. From this it was concluded that the optimized nanoemulsion formulation was safe to be used for transdermal drug delivery.

**In Vivo Efficacy Study**

Based on higher drug permeation, lowest droplet size, lowest viscosity, and lowest polydispersity index, formulation F1 was selected for the study of in vivo anti-inflammatory effects. The anti-inflammatory and sustaining action of the optimized formulation was evaluated by the carrageenan-induced hind paw edema method developed by Winter et al[28] in female Wistar rats. The percent inhibition value after 24 hours of administration was found to be high for F1—that is, 82.2% as compared with 41.8% for CG; this difference was extremely significant ($P < .01$). The percent inhibition value for formulation NG1 was 71.4% (Figure 5), and the difference between F1's and NG1's percent inhibition was significant ($P < .05$). The enhanced anti-inflammatory effects of formulation F1 could be due to the enhanced permeation of aceclofenac through the skin.

**CONCLUSION**

On the basis of highest drug permeation, lowest droplet size, lowest polydispersity, lowest viscosity, and optimum surfactant and cosurfactant concentration, we selected formulation F1 of aceclofenac, which contained Labrafil (10% wt/wt), Triacetin (5% wt/wt), Tween 80 (35.33% wt/wt),

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Transcutol P (17.66% wt/wt), and distilled water (32% wt/wt), for use in in vivo studies. The in vivo studies revealed a significant increase in the anti-inflammatory effects as compared with aceclofenac gel and nanoemulsion gel. From in vitro and in vivo data it can be concluded that the developed nanoemulsions have great potential for transdermal drug delivery.

**Figure 3**. In vitro skin permeation profile of aceclofenac from 6 different nanoemulsion formulations (F1-F6).

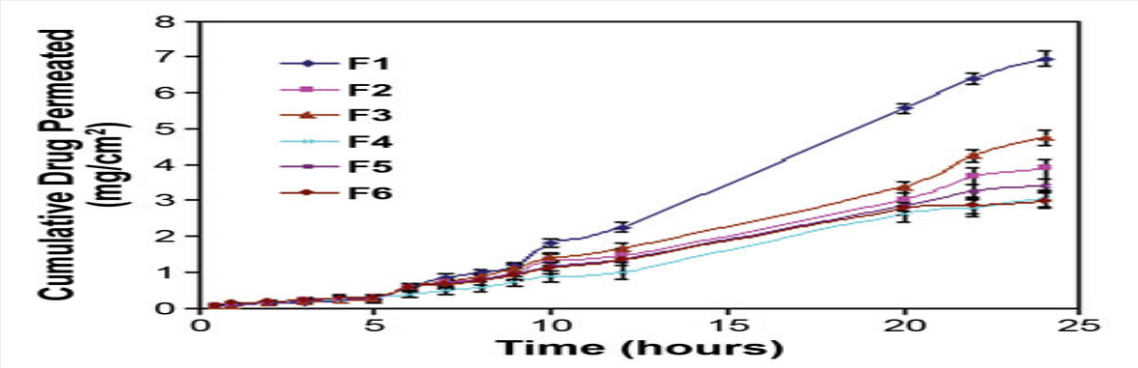


**Table 5**. Refractive Index of Selected Nanoemulsions and Placebo Nanoemulsion Formulations (n = 6)

| | **Refractive Index ± SD** | |
|---|---|---|
| **Sample Code** | **Fresh Formulation** | **Placebo Formulation** |
| F1 | 1.401 ± 0.007 | 1.405 ± 0.005 |
| F2 | 1.403 ± 0.008 | 1.406 ± 0.009 |
| F3 | 1.404 ± 0.009 | 1.407 ± 0.052 |
| F4 | 1.409 ± 0.014 | 1.411 ± 0.012 |
| F5 | 1.407 ± 0.013 | 1.402 ± 0.021 |
| F6 | 1.411 ± 0.015 | 1.412 ± 0.015 |

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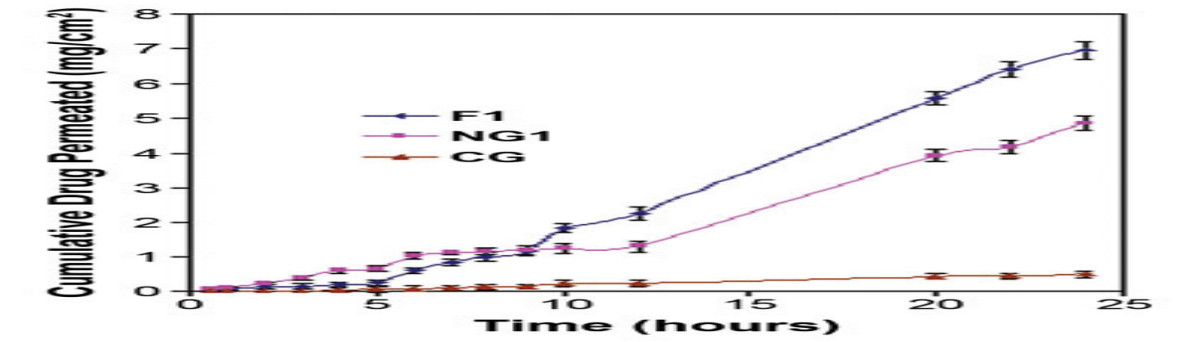


**Figure 4**. Comparative in vitro skin permeation profile of aceclofenac from F1, NG1, and CG. NG1 indicates nanoemulsion gel; CG, conventional aceclofenac gel formulation.

**Table 6**. Permeability Parameters of Different Formulations (n = 3)*

| Formulation Matrices | $J_{ss}$ ± SD (mg/cm$^2$/h) | $K_p$ ± SD (cm/h) × $10^{-2}$ | $E_r$ |
|---|---|---|---|
| CG | 0.021 ± 0.012 | 0.109 ± 0.091 | — |
| F1 | 0.313 ± 0.096 | 1.565 ± 0.120 | 14.360 |
| F2 | 0.170 ± 0.085 | 0.853 ± 0.130 | 7.830 |
| F3 | 0.202 ± 0.068 | 1.014 ± 0.161 | 9.300 |
| F4 | 0.134 ± 0.031 | 0.671 ± 0.103 | 6.150 |
| F5 | 0.152 ± 0.110 | 0.762 ± 0.098 | 6.990 |
| F6 | 0.134 ± 0.1□0 | 0.674 ± 0.113 | 6.180 |
| NG1 | 0.199 ± 0.230 | 0.997 ± 0.161 | 9.140 |

*CG indicates conventional aceclofenac gel formulation (used as control formulation); NG1, nanoemulsion gel.

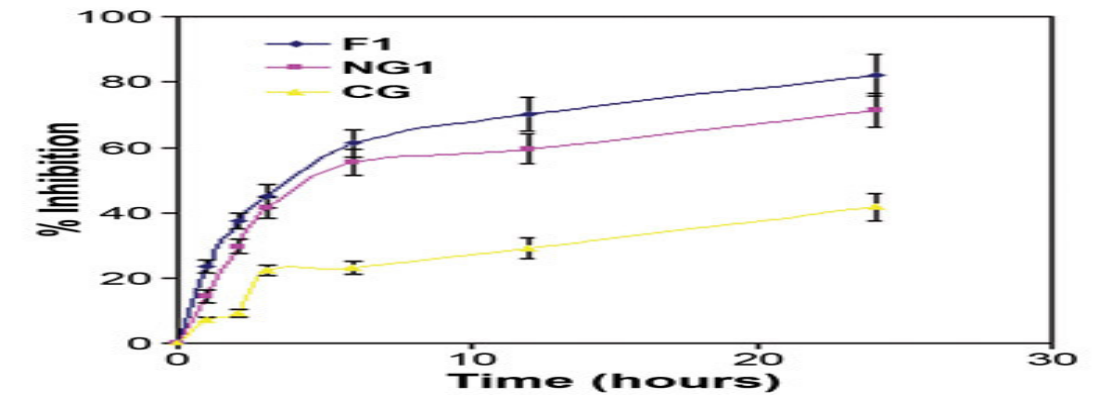


**Figure 5**. Anti-inflammatory effects of F1, NG1, and CG. NG1 indicates nanoemulsion gel; CG, conventional aceclofenac gel formulation.

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